5 Allied Components and Systems

5.1 Civil Structures

Based on the review of Plant layout, SgurrEnergy observed that the inverter stations are placed at centre of each block module to minimise cable losses.

5.1.1 Inverter Station

TBC

5.1.2 Main Control Room

TBC

5.2 PV Power Transfer

SgurrEnergy has reviewed the electrical schematic provided by the Client. The electrical schematic describes the overall connection of the PV modules, inverters, transformers, switchgear and plant substation as well as providing the ratings of all the components.

SgurrEnergy has been provided with the following electrical schematic for the Project.

- *Single line diagram of 132/33kV switchyard*", revision 1 – for approval, dated 06.06.17.
- *"30MW AC SLD"*, revision 1, dated 22.06.17.
- *"50MW AC SLD"*, revision 0, dated 22.06.17
- *"30MW DC single line diagram"*, revision 3 As Built dated 25.06.2018.
- *"50MW DC single line diagram"*, revision 3 As Built dated 25.06.2018.
- *"30MW PV array layout"*, revision 4, As Built dated 21.06.18.
- *"50MW PV array layout"*, revision 4, As Built dated 12.06.18.

30MW$_{AC}$ solar PV Plant: -

The 30MW$_{AC}$ solar PV Plant is designed with 325Wp JA solar and 330Wp Canadian PV modules and 2000kW ABB inverters. Modules are interconnected to form a string of 31 modules. Each string forms a single output that feeds as a single input to the 24 input combiner boxes. Twelve string combiner boxes are further connected to the inverter.

Plant is configured with a total of 15 ABB make central inverters of 2000kW capacity each thereby taking the total AC installed capacity to 30 MW$_{AC}$. The Project has seven inverter station comprising of 2 inverters each. Further one inverter is located in the Main control room (MCR).

50MW$_{AC}$ solar PV Plant: -

The 50MW$_{AC}$ solar PV plant is designed with 325/ 320Wp Astroenergy and 325/330Wp Canadian PV modules and 2000kW ABB inverters. Modules are interconnected to form a string of 31 modules. Each string forms a single output that feeds as a single input to the 24 input combiner boxes. Eleven string combiner boxes are further connected to the inverter.

The plant is configured with 25 ABB 2000kW central inverter thereby taking the total AC installed capacity to 50MW$_{AC}$. The Project has been implemented with twelve inverter station comprising of 2 inverters each. Further one inverter is placed in the MCR.

Subsequent to the review of DC and 33kV AC SLD, SgurrEnergy observed that the electrical schematic of both the PV plants under review is identical.

Each inverter station of 4MW$_{AC}$ capacity consists of two 2000kW inverters; which are further connected to 0.660/0.660/33kV three winding, 4MVA transformer for stepping up the voltage to 33kV. Further one inverter is placed in MCR which is further connected to 0.660/33kV two winding, 2MVA transformer for stepping up the voltage to 33kV.

Each of the two solar PV plant sections have independent main control rooms. The main control room of the 30MW$_{AC}$ solar PV plant combines the 33kV output of the inverter station located within 30MW$_{AC}$ solar PV plant. Further the combined power is further transferred to the 33kV main switchboard located within the 50MW$_{AC}$ solar PV plant, through two feeders of AC capacity of 16MW and 14MW.

In addition to the two feeders originating from the 30MW$_{AC}$ solar PV plant, the main control room of the 50MW$_{AC}$ solar PV, also combines the 33kV output of the inverter station located within 50MW$_{AC}$ solar PV plant. The combined energy at 33kV is further stepped up to 132kV within the 132/33kV substation through two 50/55MVA ONAN/ONAF two winding power transformers.

The combined power is transferred to Pangari substation located approximately 11kms from the Project site through ACSR panther single circuit transmission line from solar PV plant. The point of interconnection will be at the Pangari substation.

Figure below illustrates a power flow summary for the 80MW$_{AC}$ Solar PV plant.

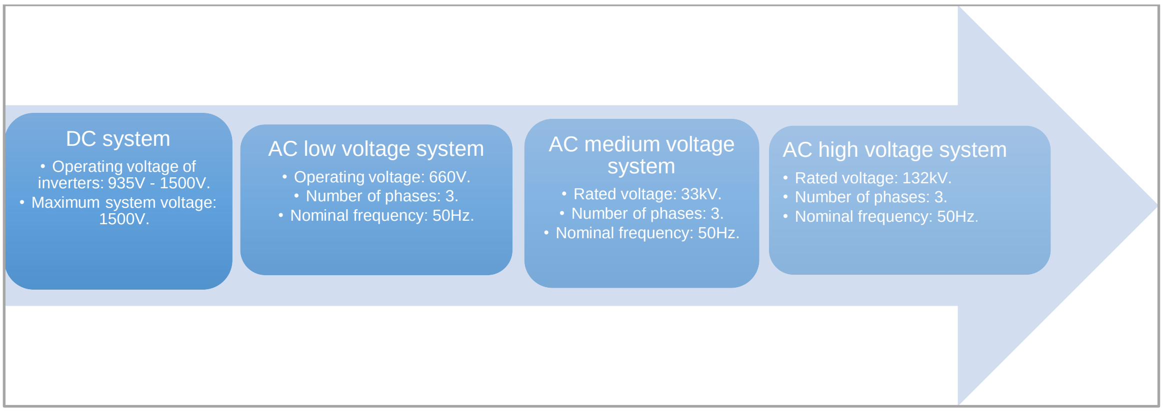

Figure 5-1: Power flow of 80MW$_{AC}$ PV plant

5.3 Cabling

5.3.1 DC Cabling

DC cabling comprises of PV module leads, string cables connecting the PV module strings to combiner box and main DC cables connecting the combiner box to the inverter fuse and then to the inverter. Modules are interconnected in series with solar grade cables that are tied along with the module mounting structures. Modules are interconnected in leap frog scheme to form a string of 31 modules using these leads. Each string forms a single input to the string combiner box. 4mm^2 multi-stranded copper PV cables have been used to connect each string to the string combiner box. These combiner boxes are equipped with 15A fuse for each of the string connection and a 400A disconnector switch on output side. Power from string combiner box is further transferred to the inverter using 2 runs, 1C, 300mm^2, 1.5kV aluminium XLPE ((2R X 1C X 300Sqmm, 1.5kV AL. XLPE Armoured) cables.

5.3.2 AC Cabling

AC output from each inverter is connected using 15 Runs single core 300mm^2 Aluminium Armoured XLPE PVC cable (15R (5R/PH) X1C x 300mm^2 Al. Ar. XLPE, PVC Cable) to the LV side of the inverter transformer. Further 1R,3C, 185mm^2 33kV Al XLPE armoured cables are utilised to connect inverter transformer and the 33kV circuit breaker in outdoor type 33kV HT panel located in inverter station.

In case of 30MW$_{AC}$ solar PV plant, cabling between transformer, 33kV main HT panel and 33kV main MV switchboard has been done with single Run 3 core,185mm^2, 33kV XLPE insulated aluminium cable.

The 30MW$_{AC}$ solar PV plant is consist of two 33kV Double Pole (DP) structure located near MCR, the AC capacity of one DP structure is 16MW$_{AC}$ and other is 14MW$_{AC}$, the cumulative power of both the DP structure is 30MW$_{AC}$.

The power from 33kV MV switchboard is to transmitted to 33kV DP structures through two Runs, 3 Core, 185mm^2 ,33kV Aluminium XLPE PV Armoured (2RX3CX185mm^2,33kV Al. XLPE, PVC, Ar) cable. Subsequently power from both the DP structure is evacuated to Main HT panel located at 50MW$_{AC}$ solar PV plant through 33kV ASCR conductor overhead line.

The power of 50MW$_{AC}$ and 30MW$_{AC}$ solar PV plant from the Main HT panel located at 50MW$_{AC}$ solar PV plant is transferred to 33/132kV, 50/55MVA power transformer through 12 Runs single core, 300mm^2, 33kV Aluminium XLPE PVC Armoured (12R {4R/PH} x 1C x 300sqmm 33kV[E], Al, XLPE, PVC, Ar.) cable.

Further the combined power of both the solar PV plant is feed to the 132kV Pangri substation through 132kV Transmission line.

5.4 Inverter Station

ABB make 2000kW indoor type central inverters have been used in PV plant under evaluation. The 50MW$_{AC}$ solar PV plant consist of 12 inverter station with one inverter in main control room (MCR) whereas in 30MW$_{AC}$ solar PV plant consist of 7 inverter station with one inverter located in the MCR.

A typical inverter station comprises of two 2000kW central inverter and one 0.660/0.660/33kV, 4MVA, 3 winding inverter duty transformer with allied switchgears. The plant has two type of panel further the blocks are connected as ring mail unit (RMU).

The odd number of inverter blocks consist of 2in 1 out MV Panel whereas even number of blocks consist of ICOG panel. 33kV outdoor type HT panel comprises of 100/1-1A current transformer, 33kV/110V fixed type line potential transformer, 33kV EDO TP, 630A Vacuum Circuit Breaker and other electrical protection system. The power from inverter duty transformer is transferred to aforesaid MV panel.

5.5 LV/MV Transformers

SgurrEnergy has reviewed the SLD and observed two type of inverter duty transformer has been used in the project. The inverter station comprises of 4MVA, 33kV/2x0.66kV, Dy11y11, three winding transformer while single inverter placed in the MCR is connected to 33kV/660V, Dy11 two winding transformer. These inverter duty transformers step up the voltage to 33kV.

The inverter duty transformers output is connected to 33kV HT panels located within inverter station. The energy from all the inverter stations ICOG/RMU panels are radially combined at 11/33kV main switchboard located in main control room.

5.6 33kV Main Switchboard

Each 50MW$_{AC}$ and 30MW$_{AC}$ solar PV plant comprise of 33kV main switchboard, which comprises of inverter station incoming feeders, auxiliary transformer feeders, bus coupler feeder, two outgoing feeders and one spare feeder. Each feeder comprises of dedicated VCB, instrument transformer with metering and protection class. All feeders have been provided with relay and metering unit. The 33kV main switch board outgoing and incoming feeders are provided with instantaneous and IDMT (50/51) O/C relay instantaneous and IDMT (50N/51N) E/F relay protections. The 33kV outgoing feeders are provided with 0.2S class instrument transformers.

Further in 30MW$_{AC}$ solar PV plant the power from 33kV MV switchboard is to transmitted to 33kV Main Switchboard located in the premises of 50MW$_{AC}$ solar PV plant through two 33kV ASCR conductor overhead line.

Further the combined power of both the solar PV plant is feed to the 132kV Pangri substation through 132kV Transmission line.

Tariff metering yard has been provided with instrument transformers of 0.2S class, main and check ABT meters at government substation end.

5.7 132/33kV Switchyard

The 50MWac solar PV plant comprise of 33kV main switchboard, which comprises of inverter station incoming feeders, auxiliary transformer feeders, bus coupler feeder, two outgoing feeders and one spare feeder. Each feeder comprises of dedicated VCB, instrument transformer with metering and protection class. All feeders have been provided with relay and metering unit. The 33kV main switch board outgoing feeders are provided with instantaneous and IDMT (50/51) O/C relay instantaneous, IDMT (50N/51N) E/F relay protections, (63X) transformer fault Auxiliary relay, (64R HV/ LV) HV and LV side of restricted earth fault relay, sensitive earth fault relay (51G), directional over current relay (67), directional earth fault relay (67N), transformer differential relay(67N), transformer differential relay(87T) and other supporting relays.

The 33kV switchboard panel outgoing feeders are connected to respective 50/55MVA, ONAN/ONAF, YNyn0, 132/33kV, power transformers located in 132/33kV plant end switchyard.

The 132/33kV switchyard is observed to be equipped with SF_6 circuit breaker, instrument transformers with metering & protection cores. The 132kV outgoing cable is protected with cable differential protection, which is considered to be standard engineering practice.

Further, each transformer line feeders are equipped with 0.2S instrument transformers with ABT main and check meters for measurement purpose, and isolators at incoming line for maintenance. The 120kV, 10kA surge arrestor is provided at 132kV incoming feeders to discharge surge currents caused by lightning strokes and switching operation of equipment's.

Subsequently energy from 132/33kV plant end switchyard single feeder is evacuated to 132kV, Pangri substation at 132kV level through overhead cable.

5.8 Auxiliary Power Supply

SgurrEnergy had reviewed the electrical schematics shared for the projects to evaluate auxiliary system. The inverter stations of all blocks are equipped with 20kVA auxiliary transformers. Further two 100kVA transformers are provided in the 33kV main switchboard located in 50MWac solar PV plant.

5.9 Bus-Bar Schemes

The bus bar scheme consisted of 132kV,1250A, TP,31.5kA per 1second twin ACSR Zebra conductor. The single bus bar scheme has been considered as cost effective for evacuation at 132kV.

5.10 Power transformer

The 132/33kV AIS switchyard located within the premises of 50MWac solar PV plant comprises of two 50/55MVA, 132/33kV, YNyn0 two winding transformer. These power transformers step up the voltage to 132kV.

The power transformer output is connected to 132kV,1250A,TP.31.5kA/1sec, Twin ACSR Zebra conductor busbar. Further the combined power of both the feeders will further evacuate to the 132kV Pangri substation.

5.11 Circuit Breakers

Circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal and abnormal circuit conditions. The circuit breakers are three poles type with electrically and mechanically operated trip-free with anti-pumping facility suitable for remote electrical closing and tripping. The circuit breakers are normally mounted on individual structures.

Following the review of 132kV SLD, SgurrEnergy observed 145kV,1250A,31.5A/3sec SF6 motorized circuit breaker has been used in the project.

5.12 Isolators

Isolators are used to transfer load from one bus to another and also to isolate equipment for maintenance.

Based on the review of 132kV SLD, SgurrEnergy observed manual type 132kV, 1250A, 31.5kA/3sec isolator with and without earth switch has been used in the project.

5.13 Instrument Transformers

Current transformers (CT) and voltage/potential transformers (VT) are known to be as instrument transformers. Instrument transformers are devices used to transform the values of current and voltage in the primary system to values suitable for the measuring instruments, meters, protective relays, etc.

The current transformers with accuracy class of 0.2s for metering and class 5P and PS for protection has been used in 80MW$_{AC}$ solar PV plant. The potential transformers with accuracy class of 0.2 for metering and class 3P for protection has been used in the project.

5.14 Surge Arresters

The substation equipment has to be protected against travelling waves due to lightning strokes on the lines entering the substation. The apparatus most commonly used for this purpose is the surge arrester. Transformer is the most costly equipment in substation and it is normal practice to install surge arrester near to the transformer. Additional surge arresters shall be provided either on bus or on various lines for protection of the equipment.

Following the review, SgurrEnergy observed 120kV, 10kA, CL-03 gapless Metal Oxide Surge arrestor has been used in the switchyard.

5.15 Metering

In addition to the metering and monitoring arrangement in inverters, monitoring of voltage, current and energy will be provided at the medium voltage switchboards for each of the feeder sections. These meters will be digital with an RS 485 port for remote monitoring. These usually have an accuracy class of 0.5

Similarly, HV side shall also be equipped with voltage, current, power and energy meters in order to correlate the energy generation and losses. Class of meters at the evacuation point shall be 0.2S.

6 Solar Resource assessment

The accuracy of any solar energy yield prediction is heavily dependent on the accuracy of the solar resource dataset used. Solar irradiation data is currently not being measured at the location of the proposed power plant and it is therefore necessary to use alternative data sources to obtain estimates of the irradiation figures for the site.

The solar resource of a location may be defined by values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation is the total solar energy received on a unit area of horizontal surface. It includes energy received from the sun in a direct beam and energy that is received from radiation scattered off the atmosphere arriving from all directions of the sky (diffuse irradiation). The units of GHI are given in kWh/m2. Values are often provided for a period of a day, a month or a year.

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the energy received from radiation scattered off the atmosphere arriving from all directions of the sky on a unit area of horizontal surface. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the total solar energy received on a unit area of surface *directly facing the sun at all times*. The units of DNI are kWh/m^2. The direct normal irradiation is of particular interest for solar installations that track the sun and to concentrating solar technologies as only radiation coming directly from the sun may be focussed by a lens or mirror.

For modelling of solar PV plants, GHI and DHI are required for calculating the estimated energy yield. In the northern hemisphere, tilting the modules at an angle towards the south increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations.

Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo. Albedo and global tilted irradiation are described below.

Global Tilted Irradiation (GTI) – The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m^2. A transposition model is used for translating horizontal irradiation to tilted irradiation within PV modelling software.

Albedo – The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

Comparison of Resource Data

There are a variety of possible solar irradiation data sources that may be accessed. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite imagery. A minimum of 10 years of data is recommended to allow for the expected variability of resource data between years. SgurrEnergy has sourced monthly horizontal plane irradiation data for the Project site from:

- ***NASA****'s Surface Meteorology and Solar Energy data set;* holds satellite derived monthly data for a grid of 0.5° × 0.5° covering the globe for a thirty-four-year period

(1984-2017). The data are suitable for pre-feasibility studies of solar energy projects.

- *The **METEONORM (version 7.3)** global climatological database and synthetic weather generator;* contains a database of ground station measurements of irradiation and temperature. Where a site is over 11km from the nearest measurement station it outputs climatologic averages estimated using interpolation algorithms. Where no radiation measurement station is within 300km from the site, satellite information is used. If the site is between 50 and 300km from a measurement station a mixture of ground and satellite information is used. The accuracy of irradiation figures close to measurement stations are within a few percent. Uncertainty increases with distance between the site and the measurement station, especially in hilly and mountainous terrain.
- **SolarGIS:** SolarGIS is developed and operated by GeoModel a solar company maintaining databases of climate data to support solar energy projects and systems. Database is derived from Meteosat and Geostationary Operational Environmental Satellite system (GOES) satellite data and atmospheric parameters (aerosol and water vapour) using high performance algorithms. SolarGIS regional coverage includes Europe, Africa, Asia and parts of South America and Australia. The spatial resolution of primary parameters for European region is approximately 4km × 4km with a temporal resolution of between 15 minutes to 3 hours. SolarGIS radiation models use multispectral channels and multi-dimensional statistical treatment of ground albedo, daily values of aerosol and water vapour. SolarGIS models is validated by *IEA (International Energy Agency) SHC Collaboration Agreement, and EU FP6 project MESoR* in terms of bias and RMSE.
- **Solar and Wind Energy Resource Assessment (*SWERA)* / National Renewable Energy Laboratory *(NREL)*** data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground-based data to ensure quality of the measurements.

6.1 Solar Resource Assessment

SgurrEnergy has compared the irradiation datasets given by NASA - SSE, Meteonorm 7, SolarGIS and, NREL (SWERA) data for the site. The comparison is graphically illustrated in Figure 6-1 and Figure 6-2 below.

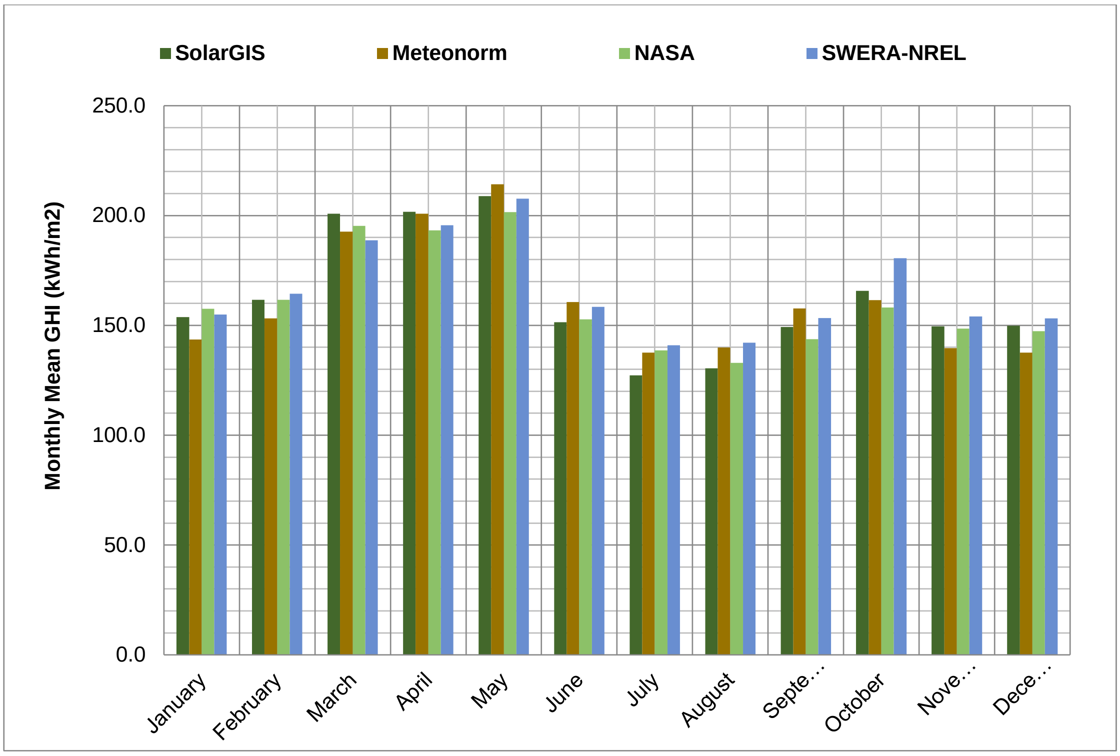

Figure 6-1: Monthly Global Horizontal Irradiation for 30MW$_{AC}$ site

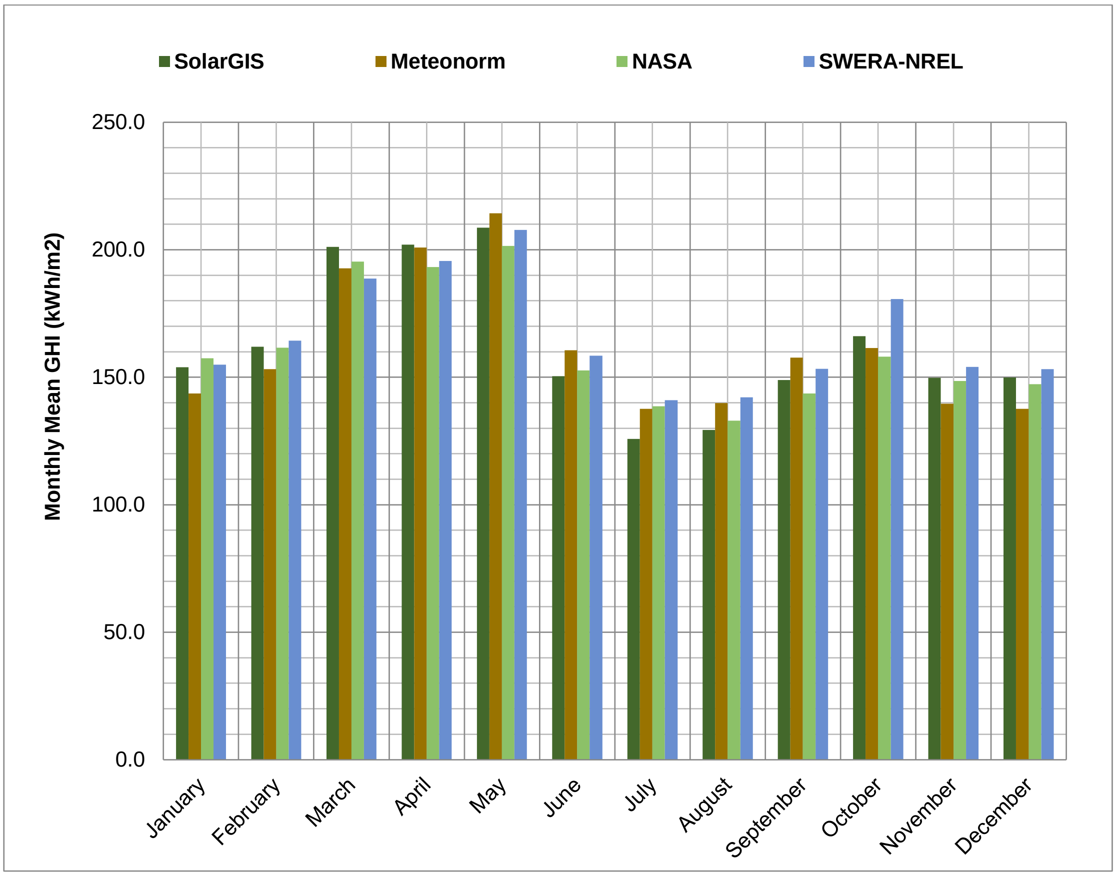

Figure 6-2: Monthly Global Horizontal Irradiation for 50MW$_{AC}$ site

Table6-1: Comparison of Solar Irradiation Datasets for the 30MW$_{AC}$ site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m^2/annual)
SolarGIS	4km × 4km	3.9%	1,950.1
Meteonorm 7.3	14km × 14km	4.0%	1,939.2
NASA	55km × 55km	Unknown	1,931.0
NREL (SWERA)	40km × 40km	Unknown	1,993.9

Table6-2: Comparison of Solar Irradiation Datasets for the 50MW$_{AC}$ site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m^2/annual)
SolarGIS	4km × 4km	3.9%	1,948.1
Meteonorm 7.3	14km × 14km	4.0%	1,939.2
NASA	55km × 55km	Unknown	1,931.0
NREL (SWERA)	40km × 40km	Unknown	1,993.9

The comparison of solar data for the 30MW$_{AC}$ and 50MW$_{AC}$Project site location illustrated in Table6-1 and Table6-2 indicates NREL (SWERA) dataset to give the highest irradiation levels. The next highest irradiation is given by SolarGIS followed by Meteonorm 7.3 and NASA.

The irradiation values given by Meteonorm 7.3 typically provide a combination of ground and satellite measured data. Meteonorm 7.3 has interpolated the data using satellite data for the proposed site. Uncertainty of satellite data is obtained as 4% for the proposed site.

The NREL (SWERA) data illustrated has been obtained for a location approximately 5.23 km away from the proposed site. SgurrEnergy performed iteration on an extensive list of NREL (SWERA) datasets to obtain appropriate coordinates that lie within the Indian boundaries. The results give only irradiation data without temperature and wind data.

The NASA-SSE data source provides purely satellite measured data for a grid covering 0.5° × 0.5° on the earth's surface and generally more suited for initial site selection.

The SolarGIS dataset has been compared with good quality ground measurements for more than 200 sites. The resulted mean bias for GHI is 0%. SolarGIS data base has also been compared with other data sources globally. The IEA (International Energy Agency) validation study conducted by University of Geneva in 2011 has resulted in SolarGIS to be the best performing database among five satellite databases. Similar IEA validation study was repeated in 2013 by University of Geneva which again resulted in SolarGIS to be the best performing database among six satellite databases. Validation study in 2013 was conducted using 18 validation sites in Europe and Mediterranean regions. Furthermore, SolarGIS has conducted its own validation for six Indian locations[11] with the following bias in GHI;

- Pantnagar (Uttarakhand)
- Kanpur (Uttar Pradesh)
- Mysore (Karnataka)
- Warangal (Telangana)
- Jaipur (Rajasthan)

[11] https://solargis.com/docs/accuracy-and-comparisons/overview/

– Ranchi (Jharkhand)

Comparative analysis of all the data sets available, indicate SolarGIS has been validated for India. Furthermore, SolarGIS dataset is based on the most recent long-term average that is from 1999 – 2015, while Meteonorm dataset is based on the time-period of 1991 - 2010. The uncertainty of SolarGIS is 3.9% while that of Meteonorm is 6%.

SgurrEnergy is therefore of the opinion that SolarGIS dataset may be considered reasonable and a representative data source for conducting an energy yield assessment for the project location.

6.1.1 Global, Direct and Diffuse Irradiation on a Horizontal Plane

Horizontal plane irradiation data based on long-term monthly averages are presented in Table 6-3, Table 6-4 and shown graphically in Figure 6-3 and Figure 6-4. Diffuse irradiation accounts for 48.48% and 48.53% of the total irradiation for the 30MW$_{AC}$ and 50MW$_{AC}$ sites respectively.

Table 6-3: SolarGIS Irradiation Data for the 30MW$_{AC}$ Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	153.8	61.1	7.9%
February	161.7	63.6	8.3%
March	200.8	82.5	10.3%
April	201.7	89.7	10.3%
May	208.9	96.1	10.7%
June	151.4	91.2	7.8%
July	127.2	92.4	6.5%
August	130.4	90.2	6.7%
September	149.2	84.9	7.7%
October	165.7	75.6	8.5%
November	149.5	60.6	7.7%
December	149.8	57.7	7.7%
Annual Sum	**1,950.1**	**945.5**	**-**

Table 6-4: SolarGIS Irradiation Data for the 50MW$_{AC}$ Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	154.0	61.1	7.9%
February	162.0	63.6	8.3%
March	201.1	82.5	10.3%
April	202.0	90.3	10.4%
May	208.7	96.4	10.7%

Month	Monthly GHI (kWh/m²)	Monthly Diffuse (kWh/m²)	Proportion of GHI to Annual
June	150.4	90.9	7.7%
July	125.8	91.8	6.5%
August	129.4	89.6	6.6%
September	148.9	84.9	7.6%
October	166.1	75.6	8.5%
November	149.8	60.9	7.7%
December	149.9	58.0	7.7%
Annual Sum	**1,948.1**	**945.5**	**-**

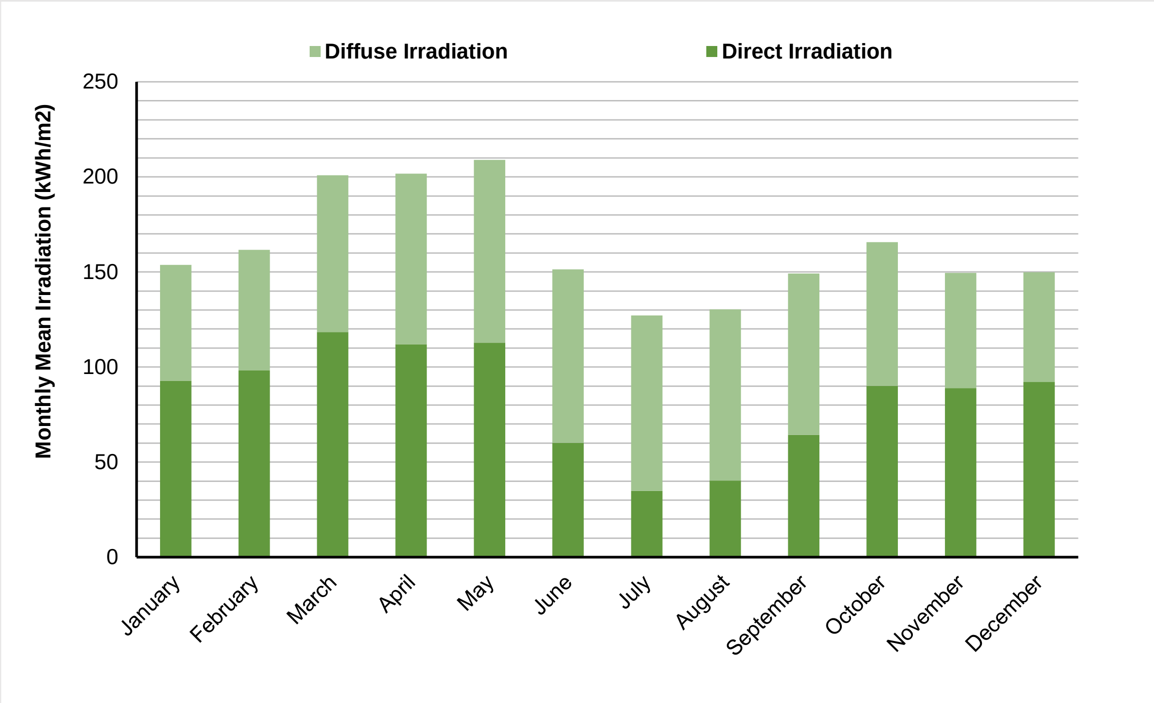

Figure 6-3: Monthly Direct and Diffuse Irradiation on a horizontal plane for the 30MW$_{AC}$ site

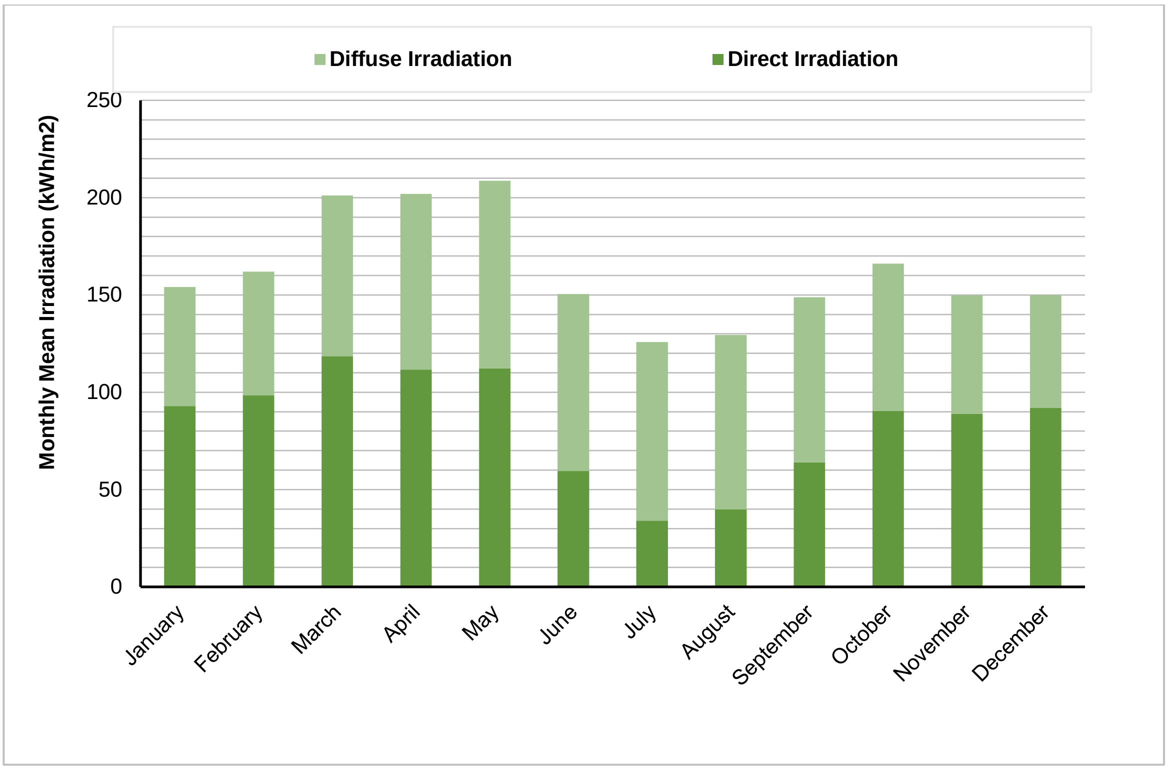

Figure 6-4: Monthly Direct and Diffuse Irradiation on a horizontal plane for the 50MW$_{AC}$ site

6.1.2 Global Tilted Irradiation

Industry standard PV modelling software PVsyst (v.7.1.1), was used. An albedo of 0.2 was assumed based on the ground surface covering within and around the PV array. Table -6-5 and Table 6-6 represents the monthly GTI profile for the 30MW$_{AC}$ and 50MW$_{AC}$ sites respectively.

Table -6-5: Monthly Global Tilted Irradiation Data for 30MW$_{AC}$ site

Month	GTI (kWh/m^2)
January	180.9
February	182.7
March	213.4
April	202.5
May	199.7
June	142.5
July	121.1
August	127.7
September	152.7
October	181.3
November	174.3
December	180.6
Annual Sum	**2059.4**

Table 6-6: Monthly Global Tilted Irradiation Data for the 50MW$_{AC}$ sites

Month	GTI (kWh/m^2)
January	181.8
February	183.3
March	213.8
April	202.5
May	199.1
June	141.4
July	119.7
August	126.5
September	152.0
October	181.9
November	175.0
December	181.0
Annual Sum	**2057.9**

6.1.3 Climate

For wind speed analysis, data sourced from Meteonorm dataset was used and has been tabulated in Table 6-7 and Table 6-8 below. The average wind speed of 1.3 m/s was measured at 10m height from ground level for the proposed project site location.

Table 6-7: Simulated Wind Speed for 30MW$_{AC}$ site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	0.7
February	0.9
March	1
April	1.2
May	2.2
June	2.3
July	2.1
August	1.9
September	1.1
October	0.6
November	0.6
December	0.5
Yearly Average	1.3

Table 6-8: Simulated Wind Speed for 50MW$_{AC}$ site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	0.7

Month	Average Wind Speed (m/s) – Meteonorm Data
February	0.9
March	1
April	1.2
May	2.2
June	2.3
July	2.1
August	1.9
September	1.1
October	0.6
November	0.6
December	0.5
Yearly Average	1.3

6.1.4 Temperature

Temperature data has been sourced from the SolarGIS database. A typical operating temperature range for PV modules is -40°C to +85°C. Inverter operating ranges are more bounded to temperature, typically -20°C to +45°C, with the electronic equipment in the inverter degrading quicker in high temperature environments. Thus, considering the temperature range at selected site, the modules and inverters should be able to operate normally.

The effect of temperature on module performance and the corresponding plant performance may be quite significant. Typically, a reduction in efficiency of 0.40 – 0.45%/°C is noted for crystalline modules and 0.25 -0.30%/°C for thin film modules for increase in temperatures above 25°C. Therefore, during the summer months (February-June) temperature losses may be significantly high as module temperatures typically go beyond 50°C.

Table 6-9: SolarGIS Temperature Data for 30MW$_{AC}$ Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	22.2
February	25.0
March	29.1
April	32.7
May	33.8
June	29.8
July	26.4
August	25.0
September	25.3
October	24.4
November	22.4
December	21.0

Months	Average Monthly Temperature (°C)
Annual Average	26.4

Table 6-10: SolarGIS Temperature Data for 50MW$_{AC}$ Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	22.2
February	25.1
March	29.2
April	32.8
May	33.9
June	29.9
July	26.5
August	25.1
September	25.4
October	24.4
November	22.4
December	21.1
Annual Average	26.5

6.1.5 Precipitation

The rainfall figures have been simulated using Meteonorm 7.3 as illustrated in figure below. These figures show that the identified site is situated in a region that has marginal rainfall.

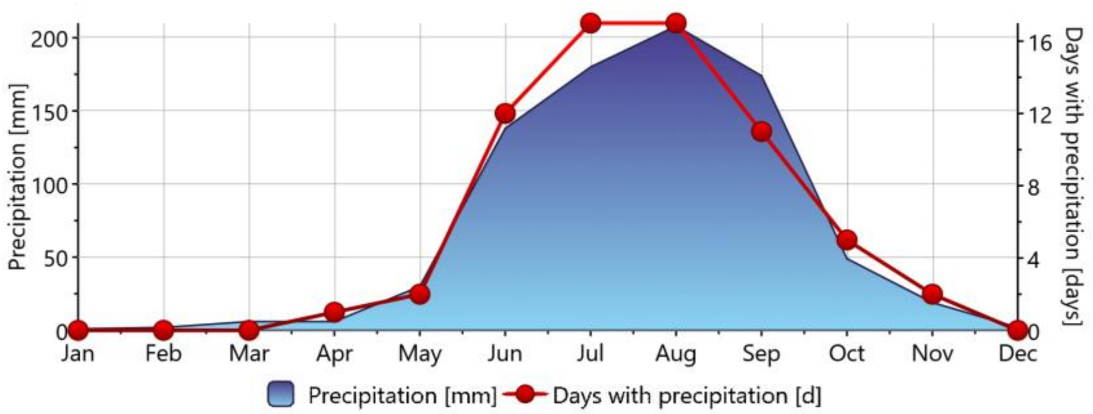

Figure 6-5 Meteonorm Predicted Precipitation for the 30MW$_{AC}$ site

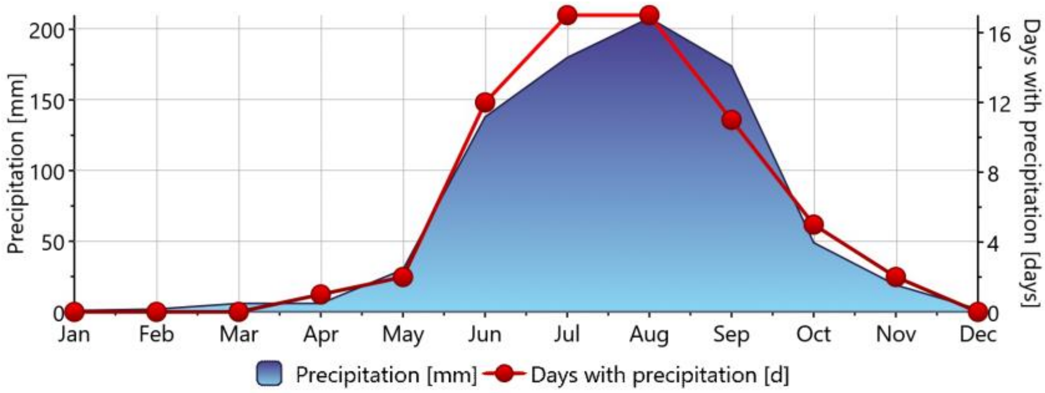

Figure 6-6 Meteonorm Predicted Precipitation for the 50MW$_{AC}$ site

PV modules are soiled by particulates of dust, dirt and bird droppings. Soiling of modules has a high impact on the energy yield thereby leading to a loss up to 3% in non-arid regions. Therefore, the modules need to be cleaned for avoiding the loss due to soiling.

Frequency of module cleaning depends on the rainfall frequency and the prevalence of dust and pollution in the local vicinity. Typical cleaning techniques include water cleaning, dry brushes or vehicle-based mechanical cleaning.

The frequency of module cleaning is primarily dependent on the amount of soiling experienced on the site. Soiling loss of 1.5% has been considered by considering cleaning frequency of twice a month. However, a monthly cleaning schedule is understood to be maintained in the O&M scope of work and conditions at site are understood to be monitored to determine the exact frequency and cleaning strategy during operations.

7 Annual Energy yields

For energy yields SgurrEnergy has:

1) Sourced average monthly horizontal irradiation, wind speed and temperature data with the other sources which included satellite image derived data. These data have been assessed for use in the energy yield simulation software.
2) Following the assessment, SgurrEnergy has selected site specific data sourced from SolarGIS to arrive at representative energy yield estimates.
3) Calculated the global incident radiation on the tilted plane, taking into account shading.
4) Applying downtime losses, AC ohmic losses, and module degradation losses to obtain energy yields that reflect twenty-five-year plant life.

Using statistical analysis of resource data for inter-annual variability to derive appropriate levels of uncertainty in the energy yield prediction, steps 2 and 3 are facilitated using industry standard photovoltaic simulation software which simulates the energy yield using hourly time steps. The software takes as input detailed specifications of:

- The solar PV modules.
- The inverter.
- Mounting system.
- Electrical configuration including number of modules in series and parallel.

7.1 Correction and Losses

Data obtained for irradiation on collector plane, PV module and inverter specifications and plant configuration are input into the PV modelling software to calculate DC energy generated from the modules in hourly time steps throughout the year. This direct current is converted to AC in the inverter.

A number of losses occur during the process of converting irradiated solar energy into AC electricity fed into the grid. The losses may be described as a yield loss factor. They are calculated within the PV modelling software and calculated from the cable dimensions. Others are nominal figures applied from knowledge of performance of similar PV plants. The losses are broadly summarised in below.

Table 7-1: Description of Energy Yield Losses

Loss	Description
Shading	Three types of shading losses are considered in the PV energy yield model: horizon shading, shading between rows of modules and near shading due to trees and buildings.
Incident Angle	The incidence angle loss accounts for losses in radiation penetrating the front glass of the PV modules due to angles of incidence other than perpendicular.
Low Irradiance	The conversion efficiency of a PV module reduces at low light intensities.
Module Temperature	The characteristics of a PV module are determined at standard temperature conditions of 25˚C. For every ˚C temperature rise above this, module efficiency reduces according to their temperature coefficient.
Soiling	Losses due to dust and bird droppings; soiling the module.

Loss	Description
Module Quality	Most PV modules do not match exactly the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a given tolerance within which the actual power is guaranteed to lie.
Module Mismatch	Losses due to "mismatch" are related to the fact that the real modules in an array do not all rigorously present the same current/voltage profiles: there is a statistical variation between them.
DC Wiring Resistance	Electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).
Inverter Performance	Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.
MPP Tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the maximum power point voltage. Different inverters do this with varying efficiency.
AC Losses	This includes ohmic losses from inverter to evacuation point.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
Grid Availability and Disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Power Curtailment Losses	Curtailment loss is attributed to the utility limiting the power intake at the contracted AC capacity of the PV Plant; thus, the excess energy generated beyond the limit of 30MW$_{AC}$ at the metering level shall not be accounted
Degradation	The performance of a PV module decreases with time.

7.2 Annual Energy Yields

SgurrEnergy has computed the annual energy yields for the 30MW$_{AC}$ and 50MW$_{AC}$ Solar PV Plant using basic designs and indicative layout. Energy yields for all the PV technology configurations under evaluation is further elaborated in the following section.

Table 7-2: Plant parameters for the 30MW$_{AC}$ Solar PV Plant

Parameter	Description
Modules	JA Solar 325 W$_p$, (JAM60S08-325) JA Solar 330 W$_p$ (JAM60S08-330) Canadian solar 325 W$_p$ (CS3K-325MS)
Inverters	ABB Central Inverters – 2.0MW$_{AC}$ (PVS980-58-2000kVA-K)
Mounting System	Fixed Tilt
DC Capacity (MW$_p$)	39.4

Table 7-3: Plant parameters for the 50MW$_{AC}$ Solar PV Plant

Parameter	Description
Modules	Canadian solar 320 W_p (CS1K-320MS 1500V) Canadian solar 325 W_p (CS3K-325MS 1500V) Astronergy 325 W_p (CHSM6612P/HV-325)
Inverters	ABB Central Inverters – 2.0MW$_{AC}$ (PVS980-58-2000kVA-K)
Mounting System	Fixed Tilt
DC Capacity (MW_p)	64.63

7.2.1 P50 Energy Yield Predictions

This section presents the SgurrEnergy's independent energy yield prediction for the 30MW$_{AC}$ and 50MW$_{AC}$solar PV Plant with JA Solar and Canadian solar PV modules and ABB central inverters. Table 7-4 summarises the solar PV power plant, the available resource, the losses and the predicted P50 yields.

Table 7-4: Energy Yield for the 30MW$_{AC}$ and 50MW$_{AC}$ Solar PV Plant

Parameters	Description-30MW$_{AC}$	Description-50MW$_{AC}$
PV Module Technology	Monocrystalline – PERC	Monocrystalline – PERC, Polycrystalline
DC Capacity (MW_p)	39.4	64.63
AC Capacity (MVA)	30.0	50.0
Contracted Capacity (MW)	30.0	50.0
P_{NOM} Ratio	1.31	1.29
Tilt (°)	16	16
Pitch (m)	5	6
Annual Global Horizontal Irradiation (kWh/m^2)	1,950.10	1948.1
Global Irradiation Incident on Collector Plane (kWh/m^2)	2059.4	2058
Transposition Factor	1.06	1.06
Losses		
Horizon Shading	0.00%	0.00%
Incident Irradiation Below Threshold	0.00%	0.00%
Near Shading	2.10%	1.93%
Incident Angle	2.27%	2.29%
Soiling	1.50%	1.50%
Low Irradiance	0.48%	0.84%
Module Temperature	8.00%	8.49%
Electrical Shadings	0.15%	0.16%
Module Quality	0.00%	0.00%
First year Degradation	1.50%	1.50%

Parameters	Description-30MW$_{AC}$	Description-50MW$_{AC}$
Module Mismatch	1.00%	1.00%
DC Ohmic	1.07%	1.07%
Inverter Performance	1.75%	1.76%
Availability	1.00%	1.00%
AC Ohmic	0.56%	0.56%
Transformer (LV/MV)	1.08%	1.08%
Transformer (MV/HV)	-	-
Transmission Line	0.41%	0.46%
Auxiliary Consumption	0.60%	0.60%
Curtailment		
Total Annual Loss Factor	***0.783***	***0.777***
Third Year P50 Energy Yield (MWh/annum)	**62,919.13**	**1,02,278.79**
Third Year Specific Yield (kWh/kW$_p$)	**1596.93**	**1582.52**
Third Year CUF on AC Installed Capacity	**23.94%**	**23.35%**
Third Year CUF on Contracted Capacity	**23.94%**	**23.35%**
Third Year CUF on DC Installed Capacity	**18.22%**	**18.06%**
Third Year Performance Ratio	**77.54%**	**76.89%**

Graphical representation of the monthly generation, performance ratio and CUF for 30 MW$_{AC}$ and 50MW$_{AC}$ evaluated is illustrated graphically in figure below.

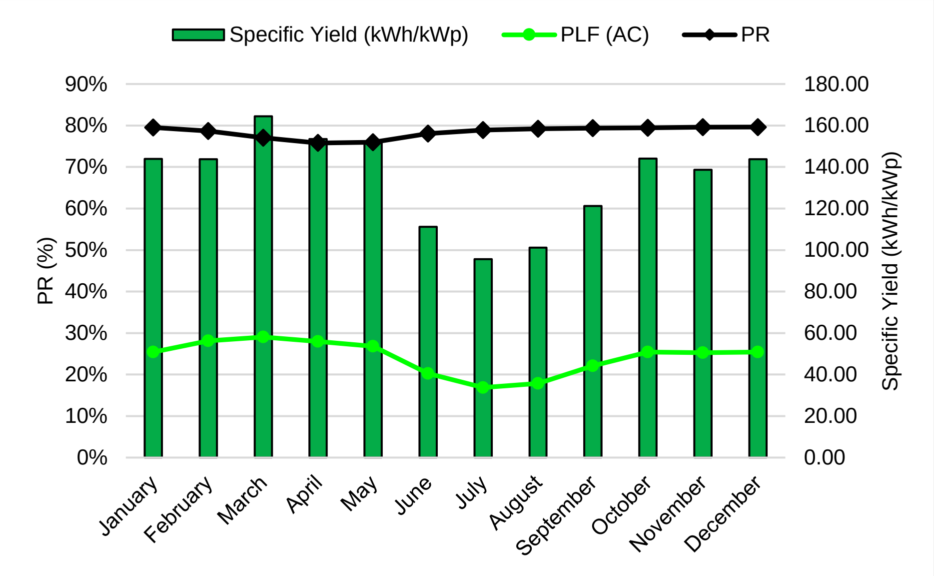

Figure 7-1: Monthly Energy Yield for 30MW$_{AC}$

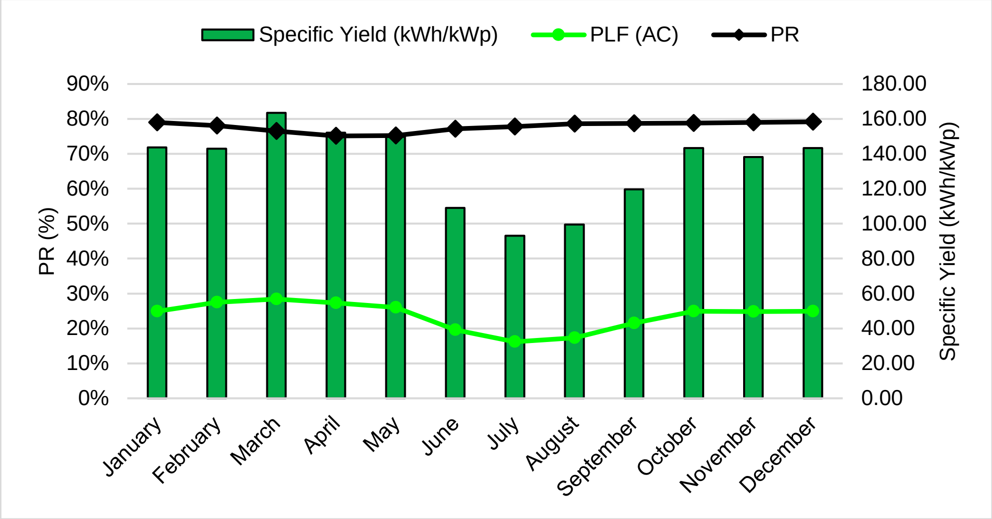

Figure 7-2: Monthly Energy Yield for 50MW$_{AC}$

7.2.2 Yield Uncertainty

The uncertainty in energy yield predictions is difficult to quantify as it is a function of many independent factors. The discussion below represents simplification of the estimated uncertainty which is believed to be the best approach given the uncertainty in the resource data.

7.2.2.1 Solar Resource Measurement Uncertainty

Energy yield prediction is based on SolarGIS database, a satellite data which is derived from Meteosat Indian Ocean Data Coverage (Meteosat IODC) and atmospheric parameters using high performance algorithms set by SolarGIS method.

The resource data for 16+ years (1999-2015) has been obtained from the SolarGIS climatological database. SolarGIS recommends an uncertainty of 3.9%.

The uncertainty in transposing the global horizontal irradiation to global tilted irradiation is dependent on the accuracy of the initial data and the characteristics of the specific location. Based on the SgurrEnergy's experience, the uncertainty associated with the transposition model is 1.5%.

7.2.2.2 Inter – Annual Variation in the Solar Resource

Mean global daily irradiation on a horizontal plane varies on an annual basis. This means that the plant owner does not know what energy yield to expect in any given year but can have a good idea of the expected yield in the long term.

The likely variation can be quantified based on analysis of variation in long-term irradiation data in the vicinity of site. SgurrEnergy has sourced 35 year's data from NASA database for the proposed site location which is used to estimate the standard deviation of variation in irradiation. SgurrEnergy has analysed this dataset and computed the coefficient of variation (standard deviation divided by the mean) as shown in Table 7-5.

Table 7-5: Summary of Figures for Inter-Annual Variation in Resource

Number of Years of Data	35
Coefficient of Variation	3.28

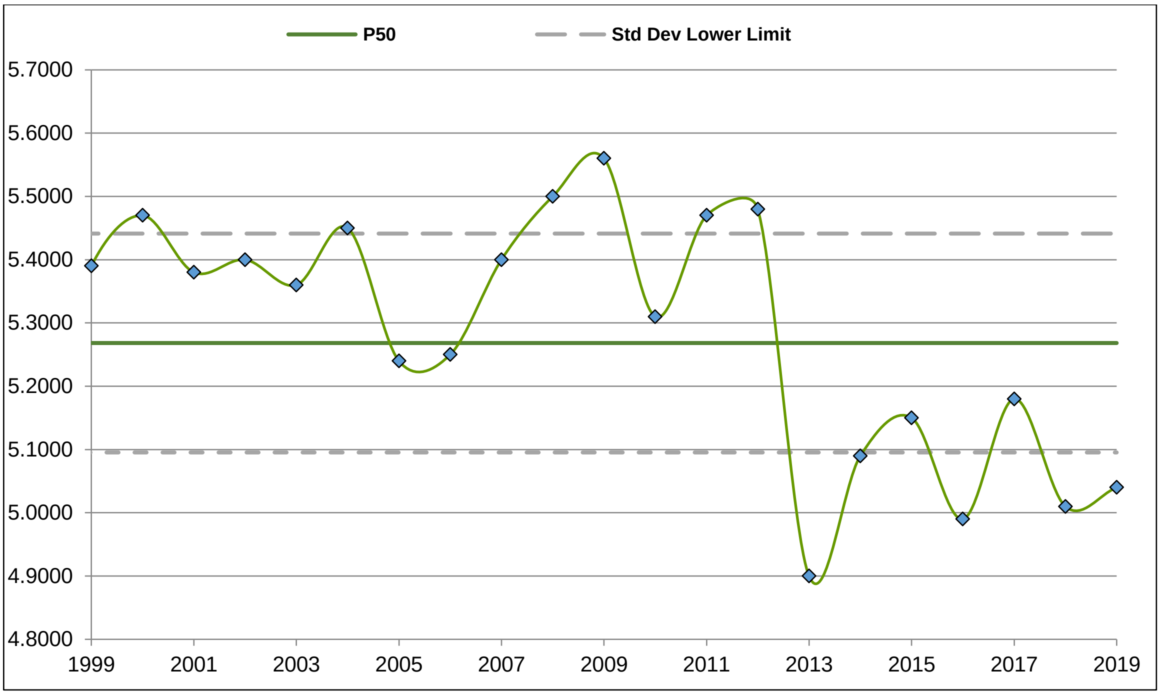

Figure 7-3: Inter-Annual Variability of GHI

Graphical illustration of inter annual variation is presented in Figure 7-3.

SgurrEnergy uses a coefficient of variation of 3.28% to quantify the inter-annual variation in the solar resource.

7.2.2.3 Modelling Uncertainty

The modelling uncertainty is a combination of the various uncertainties for each loss factor assessed in the modelling process. Efforts to validate the photovoltaic simulation software used data from seven grid connected systems in Europe. These indicated that the accuracy of the results of the simulation is in the order of 2 to 3%.

7.2.2.4 Total Uncertainty (P75, P90 and P99 Energy Yield Predictions)

Combining the uncertainties in energy yield and inter-annual variation in the solar resource, the P50, P75 and P90 confidence interval are presented for each PV plant configuration in the table below.

Table 7-6: Life Cycle P50, P75 and P90 Generation Prediction for 30 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[12] (MWh/annum)	P90 Generation Prediction[13] (MWh/annum)
3	62,919.13	60,258.76	57,864.35
4	62,604.53	59,957.47	57,575.03
5	62,291.51	59,657.68	57,287.15
6	61,980.05	59,359.39	57,000.72
7	61,670.15	59,062.60	56,715.71

[12] The P75 values have been calculated over 10-year averages

[13] The P90 values have been calculated over 10-year averages

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[12] (MWh/annum)	P90 Generation Prediction[13] (MWh/annum)
8	61,361.80	58,767.28	56,432.13
9	61,054.99	58,473.45	56,149.97
10	**60,749.72**	**58,181.08**	**55,869.22**
11	60,445.97	57,890.17	55,589.88
12	60,143.74	57,600.72	55,311.93
13	59,843.02	57,312.72	55,035.37
14	59,543.81	57,026.16	54,760.19
15	59,246.09	56,741.03	54,486.39
16	58,949.86	56,457.32	54,213.96
17	58,655.11	56,175.03	53,942.89
18	58,361.83	55,894.16	53,673.17
19	58,070.02	55,614.69	53,404.81
20	**57,779.67**	**55,336.61**	**53,137.78**
21	57,490.78	55,059.93	52,872.10
22	57,203.32	54,784.63	52,607.74
23	56,917.30	54,510.71	52,344.70
24	56,632.72	54,238.15	52,082.97
25	**56,349.55**	**53,966.96**	**51,822.56**

Table 7-7: Life Cycle P50, P75 and P90 Generation Prediction for 50 MW$_{AC}$

Table 7-8: Life Cycle P50, P75 and P90 Generation Prediction for 50 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[14] (MWh/annum)	P90 Generation Prediction[15] (MWh/annum)
3	1,02,278.79	97,954.20	94,061.94
4	1,01,767.39	97,464.43	93,591.63
5	1,01,258.56	96,977.11	93,123.67
6	1,00,752.26	96,492.22	92,658.05
7	1,00,248.50	96,009.76	92,194.76
8	99,747.26	95,529.71	91,733.79
9	99,248.52	95,052.06	91,275.12
10	**98,752.28**	**94,576.80**	**90,818.74**
11	98,258.52	94,103.92	90,364.65

[14] The P75 values have been calculated over 10-year averages

[15] The P90 values have been calculated over 10-year averages

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[14] (MWh/annum)	P90 Generation Prediction[15] (MWh/annum)
12	97,767.23	93,633.40	89,912.83
13	97,278.39	93,165.23	89,463.26
14	96,792.00	92,699.41	89,015.95
15	96,308.04	92,235.91	88,570.87
16	95,826.50	91,774.73	88,128.01
17	95,347.37	91,315.86	87,687.37
18	94,870.63	90,859.28	87,248.94
19	94,396.28	90,404.98	86,812.69
20	**93,924.29**	**89,952.96**	**86,378.63**
21	93,454.67	89,503.19	85,946.74
22	92,987.40	89,055.68	85,517.00
23	92,522.46	88,610.40	85,089.42
24	92,059.85	88,167.35	84,663.97
25	**91,599.55**	**87,726.51**	**84,240.65**

8 Operational Analysis and Generation Comparison

To assess the operational performance of the plant, SgurrEnergy has comparatively evaluated the monthly energy yield predicted using satellite-based weather data with the plant generation SCADA values. A factor of 0.6% degradation has been considered for values after a duration of 1 year from COD (Commercial Operational Date) and henceforth. The variation has been evaluated with respect to the difference between the two generation figures.

Based on the information provided by the Owner, SgurrEnergy understands that the SEPEPL solar PV plant was commissioned in two phases. The 50MW capacity of the solar PV plant was commissioned on 8th April 2018 and subsequently the remaining 30MW solar PV plant was commissioned on 22nd April 2018. SgurrEnergy was provided with plant and grid availability records from May 2018 to March 2021[16] for the solar PV plant. However, the irradiation measurement records were provided from September 2018 to March 2021.

SgurrEnergy has thus carried out the generation comparison for the PV project for the period from September 2018 to March 2021, henceforth referred to as 'operational period'. SgurrEnergy compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Owner.

SgurrEnergy also observed that the monthly availability figures were provided for the operational period of the solar PV plant. These availability figures were captured within the monthly energy yield predictions assessed for the site in question and were accounted for representative comparison. The average availability based on the provided data has also been specified below.

Based on the availability records provided, SgurrEnergy has analysed the trend in the plant availability and grid availability for each month as presented in the following sections.

1.1.1 Grid Availability

The ability of a PV power plant to export power is dependent on the availability of the grid transmission network and the utility grid substation. Grid unavailability is solely due to the breakdown events associated with the grid substation and substation maintenance, which is beyond the Owners control.

The monthly records of the grid availability from September 2018 to March 2021 have been graphically illustrated in Figure 8-1 below.

[16] SgurrEnergy was provided with both the plant and grid availability records until March 2021 and hence the analysis conducted in the sections below has been done to incorporate the available data.

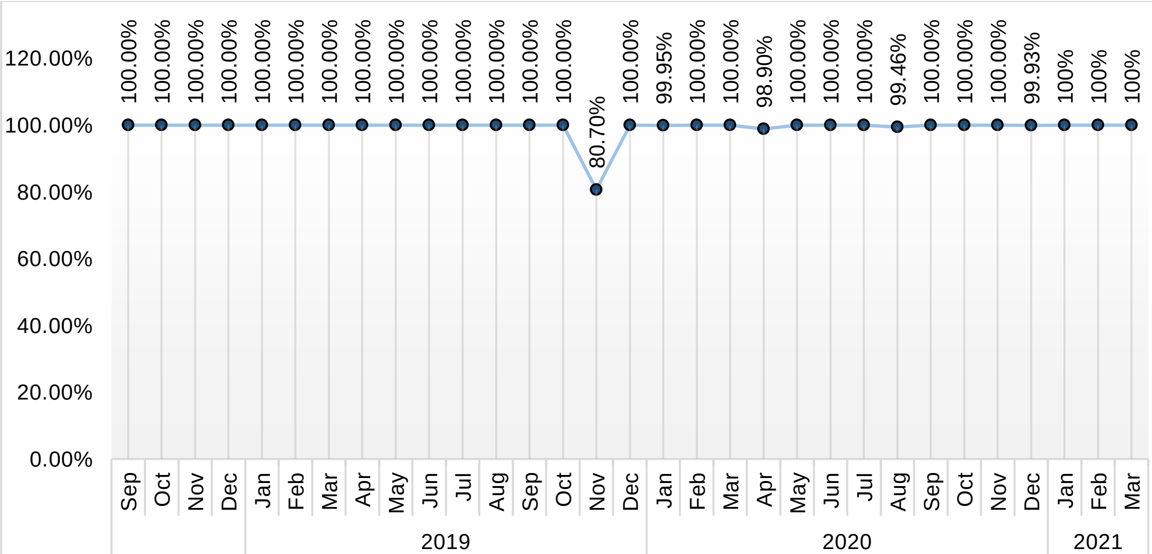

Figure 8-1: Grid Availability

From the above illustration, SgurrEnergy notes that the unavailability loss experienced due grid anomalies are minimal over the operational period and are within expected range. However, for the month of November 2019 the unavailability due to grid was significantly high when compared to other months. The downtime due to grid unavailability was comparatively less severe during the remaining months for which the grid availability was noted to be exceeding 98.9%.

Overall, the average grid availability experienced on site for the operational period was calculated to be 99.32%

1.1.2 Plant Availability

Plant downtime is a period when the plant does not generate due to failure of equipment in plant until the injection point. The plant downtime period depends on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.

Plant availability of the SEPEPL solar PV plant is graphically illustrated below in Figure 8-2.

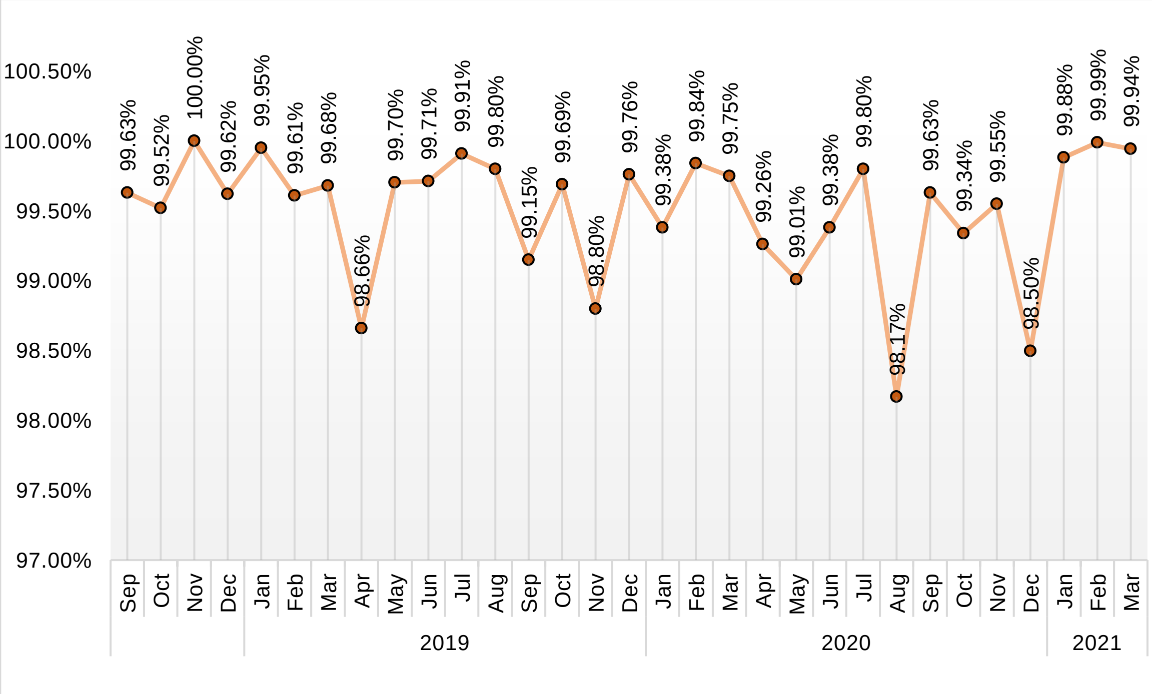

Figure 8-2: Plant Availability

Based on the above illustrations, SgurrEnergy notes the plant availability for the SEPEPL solar PV plant is notably inconsistent for all the months ranging between 98.17% to 100%. The average plant availability is noted to be 99.50% which is considered to be within expected range.

1.2 Energy Yield Comparison

SgurrEnergy has compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Client. To make the operational energy yield predictions more representative, SgurrEnergy has applied the monthly losses due plant and grid unavailability provided by the Client. These predictions are in turn compared with the actual performance of that plant, which are the generation figures shared by the Client.

The yearly comparison of the generation data is illustrated below in Figure 8-3.

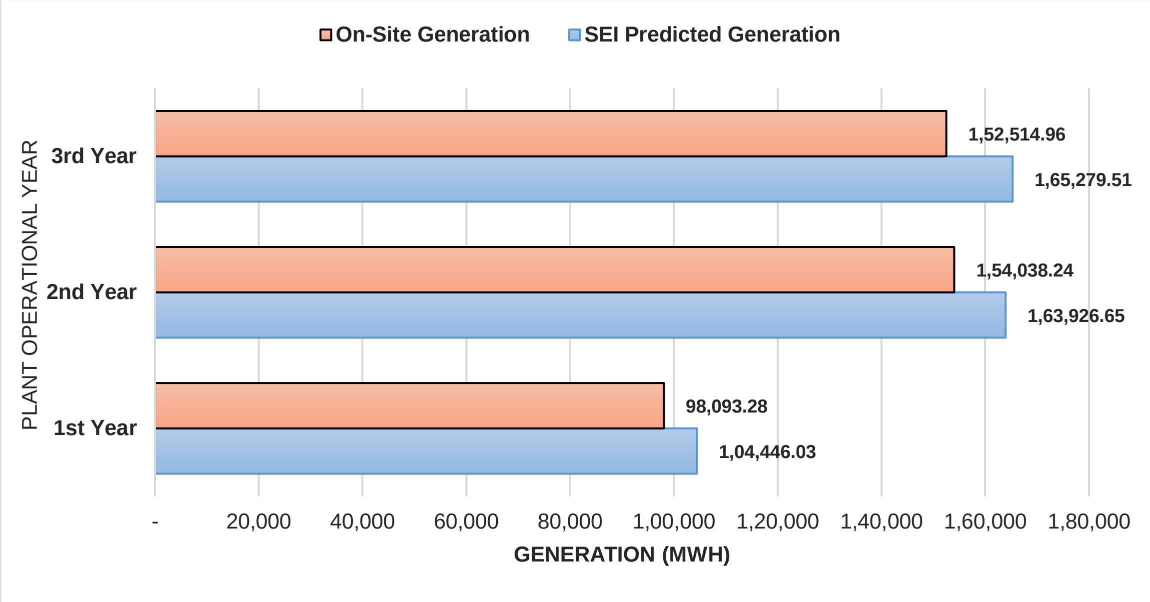

Figure 8-3: Generation Comparison

The variation of the performance of the PV plant for the period of evaluation has been tabulated below in Table 8-1

Table 8-1: PV Plant Performance – SEPEPL 80MW

PV Plant Operation Period	Predicted Generation (MWh)	Recorded Generation (MWh)	Performance Percentage[17] (%)
Sep 2018 -Mar 2019	1,04,446.03	98,093.28	-6.08%
Apr 2019 -Mar 2020	1,63,926.65	1,54,038.24	-6.03%
Apr 2020 –Mar 2021	1,65,279.51	1,52,514.96	-7.72%
Cumulative Period	**4,33,652.18**	**4,04,646.48**	**-6.69%**

Based on the above comparison, SgurrEnergy notes that the PV plant is generating lower than the expected yield. However, SgurrEnergy considers that such variations in the energy yield can be attributed to lower irradiation level experienced on the Project site. The irradiation levels significantly impact the actual generation from the PV plant as the system losses may vary significantly due to slight change in the irradiation.

In order to understand the deviation in the irradiation pattern, SgurrEnergy has compared the monthly incident irradiation data provided by the Client with the monthly incident irradiation predicted using satellite-based meteorological data for the period of evaluation. The result of the comparison is presented in the table below and the same is graphically illustrated in the Figure 8-4.

Table 8-2: Irradiation Comparison– SEPEPL 80MW

PV Plant Operation Period	Predicted Irradation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[18] (%)
Sep 2018 -Mar 2019	1,267.35	1,227.86	-3.12%
Apr 2019 -Mar 2020	2,058.70	1,896.15	-7.90%
Apr 2020 -Mar 2021	2,058.70	1,924.43	-6.52%

[17] Positive values indicate higher generation, while negative values indicate lower generation

[18] Positive values indicate higher irradiation, while negative values indicate lower irradiation

PV Plant Operation Period	Predicted Irradiation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[18] (%)
Cumulative Period	5,384.75	5,048.44	-6.25%

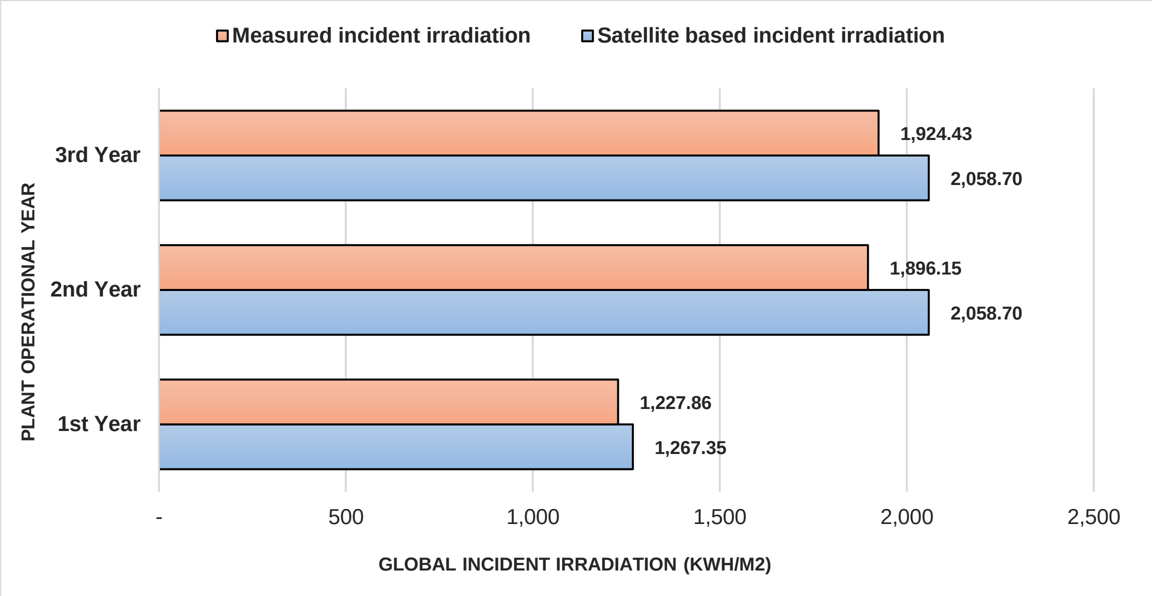

Figure 8-4: Irradiation Comparison

Based on the above illustration, it is observed that the overall recorded generation is approximately 6.69% lower than the generation predicted on site. Correspondingly, it has also been observed that the recorded irradiation is approximately 6.25% lower than the predicted irradiation.

Based on the comparative analysis, the drop-in generation can be attributed to the drop-in irradiation for the period of evaluation (September –18 to March –21).

9 Solar Plant Life beyond 25 years

The traditional life of a solar plant is 25 years, which is based primarily on solar panel warranty period. The National Renewable Energy Laboratory (NREL) in the U.S however lists solar PV plants as having a lifetime of 25-40 years[19].Most modules are expected to see a degradation rate of 0.7% for the 25 years and hence the expected power output at the end of 25 years is around 80% of the rated power. However, research from NREL[20] shows that the median degradation rates of panels are around 0.5% and power output after the 25 year term could be higher than the power output guaranteed by the module manufacturer. Hence the possibility of the module producing electricity beyond 25 years with a year on year degradation is not farfetched, however whether these degradation rates will be in a linear pattern or in an unpredictable pattern is yet discovered and hence evaluating the generation/ performance of the plant and life of the plant beyond 25 years becomes risky. The life of the plant also depends on the quality of the other components such as inverters, cables, transformers used. Over the twenty five year plant life, these component will need to be serviced and repaired, as the warranty period for all of these components are less than 10 years. The repair and service of these equipment can continue beyond 25 years and the component may be fit for use for another ten years, however the risk of equipment failure increases year on year. The life of the plant also depends on the operations and maintenance activities carried out during the plant lifecycle and hence carrying out O&M activities diligently during the lifetime of the plant can increase the life of the plant beyond 25 years.

Overall, the PV plant is expected to function beyond plant life of 25 years, however the risk associated with the plant operation increases as the panel warranties would have expired, degradation rates beyond 25 years are unknown and other components used in the plant would also need additional repair/replacement.

[19] https://www.nrel.gov/analysis/tech-footprint.html

[20] https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

Virescent Infrastructure

13MW(AC) SSEGPL Solar PV Plant

Sindicatum Solar Energy Gujarat Private Limited

Technical Assessment Report

July 2021

Report Details

Prepared for:	Virescent Infrastructure
Client Contact:	Atul Raaizada
Report Distribution:	
SgurrEnergy:	Ahmed Dalvi
Report Classification:	Confidential

	Name	Job-Title	Signature
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Reviewed by	Ahmed Dalvi	Sr. Project Engineer	
Authorised by	Arif Aga	Director	
Date of Issue	20 July 2021		

Amendment Records

Revision Number	Date	Purpose of Revision	Summary of Amendments
B1	23 June 2021	Draft Issue	-
B2	28 June 2021	Minor Updates	-
B3	2 July 2021	Minor Updates	-
B4	6 July 2021	Minor Updates	-
B5	15 July 2021	Minor Updates	-

SF/04/023

Contents

Figures

Tables

Executive Summary

Virescent Infrastructure (the Client) backed by leading global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy has been appointed by the Client to conduct a technical appraisal of 13MW$_{AC}$ SSEGPL plant. The summary of the technical assessment is captured in the below table.

Table 1-1: Summary

Sr. No.	Parameter	Comment
1	Plant Overview	Review presented in Section 2
2	PV Module	According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of First Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard. Further, the warranty document was not provided for review, based on review of datasheet provided, it is noted that First solar provides a limited product warranty of 5 years. SgurrEnergy considers five-year product warranty provided by First Solar to be lower than the industry standard of 10-years and suggests getting clarity from the manufacturer regarding the warranty offered for the modules utilized for the project. SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules. Regarding the certifications, the complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.
3	Inverter	SgurrEnergy has conducted review of the Power-one's PVI-500.0-TL-CN -500kVA central inverter. The central inverter make have the required certification for use in solar PV plants. The technical characteristics of the inverters are in-line with the industry standard. Referring the warranty document available in public domain, SgurrEnergy understands that Power-one offer a product warrant of 66 months, which is in line with the current industry standards. In conclusion, Power-one (ABB) can be considered as established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern in the utilization of Power-one inverters for the project.
4	Inverter and Power Transformer	The inverter transformers (1250kVA) and power transformer (6.25MVA and 10/12.5MVA) used within the project are manufactured by Areva T&D. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

<table>
<tr><th>Sr. No.</th><th>Parameter</th><th>Comment</th></tr>
<tr><td>5</td><td>String Sizing</td><td>The V_{OC} does not exceed the inverter input voltage for the site, and therefore, SgurrEnergy considers the number of modules in series to be acceptable for the PV Project.</td></tr>
<tr><td>6</td><td>Resource Assessment</td><td>For resource analysis, SgurrEnergy has compared various satellite datasets. For the satellite databases, SEI has compared Meteonorm 7.3, NASA, SWERA and SolarGIS data to find the most suitable solar resource for long-term energy yield prediction. Owing to low uncertainty and high resolution, SEI considers SolarGIS dataset to be the most representative satellite database among all the satellite databases for long-term energy yield assessment.</td></tr>
<tr><td>7</td><td>Operational Analysis and Generation Comparison</td><td>Review presented in Section 8</td></tr>
<tr><td>8</td><td>Allied Components and Systems</td><td>Review presented in Section 4</td></tr>
<tr><td>9</td><td>Energy Yield Assessment</td><td>Subsequent to the solar resource assessment, SEI considers SolarGIS database as the most representative for long-term energy yield predictions. The table below summarises the energy yield predictions for ninth year of plant operation for the 13 MW$_{AC}$ PV plant.
<table>
<tr><td>Global Horizontal Irradiation (kWh/m2)</td><td>2006.60</td></tr>
<tr><td>Global Inclined Irradiation (kWh/m^2)</td><td>2196.32</td></tr>
<tr><td>First Year P50 Energy Yield (MWh/annum)</td><td>26,543.854</td></tr>
<tr><td>Ninth Year P50 Energy Yield (MWh/annum)</td><td>24,493.20</td></tr>
<tr><td>Ninth Specific Yield (kWh/kW$_p$)</td><td>1629.72</td></tr>
<tr><td>Ninth Performance Ratio (PR)</td><td>74.20%</td></tr>
<tr><td>Ninth PLF on Contracted Capacity (13MW$_{AC}$)</td><td>21.51%</td></tr>
</table></td></tr>
</table>

Glossary

A	Amp
AC	Alternating Current
a-Si	Amorphous Silicon
CdTe	Cadmium Telluride
c-Si	Crystalline Silicon
CIGS/CIS	Copper Indium (Gallium) Di-Selenide
CPV	Concentrated photovoltaic
CSP	Concentrating solar power
CUF	Capacity Utilization Factor
°C	Degrees Centigrade
°	Degrees
DC	Direct Current
E	East
GWh	Giga Watt hour
HV	High Voltage
Hz	Frequency, Hertz
IAM	Incident Angle Modifier
Isc	Short Circuit Current
IEC	International Electro technical Commission
kA	One Thousand Amps
km	One metric kilometre
kV	One thousand Volts
kVA	One thousand Volt Amps
kWp	One thousand Watts peak
kWh	One thousand Watt hours
LV	Low Voltage
m	Meters
m^2	Meters squared
mm	Millimetres
mm^2	Millimetres squared
m/s	Meters per second
mc-Si	Mono-crystalline Silicon

MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MTBF	Mean Time Between Failures
MV	Medium Voltage
MVA	One million Volt Amps
MW	One million Watts or Megawatt
MWp	Megawatt peak of Solar PV modules
N/m^2	Newton per meter Squared
N	North
NASA	National Aeronautics and Space Administration
NEC	National Electric Codes
O&M	Operations and Maintenance
ONAN	Oil Natural Air Natural
ONAF	Oil Natural Air Forced
%	Percentage
pc-Si	poly-crystalline Silicon
PV	Photovoltaic
REC	Renewable Energy Certificates
RPO	Renewable Purchase Obligation
STC	Standard Test Conditions
SWERA	Solar and Wind Energy Resource Assessment
TUV	TÜV Rheinland Group Testing and Standards Organisation.
V	Volts
Voc	Open Circuit Voltage
VT	Voltage Transformer
W/m^2	Watts per metres squared
Wp	Watt peak
XLPE insulation	Cross-Linked Polyethylene insulation

1 Introduction

Virescent Infrastructure (the Client) backed by global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy India (SEI) has been appointed by the Client to conduct technical appraisal for the 68MW$_{AC}$ portfolio of Solar PV projects in India. The portfolio comprises of four projects, as presented within Table 1-1.

Table 1-1: Project Key Summary

Project Name	SSEPL – 5MW$_{AC}$	SSEGPL – 13MW$_{AC}$	PLG – 20MW$_{AC}$	USUPL – 30MW$_{AC}$
Site Location	26.52”N, 72.85E, Tiwari, Jodhpur, Rajasthan, India	23.9128°N, 71.2183°E, Santalpur, Patan, Gujarat, India	23.9°N, 71.5°E, Dahisar, Patan, Gujarat, India	25°18'52.79"N, 79°25'2.49"E, Devgaon, Mahoba, Uttar Pradesh, India
Owner	Sindicatum Solar Energy Private Limited (SSEPL)	Sindicatum Solar Energy Gujarat Private Limited (SSEGPL)	PLG Photovoltaic Private Limited (PPPL)	Universal Saur Urja Private Limited (USUPL)
DC / AC Capacity	5.745MW$_P$ / 5MW$_{AC}$	15MW$_P$ / 13MW$_{AC}$	20MW$_P$ / 20MW$_{AC}$	36.98MW$_P$ / 30MW$_{AC}$

This report presents the evaluation of the 13MW$_{AC}$ solar PV plant developed by Sindicatum Solar Energy Gujarat Private Limited (SSEPL). The Solar PV plant under evaluation is located in Santalpur village, Patan district in Gujarat state. The purpose of this report is to provide a technical appraisal of PV plant under evaluation.

The report focuses on the following key parameters:

- System Design.
- Major Components.
- Engineering Design.
- Independent Solar Resource Assessment and Energy Yield Prediction.
- Plant Operational Analysis and Generation Comparison.
- Permits and Approvals.

This report presents independent technical appraisal of the Project and is based on information made available by the Client through online data room. The main Project characteristic is summarised in Table 1-2.

Figure 1-1 illustrates the project structure indicating key project participants for the 5MW$_{AC}$ solar PV plant.

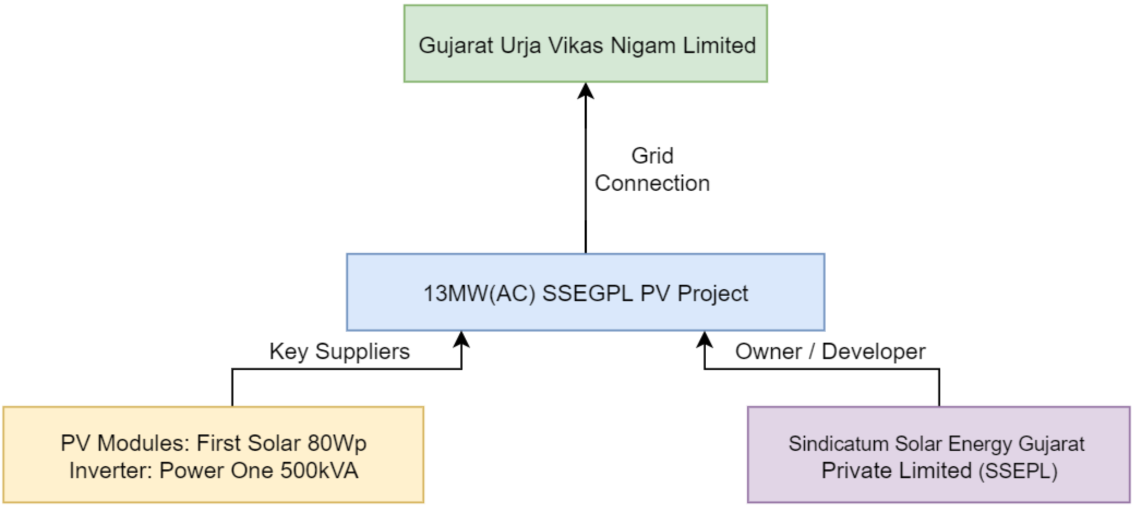

Figure 1-1: Project Structure for 13MW$_{AC}$Solar PV Plant

Table 1-2: Project Key Summary

Project Information	
Project Name	13MW$_{AC}$ SSEGPL solar PV plant
Location	Santalpur, Patan, Gujarat
Developer	Sindicatum Solar Energy Private Limited
DC/ AC capacity	13MW$_{AC}$ PV Plant – 15MW$_{P}$ / 13MW$_{AC}$
Key Equipment Manufacturers	PV Modules: First Solar Inverters: Power One
MMS Configuration	Fixed Tilt: 22°, Azimuth: 0°
Commissioning Status	Commissioning for 4MW$_p$ was achieved on 4 March 2012, 6MW$_p$ was achieved on 31 March 2012, 4.92MW$_p$ was achieved on 12 April 2012 and 0.08MW$_P$ was commissioned on 31 October 2021.

2 13MW$_{AC}$ Solar PV Plant Overview

The project site lies around the coordinates 23.9128°N, 71.2183°E. Satellite imageries of 13MW$_{AC}$ solar PV plants are illustrated below in Figure 2-1. The Owner has leased approximately 78.52 acres of land from the government for the project. The Project site is located near the *Santalpur* village, in *Patan* district of Gujarat.

Project is contracted for generating 13MW$_{AC}$ power; SEI therefore interprets 13MW$_{AC}$ as the maximum AC installed capacity for the solar PV plant.

Figure 2-1: Satellite image of 13MW$_{AC}$ plant

2.1 13MW$_{AC}$ Project Summary

Solar PV plant is modular in nature; therefore, SSEGPL 13MW$_{AC}$ solar PV plants is implemented by adopting modularity in designs. 2MW$_{AC}$ and 1 MW$_{AC}$ are the typical inverter stations considered for implementing SSEGPL 13MW$_{AC}$ solar PV plant.

Table 2-1 presents the summary of 13MW$_{AC}$ PV plant.

Table 2-1: Summary of 13MW$_{AC}$ Plant Configurations

General	
PV Module Technology	Cd-Te Thin Film
Inverter Technology	Central Inverters
Installed DC Peak Capacity (MW$_p$)	15.00
Installed AC Capacity (MW)	13.00

General	
Mounting Type	Fixed Tilt
Tilt Angle (°)	22°
Pitch (m)	6.8
PV Modules	
PV Module Manufacturer	First Solar
Model	FS-280
Wattage (W_p)	80W_p
Number of Modules per String	10
Inverter	
Inverter Manufacturer / Model	Power One / PVI-Central-500
Inverter Nominal AC Output	500kW
Number of Inverters	26
Mounting Structure	
Mounting Structure Details (rows × columns)	6 × 10
Orientation of Modules	Landscape

The 13MW$_{AC}$ plant is implemented with a total of seven (7) inverter stations of capacity 2MW$_{AC}$ and 1MW$_{AC}$. The 2MW$_{AC}$ stations comprise of two (2) three winding transformers to accommodate 4 × 500kVA inverters, taking the individual inverter station size to 4MW$_{AC}$. While The 2MW$_{AC}$ stations comprise of one (1) three winding transformer to accommodate 2 × 500kVA inverters, taking the individual inverter station size to 1MW$_{AC}$. Inverter station is comprised of a physical block connecting 2.3MW$_p$ and 1.15MW$_p$ of installed photovoltaic array. The output of the inverter stations are connected to transformers of 12.5MVA and 6.3MVA for stepping up the voltage to 33kV.

3 Review of Major plant components

SgurrEnergy has conducted a desktop review of the main plant components which includes a high-level review of the company, its track record, product certifications obtained, technical characteristics and warranty conditions.

3.1 PV modules – First Solar

SgurrEnergy has conducted a technical review of the supplier and module specification with regards to their suitability for their use in the Projects under evaluation.

3.1.1 Company Profile

First Solar Inc. is a USA based (Tempe, Arizona) producer of Cadmium Telluride (CdTe) thin-film modules and has more than 6,400[1] employees worldwide with manufacturing facilities in the USA, Malaysia, and Vietnam. Formed in 1999 the company launched production of commercial products in 2002 and was the first company to integrate thin film solar module technology into high-volume, low-cost production.

According to information available on public domain, First Solar is committed to providing a commercially attractive recycling solution for PV power plant and module owners to help them meet their module end-of-life (EOL) obligation simply, cost-effectively and responsibly.

First Solar has received the following certifications at all of its manufacturing facilities; ISO 14001:2015 environmental management systems certification, ISO 9001:2015 quality management systems certification, and ISO 45001:2018 certification for Occupational Health and Safety Management Systems.

First Solar thin film modules are used in ground-mounted and commercial rooftop applications ranging from a few kilowatts to tens of megawatts in size.

3.1.2 Experience and track record

First Solar modules have global solar PV installed capacity of 633.7GW. First Solar modules have more than 1.8GW PV modules have installed capacity and nearly 150MW capacity is under operation in India[2]. Figure 3-1 illustrates the installed capacity of first-solar modules in India.

[1]http://www.firstsolar.com/-/media/First-Solar/Documents/Corporate-Collaterals/FS_Corporate_Factsheet.ashx

[2] https://www.firstsolar.com/en-IN/PV-Plants/Project-Development

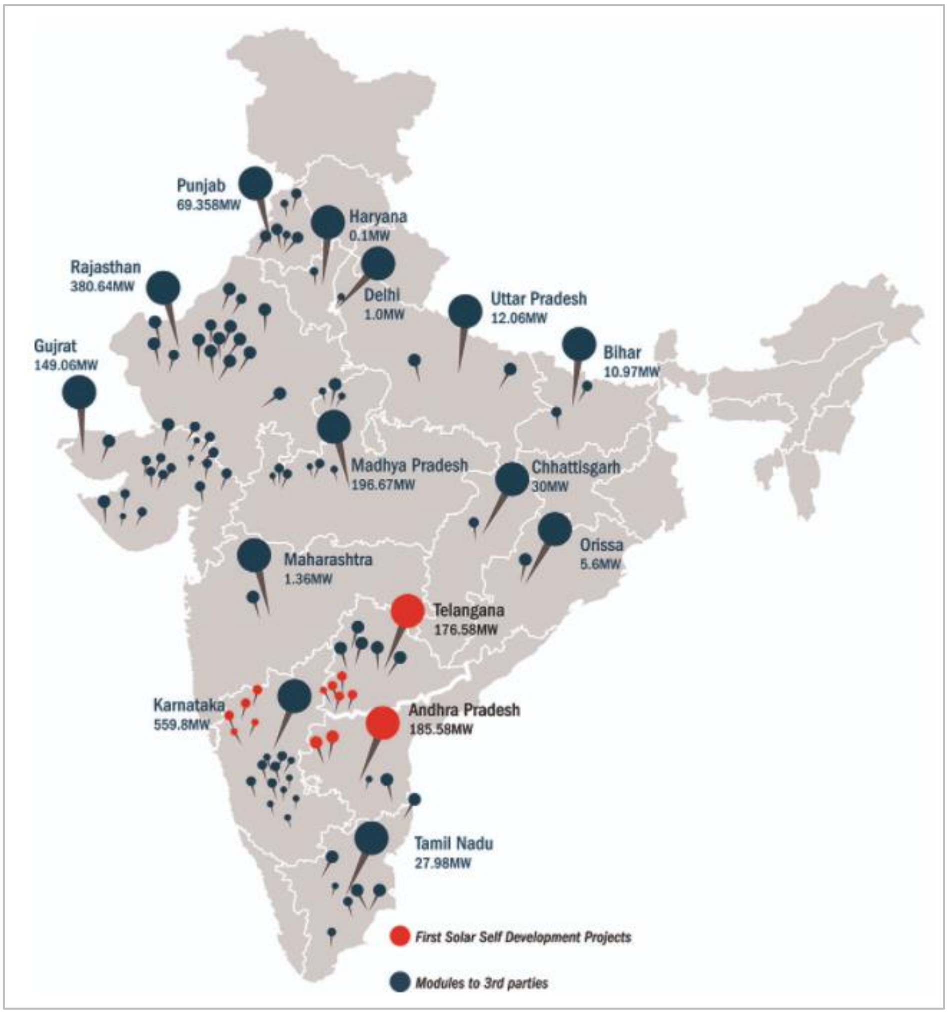

Figure 3-1: First-solar modules installed in India.

Few of the commissioned solar power plants using First Solar modules are listed in Table 3-1

Table 3-1: Track record of First Solar Modules

Sr. No.	Project	Location	Capacity (MW)	Installation Year
1	Hindupur Solar Park	Andhra Pradesh India	40.0	2016
2	Kodangal Solar Park	Telangana State India	10.0	2016
3	Mahabubnagar Solar Park	Telangana State India	10.0	2015
4	Polepally Solar Park	Telangana State India	25.0	-
5	Karoor Solar Park	Telangana State India	15.0	2016
6	Marikal Solar Parks	Telangana State India	10.0	2015
7	Hindupur Solar Park	Andhra Pradesh, India	40.0	2016

Sr. No.	Project	Location	Capacity (MW)	Installation Year
8	Topaz Solar farm	USA	550.0	-
9	Agua Caliente	USA	290.0	-
10	Copper Mountain 1	USA	48.0	-
11	Greenough River	Australia	10.0	-
12	Phalodi	Rajasthan, India	50.0	-
13	Dewa Solar plant	UAE	13.0	-

SgurrEnergy considers First solar to have an acceptable track record in delivering PV modules to PV projects worldwide.

3.1.3 Main Technical Characteristics

First Solar FS-280 modules of 80W$_P$ capacity have been used for the Project. The shortlisted modules have a temperature coefficient (Pmax) of -0.25%/˚C rise in temperature. This temperature coefficient is in line with SgurrEnergy's expectation for thin film. The technical characteristics of FS-280 are presented in the Table 3-2

Table 3-2: First Solar PV Module Technical Characteristics

Specifications	FS-280; 80W$_P$
Technology	Thin Film
Nominal power (P_{MPP})	80W$_P$
Voltage at P_{MAX} (V_{MPP})	71.2V
Current at P_{MAX} (I_{MPP})	1.1A
Open circuit voltage (V_{OC})	91.5V
Short circuit current (I_{SC})	1.2A
Maximum System Voltage	1,000V
Dimensions (length × breadth × width) (mm)	1200 × 600 × 6.8mm
Module area (m^2)	0.72m^2
Weight (kg)	12
Temperature coefficient at P_{MAX}	-0.25%/°C
Maximum reverse current	3.5A
Product warranty	5 years
Power output guarantee	25 years
Module technical characteristics are given at STC (1,000W/m^2 irradiance, 25°C module temperature, Air Mass 1.5 according to module manufacturer datasheet)	

Overall, the module characteristics can be considered to be in line with market standard.

NOCT Characteristics

The nominal operating cell temperature (NOCT)[3] characteristics of selected FS-280; 80W$_P$ modules is given in Table 3-3 relate to more realistic operating conditions compared to

[3] Irradiance = 800W/m2, Air Mass = 1.5, Ambient temperature = 45±3°C

STC. It is impacted by the module materials used as well as the packing density of module materials. The NOCT for the module is 45°C. This is comparable with other manufacturers and demonstrates the module is effective at heat dissipation.

Table 3-3: PV Module NOCT Characteristics – First Solar Modules

Model	FS-280
Maximum Power (P_{MAX})	60W_P
Maximum Power Voltage (V_{MP})	66.8V
Maximum Power Current (I_{MP})	0.9A
Open Circuit Voltage (V_{OC})	85.1V
Short circuit current (I_{SC})	1.0A

3.1.4 Certification of Modules

The modules are manufactured in an automated facility certified to ISO9001, ISO14001 and OHSAS18001. SgurrEnergy has summarised the certification obtained for the module as below in Table 3-4.

Table 3-4: Certification for PV Module

Sr. No.	Certification	Description
1	IEC 61646	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
2	IEC 61730 (Edition 1/2)	PV module safety qualifications

It is common for PV modules to hold the design, performance and safety certifications based on IEC prescribed testing methods. However, complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is operational, SgurrEnergy does not raise any major concern regarding the unavailability of IEC certificates.

3.1.5 Warranty

The warranty document is essentially required to understand the terms and conditions and also the warranted power performance values. Although the Client has not provided the warranty documents for review, however, referring to the datasheet provided, SgurrEnergy understands that the specified modules are provided with two forms of warranty: a 5-year Limited Product Warranty and a 25-year Limited Power Output Warranty. Both warranties are described in the sections below.

3.1.6 Product Warranty

First solar provides a limited product warranty of 5 years. During this period the modules shall be free from defects in materials and workmanship under normal use, installation, operation and service for a period of ten years.

SgurrEnergy considers five-year product warranty provided by First Solar to be lower than the industry standard of 10-years and suggests getting clarity from the manufacturer regarding the warranty offered for the modules utilized for the project.

3.1.7 Linear Power-Output Warranty

First solar warrants that the modules will not experience a power loss of greater than 10% during the first ten (10) years and 20% during twenty-five (25) years subject to the terms and conditions mentioned in the warranty document.

Since the warranty document was not provided for review, SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules.

3.2 Inverters- Power-one

The Developer has utilized PVI-Central- 500.0-TL capacity central inverter for the project under evaluation.

3.2.1 Company background

Founded in Chatsworth, California, in 1972 as an AC/DC power supplies manufacturer, Power-one was incorporated in late 1970s and shifted its headquarters to Camarillo. Power-one was one of the leading providers of renewable energy and energy-efficient power conversion and power management solutions and a leading designer and manufacturer of photovoltaic inverters, in the late 1990s.

The company provided services in sales, manufacturing, and R&D across Asia, Europe, and the Americas. In addition to its manufacturing units in Dominican Republic and Mexico, the company also had research and development centre in Limerick, Ireland.[4] In 2013, Power-one had over 40-years of experience of providing services for variety of industries including renewable energy, servers, storage and networking, industrial and network power systems, etc. In 2012, Power-one employed nearly 3,300 people, mainly in China, Italy, the USA and Slovakia and generated USD120million in earnings.

However, due to poor business conditions at the start of the 21st century, the company suffered significant losses. On April 22, 2013, the ABB acquired Power-one's solar inverter business.

ABB is a global leader in power and automation technologies. Based in Zurich, Switzerland, ABB is one of the largest engineering companies as well as one of the largest conglomerates in the world. ABB has operations in around 100 countries, with approximately 147,000 employees[5]. Company reported global revenue of around $34,312 million for 2017.[6]

On July 9, 2019, the Italian company FIMER acquired ABB's solar inverter business. The takeover of ABB's solar inverter business included 800 employees in 26 countries as well as two manufacturing plants, in Italy and in India, and a R&D facility in Finland.

FIMER was founded in 1942, headquartered in Vimercate, Italy, has been actively working in inverter technology since 1983. As of 2020, the company employs more than 1,100 employees across its three manufacturing facilities and three R&D centres across the globe. As a result of acquisition of ABB's PV inverter line, FIMER ranked the fifth-largest PV inverter globally in 2019.

3.2.2 Track Record

Table 3-5 lists the state-wise installed capacity of Power-one (ABB) inverters in India. However, it is to be noted that the table below doesn't not comprise of the installed capacities till date.

[4] https://www.encyclopedia.com/books/politics-and-business-magazines/power-one-inc

[5] https://new.abb.com/news/detail/26838/abb-to-exit-solar-inverter-business

[6] https://new.abb.com/investorrelations/company-profile/facts-figures

Table 3-5: Power-one (ABB) Inverter Track Record

Location	Capacity (MW)
Punjab	227
Haryana	62
Uttar Pradesh	106
Bihar	225
Rajasthan	371
Madhya Pradesh	271
Chhattisgarh	28
Odisha	20
Andhra Pradesh	647
Maharashtra	261
Tamil Nadu	747
Karnataka	305
Kerala	50

3.2.3 Technical Characteristics

Power-one PVI-500.0-TL-CN inverter has been selected for technical feasibility of the Project.

The PVI-500.0-TL-CN -500kVA Series of central inverters designed ideal for large PV Power Plants. These inverters are designed to operate with DC inputs up to 1,000 V. PVI-500.0-TL-CN -500kVA inverter is designed for outdoor use with an IP20 ingress protection class. They perform optimally at ambient air temperatures between -20°C to 55°C and relative humidity in the range of 0% to 95% with maximum noise level of less than 62dBA.

The PVI-500.0-TL-CN -500kVA inverter has peak efficiency of 98.5% and a European efficiency of 98.2%.

The main technical characteristics of these inverters are illustrated in Table 3-6.

Table 3-6: Power-one inverter specifications

ABB Central Inverter Specifications	
Inverter	PVI-500.0-TL-CN -500kVA
Type	Central Inverter
Input Data	
PV voltage range, MPP (V)	475 to 900V
Maximum DC voltage (V)	1,000V
Maximum input current (A)	1,100A
Output Data	
Nominal AC power (kW)	500kW
Maximum AC current (A)	900A
AC voltage range (V)	272 to 352V
AC grid frequency (Hz)	50Hz±5%

ABB Central Inverter Specifications	
Maximum THD	< 4%
Operating Performance	
Maximum efficiency (%)	98.50%
Euro efficiency (%)	98.20%
Power consumption	
Night-time power loss (W)	<66W
Standby operation consumption (W)	<66W
Other	
Dimensions (W × H × D) (mm)	2280mm x 2000mm x 800mm
Weight (kg)	<1400kg
Environmental Protection Rating	IP20
Operating temperature range (°C)	-20 to+55°C
Relative humidity (%)	0% to 95%

The following protection devices are included within the inverter design:

- Anti-islanding protection
- Reverse polarity protection
- AC and DC short circuit and over current protection
- AC and DC over voltage and temperature protection

Power-one inverters comprise of suitable protection devices in place on both the DC and AC side to protect the PV system and inverter components.

3.2.3.1 Certification

Power-one is certified to the internationally recognised standard for management systems and according to ISO 9001 that they conform to the latest quality standards.

Inverter reliability is further enhanced via stringent quality control procedures. Power-one inverter manufacturing facilities operate with the following certifications:

- ISO 9001:2015 Quality Certificate
- ISO 14001:2015 Environmental Certificate
- OHSAS 18001 Health and Safety Management System

Based on information available in public domain, SgurrEnergy has summarized the certification of the Power-one inverter within Table 3-7.

Table 3-7: Description of Certification of Power-one inverters

Certification	Description
IEC 61000-6-2	Electromagnetic compatibility
IEC 62109-2:2011	Safety of Power Converters
IEC 62116:2014	Islanding prevention measures

3.2.3.2 Warranties

According to the warranty documents available on public domain[7], the standard warranty offered by Power-one for central is for a period of 66 months from the date of invoice. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards and do not raise any concern over the use of inverter for the project.

3.3 Transformer- Areva Transmission & Distribution Ltd.

The solar PV plant is implemented with two level transformation. Power at low voltage from inverters is stepped up to 11kV using 1250kVA inverter transformers and further to 66kV using 10/12.5MVA and 6.25MVA Power transformers of Areva T&D make.

3.3.1 Company Profile

Established in 2001 and headquartered in Paris, France, Areva S.A. was a French multinational group providing services in nuclear power and renewable energy. Areva's global renewable energies business group was formed in 2006 as an expansion of its clean energy portfolio. The group worked majorly in four business line: concentrated solar power, offshore wind power, biomass power, and hydrogen power storage and distribution.

As a part of the restructuring program following its insolvency, Areva's transmission and distribution business was jointly acquired by Alstom and Schneider Electric in November 2009. According to the agreement signed between the parties, the transmission business was acquired by Alstom and the distribution business was acquired by Schneider Electric.

Alstom is a French multinational company established in 1928 and headquartered in Saint-Ouen-sur-Seine, France. In November 2015, Alstom sold its Power generation and grid business to General Electric.

3.3.2 Technical Specifications

The 1250kVA inverter transformer used in the project is outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

The 6.25MVA and 10/12.5MVA power transformer used in the project is outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

SgurrEnergy is satisfied that both the transformers have been designed to adhere local and country specific grid codes and relevant IS codes (IS-2026). The transformers technical characteristics are presented in Table 3-8.

Table 3-8: Technical Specification of Areva Transformer

Technical Parameters	Inverter transformer	Power transformer	
	1250kVA	6.25MVA	10/12.5MVA
Rated Power	1250kVA	6.25MVA	10/ 12.5MVA
Rated HV	11kV	66kV	66kV
Rated LV	320V	11kV	11kV

[7] https://www.renvu.com/site/downloads/Power-One%20Aurora%20Warranty%20Services%20Description%20for%20String%20Inverters%20for%20RENVU.pdf

Technical Parameters	Inverter transformer	Power transformer	
	1250kVA	6.25MVA	10/12.5MVA
Tapping on HV	-5% to +5% (steps of 2.5%)	-	-
Phases	3		
Frequency	50Hz		
Vector group	Dyn11yn11	YNyn0	YNyn0
Impedance	6.25% (with IS TOL.)	-	-
Cooling Strategy	ONAN		
Oil temperature rise	50°C	-	-
Winding temperature rise	55°C	-	-
Winding material	Electrolytic Copper		

SgurrEnergy considers the overall the technical specifications of inverter transformer to be adequate for the PV projects. However, GTP (guaranteed technical particulars) have not been provided for the power transformers for SgurrEnergy's review. Since the solar PV plant is operational, SgurrEnergy does not raise any major concern in the use of Areva transformers for the project.

3.3.2.1 Temperature Rise Detection and Protection

Referring the general arrangement of the inverter transformer and power transformers, SgurrEnergy observed that all the transformers have been provided with standard temperature sensing systems. These comprise of an analogue oil temperature indicating (OTI) unit and winding temperature indicating (WTI) unit. Both the units have been adequately provided with alarm/trip contacts and wired to relay units located at HT panel.

The transformers are adequately provided with the Buchholz Relay that essentially serves as a critical protective device in case of excessive gas pressure released in the event of higher transformer loadings and faults.

3.3.2.2 Warranties and Guaranties

Warranty document have not been provided for the transformers used for the Project. In the absence of the warranty documents, SgurrEnergy is unable to provide comments regarding the warranty offered and suggests the Client to obtain clarity from the manufacturer on the final offer.

3.4 Conclusion on Major Plant Components

PV Modules

According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of First Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard.

Further, the warranty document was not provided for review, SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules. Regarding the certifications, the complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.

Inverters

SgurrEnergy has conducted review of the Power-one's PVI-500.0-TL-CN -500kVA central inverter. The central inverter make have the required certification for use in solar PV plants. The technical characteristics of the inverters are in-line with the industry standard. Referring the warranty document available in public domain, SgurrEnergy understands that Power-one offer a product warrant of 66 months, which is in line with the current industry standards.

In conclusion, Power-one (ABB) can be considered as established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern in the utilization of Power-one inverters for the project.

Transformers

The inverter transformers (1250kVA) and power transformer (6.25MVA and 10/12.5MVA) used within the project are manufactured by Areva T&D. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

3.5 Module support structures

The Array Layout provided by the Client for the 13MW(AC) SSEGPL Solar PV Plant indicates the fixed tilt module mounting structure is inclined at 23° tilt angle.

SgurrEnergy observed that the structure has been designed with three rows of modules placed in portrait orientation with 20 modules in each row. In total there are 60 modules in one mounting structure.

Figure 3-2 illustrate the module mounting structure configuration provided by the Client for the 30MW(AC) USUPL Solar PV Plant. The material used and section sizes of MMS are not available.

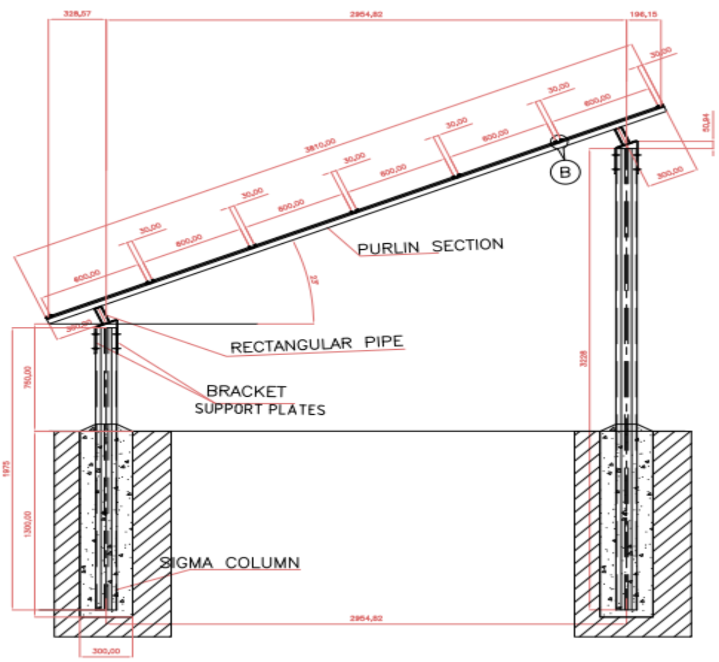

Figure 3-2: Section of the module mounting structure configuration

4 Allied Components and Systems

4.1 Civil Structures

Based on the review of Plant layout, SgurrEnergy observed that the inverter stations are placed at centre of each block module to minimise cable losses.

SgurrEnergy has reviewed the electrical schematic provided by the Client. The electrical schematic describes the overall connection of the PV modules, inverters, transformers, switchgear, and plant substation as well as providing the ratings of all the components.

SgurrEnergy has been provided with the following electrical schematic for the Project.

- 11kV Single Line Diagram-R3
- SLD on DC side control room - 1,2 & 3-R1
- SLD on DC side control room - 4,5 & 6-R1
- SLD on DC side control room - 7-R1

The 13MW$_{AC}$ solar PV Plant is designed with 80W$_p$ *First solar* make, thin film solar PV modules and 500kW *Power one* make central inverters. PV modules are interconnected to form a string of 10 modules. Such 8/9/10 strings output is connected to Array Junction Box (AJB). The 9/15/16 AJBs output is connected to string monitoring boxes. Five such string monitoring boxes are further connected to central inverters as input.

The 13MW$_{AC}$ solar PV plant has been configured with 26 *Power-One* make 500kW central inverters and seven inverter stations where 2/4 central inverters have been placed. Each inverter station is of 1MW$_{AC}$ or 2MW$_{AC}$ capacity contains 2/4, 500kW inverters. The two inverters output is connected to ACB (Air circuit breaker) panel. The power from ACB panel two feeders is connected to 1.25MVA, 11/0.320-0.320kV, ONAN three winding transformer for stepping up the voltage to 11kV.

The medium voltage output from one or two inverter duty transformers is connected with 11kV RMU (Ring Main Unit) panel placed at inverter station. The one or two such 11kV RMU (Ring Main Unit) panels are connected in ring philosophy and connected with respective 11kV switchgear panels. The 11kV output from main MV Switchgear panels shall be further connected to 10/12.5MVA and 6.3MVA power transformers located in 11/66kV switchyard. Power from 11/66kV switchyard is evacuated to GETCO substation via 2.2km underground transmission line. However, 11/66kV switchyard SLD and metering details are not provided to SgurrEnergy.

Figure below illustrates a power flow summary for the 5MW$_{AC}$ Solar PV plant.

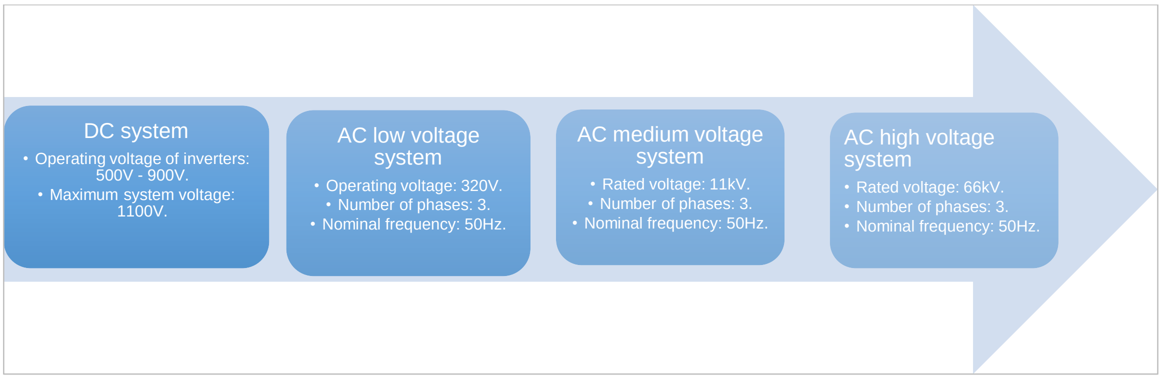

Figure 4-1: Power flow of 13MW$_{AC}$ PV plant

4.2 Cabling

4.2.1 DC Cabling

DC cabling comprises of PV module leads, string cables connecting the PV module strings to combiner box and main DC cables connecting the combiner box to the inverter fuse and then to the inverter. Modules are interconnected in series with 4mm^2 solar grade cables to form a string of 10 PV modules. Single core 4mm^2 multi-stranded copper PV cables connect string output to Array Junction Box (AJB). Power from AJBs is transmitted to String monitoring boxes (SMB) through 10mm^2 multi-stranded copper PV cables.

Power from string monitoring boxes is further transferred to the inverter using 1C, 70mm^2, and 1.1kV copper XLPE cables.

4.2.2 AC Cabling

Three phase AC output from inverter is connected to ACB panel using 4R, 3C, 300mm^2 Aluminium Armoured XLPE cable. ACB panel outgoing feeders output is connected to LV winding of a 1.25MVA three-winding transformers using 4R, 3C, 300mm^2 Aluminium Armoured XLPE cable.

The inverter duty transformer output is connected to 11kV RMU panel located in inverter station 3C, 240mm^2, 11kV Al XLPE armoured cable. The one or two such RMU panels are interconnected in ring philosophy using 3C, 240mm^2, 11kV Al XLPE armoured cables.

The 11kV output from RMU panels is transmitted to 11kV switchgear panels using 3C, 240mm^2, 11kV Al XLPE armoured cables.

The power from the 11kV switchgear panels is transferred to 10/12.5MVA and 6.3MVA power transformers located in 11/66kV outdoor switchyard using 3R/2R, 3C, 240mm^2, 11kV Al XLPE armoured cable. Further the output power of 11/66kV Switchyard is transferred to GETCO substation over transmission line.

4.3 Inverter Station

The 20MW$_{AC}$ solar PV plant has been configured with 26 inverters and seven inverter stations. Each inverter station is of 1MW$_{AC}$ and 2MW$_{AC}$ capacity consists of two or four 500kW inverters and one or two 1.25MVA inverter duty transformer.

Each two inverters are connected to ACB (Air circuit breaker) panel. The power from ACB panel two feeders is connected to 1.25MVA, 11/0.320-0.320kV, ONAN three winding transformer for stepping up the voltage to 11kV. The inverter duty transformer steps up the voltage to 11kV for all inverter stations. Further the power from the HV side of the transformer is fed to the 11kV RMU panel through underground cable.

The 11kV RMU panel comprises of 200/1A current transformer, 630A vacuum circuit breakers, 630A load break switches and other electrical protection system. The power from inverter duty transformer is transferred to aforesaid RMU panel.

4.4 LV/MV Transformers

SgurrEnergy has reviewed the SLD and observed that 1.25MVA, 11kV/2x0.320kV, Dyn11yn11 three winding transformers have been used in the project. These inverter duty transformers step up the voltage to 11kV.

The two 1.25MVA inverter duty transformers output is connected to 11kV RMU panels located within inverter station. The energy from 11kV RMU panels of one or two Inverter stations is connected in ring philosophy. The combined 1/2/4MW power from one or two Inverter Stations is transmitted to 11kV switchgear panel over ring philosophy.

4.5 11kV RMU Panel

The 11kV RMU panel comprises of inverter duty transformers incoming feeders, inverter station RMU panel incoming feeder and one outgoing feeder to nearest inverter station RMU panel or 11kV switchgear panel. Each RMU panel comprises of 200/1A current transformers, 630A vacuum circuit breakers, 630A load break switches, other electrical metering and protection system.

4.6 11kV Main HT Panel

The11kV main HT/switchgear panel comprises of inverter station incoming feeders and one outgoing feeder. Each feeder comprises of dedicated VCB, instrument transformer with metering and protection class, Core balance CT. All feeders have been provided with relay and metering unit. The 11kV main HT panel outgoing and incoming feeders are provided with instantaneous overcurrent and earth fault i.e. 50/50N and IDMT overcurrent & earth fault i.e. 51/51N protections. Furthermore, the incoming feeders are equipped with directional overcurrent (67) and directional earth fault (67N) protection relays. The 11kV outgoing feeder from main HT panel is provided with 0.5 class instrument transformers.

Power from 11kV switchgear panel is transmitted to 11/66kV outdoor Switchyard. Further power from 66kV Switchyard is evacuated to GETCO substation.

4.7 Auxiliary Power Supply

SgurrEnergy had reviewed the electrical schematics shared for the projects to evaluate auxiliary system. One 200kVA, 11/0.433kV auxiliary transformer has been considered to cater the auxiliary loads. ACDB panels have been considered for load distribution to auxiliary loads.

4.8 Circuit Breakers

Circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal and abnormal circuit conditions. The circuit breakers are three poles type with electrically and mechanically operated trip-free with anti-pumping facility suitable for remote electrical closing and tripping. The circuit breakers are mounted within the panels as well as on individual structures.

Following the review of 11kV SLD and switchyard layout, SgurrEnergy observed that 11kV, 630A, 21kA/3sec, 1250A, 25kA/3sec VCB type circuit breaker and 66kV, 2000A, 31.5kA/3sec SF6 circuit breakers have been used in the project.

4.9 Load break switch

Load break switches are used to isolate the equipment during load condition for maintenance.

Based on the review of 11kV SLD, SgurrEnergy observed 11kV, 630A load break switches switch has been used in the project.

4.10 Isolators

Isolators are used to transfer load from one bus to another and also to isolate equipment for maintenance.

Based on the review of 66/11kV switchyard equipment layout , SgurrEnergy observed 72.5kV, 1250A , 31.5kA/3sec without earth switch, with one earth switch and with two earth switch type double break isolator have been used in the project.

4.11 Instrument Transformers

Current transformers (CT) and voltage/potential transformers (VT) are known to be as instrument transformers. Instrument transformers are devices used to transform the values of current and voltage in the primary system to values suitable for the measuring instruments, meters, protective relays, etc.

The current transformers with accuracy class of 0.5/0.2S for metering and class 5P10/5P20 for protection has been used in 13MW$_{AC}$ solar PV plant. The potential transformers with accuracy class of 0.2/0.5 for metering and class 3P for protection has been used in the project.

4.12 Surge Arrestors and Lightning Arresters

The substation equipment has to be protected against travelling waves due to lightning strokes on the lines entering the substation. The apparatus most commonly used for this purpose is the surge arrester. Transformer is the costliest equipment in substation, and it is normal practice to install surge arrester near to the transformer. Additional surge arresters shall be provided either on bus or on various lines for protection of the equipment.

Following the review, SgurrEnergy observed that 60kV, 10kA, Class III surge arresters have been provided near Power Transformers and at incoming line. However, Switchyard SLD is not been provided to SgurrEnergy.

4.13 Metering

In addition to the metering and monitoring arrangement in inverters, monitoring of voltage, current and energy will be provided at the medium voltage switchboards for each of the feeder sections. These meters will be digital with an RS 485 port for remote monitoring. These usually have an accuracy class of 0.5.

Similarly, HV side shall also be equipped with voltage, current, power and energy meters in order to correlate the energy generation and losses. Class of meters at the evacuation point shall be 0.2S. GETCO metering at 66kV has been considered at 66/11kV plant end switchyard with 0.2S class current transformers and 0.2 class potential transformers.

5 System Design Appraisal

SgurrEnergy has performed a detailed analysis to evaluate the string sizing and compatibility of the inverters with PV modules used for the Project. The following sections discuss the results obtained from the analysis.

5.1 Plant Layout Design

SgurrEnergy was provided with as built plant layout and electrical schematics. SgurrEnergy has verified the plant configuration with electrical schematics provided by the Client. The PV plant is First Solar (80W$_P$) PV modules. The total DC installed capacity stands at 15.02MW$_P$. The AC installed capacity stands at 13 MW$_{AC}$ with 26 inverters of capacity 500 kW each. Overall, 13 MW$_{AC}$ PV plant is illustrated below in the Figure 5-1. All the PV modules are orientated towards South.

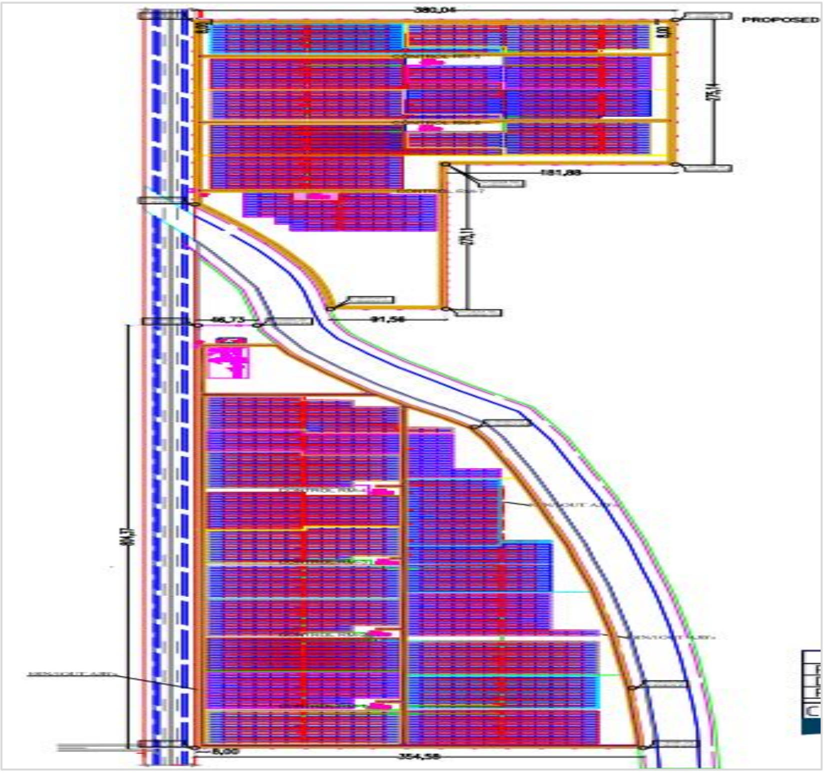

Figure 5-1: Plant layout of 13 MW$_{AC}$

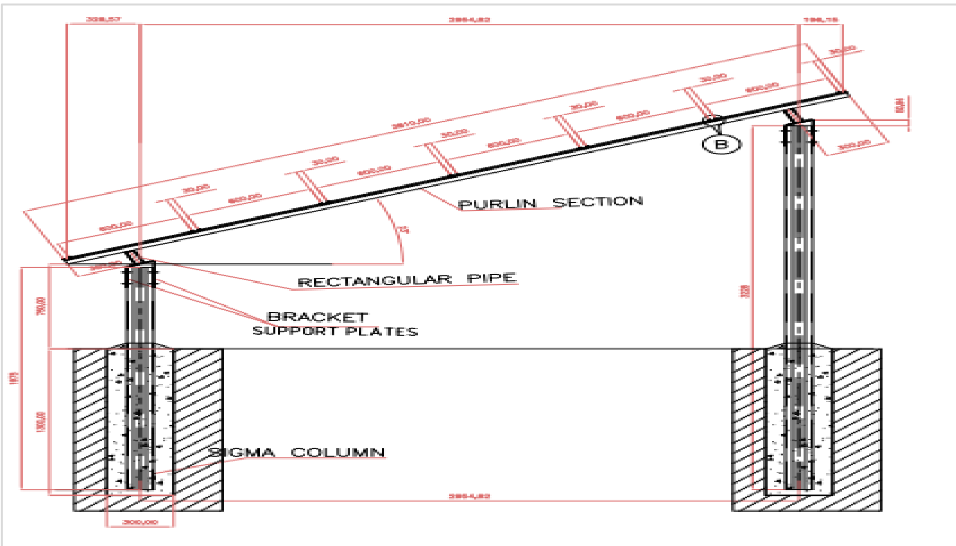

Figure 5-2: Side view of typical module mounting structure configuration

The selected tilt for the 13 MW$_{AC}$ plant is 22°. The 13 MW$_{AC}$ plant is designed with a pitch of 6.80m.

10 modules are connected in series to form a string. The nominal plant power ratio (DC to AC) of the Project is 1.16. Typically, PV plants are designed to have a nominal power ratio upto 1.45 in India; a higher ratio leads to greater overload losses during peak irradiance conditions. However, PV module temperature losses are substantial at the high ambient temperatures corresponding to the higher nominal power ratio.

5.2 String Sizing

The plant layout provided by the Developer indicate Ten 80W$_p$ First Solar CdTe modules to be connected in series to form a string for the plant.

As the string voltage is dependent on temperature and irradiation, open circuit voltage (V_{OC}) of the string must be corrected using the temperature co-efficient for the PV modules. Therefore, it becomes necessary to ensure that the maximum voltage input (i.e. the maximum V_{OC} of string at minimum temperature) to inverter does not exceed the inverter maximum operating D.C voltage and hence is a critical value considered by SgurrEnergy in validating string configuration. Subsequent to calculating open circuit voltage (V_{OC} max), maximum power voltage (V_{mp} min) is calculated to ensure that it is within the maximum power point (MPP) range of the implemented inverters.

SgurrEnergy considers the maximum and minimum ambient temperature of 45°C and 11°C respectively for system design validation to be fair and representative for the PV plants' site.

The results of string sizing validation are presented in Table 5-1. Results indicate that V_{OC} max at the minimum ambient temperature is within the maximum system voltage of 1,000V for the selected Power One (PVI-Central-500-TL) inverters.

Table 5-1: String Sizing for First Solar PV Modules

Parameters	First Solar 80W$_p$
PV module power (W$_p$)	80
Modules per string	10
Inverters	Power one - 500 KW (PVI-Central-500-TL)
Maximum Open-circuit voltage (V_{OC} max) at minimum ambient temperature of 11°C	888V
Minimum power voltage (V_{mp} min) at maximum ambient temperature of 45°C	689V

5.3 Inverter Compatibility

SgurrEnergy performed a detailed analysis on plant sizing to assess the compatibility of inverters with the PV modules used in the projects. The electrical design compatibility summary with First Solar and Power-one central inverter is presented in Table 5-2. SgurrEnergy has selected the highest rated First Solar module (80W$_p$) their compatibility with Power-one inverter, as SgurrEnergy considers this to be representative for all the First Solar PV modules installed on site.

Table 5-2: Inverter Compatibility with First Solar 80W$_p$ Modules

Parameters	Inverter Compatibility	
PV module	First Solar FS-280 (80 W$_p$)	
Modules per string	10	Acceptable
Strings per inverter	723	Acceptable
Maximum power, Pmpp at STC (kWp)	580.00	Nominal power ratio is 1.16, this is within the inverter bus current carrying capacity.
Maximum power voltage, Vmpp at STC (V)	713	Acceptable.
Maximum power current, Impp at STC (A)	770.40	Acceptable
Open-circuit voltage, Voc at STC (V)	940	Acceptable.
Minimum MPP voltage at 45ºC ambient temperature (V)	689	Acceptable: Inverter MPPT ranges 475 - 900V.
Maximum MPP voltage at 11ºC ambient temperature (V)	737	Acceptable: Inverter MPPT ranges 475 - 900V.
Maximum open circuit voltage, Voc at 11ºC (V)	888	Acceptable: Maximum inverter voltage 1000V.

Overall, SgurrEnergy does not raise any concerns regarding the string sizing and inverter compatibility.

6 Resource assessment

The accuracy of any solar energy yield prediction is heavily dependent on the accuracy of the solar resource dataset used. Solar irradiation data is currently not being measured at the location of the proposed power plant and it is therefore necessary to use alternative data sources to obtain estimates of the irradiation figures for the site.

The solar resource of a location may be defined by values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation is the total solar energy received on a unit area of horizontal surface. It includes energy received from the sun in a direct beam and energy that is received from radiation scattered off the atmosphere arriving from all directions of the sky (diffuse irradiation). The units of GHI are given in kWh/m2. Values are often provided for a period of a day, a month or a year.

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the energy received from radiation scattered off the atmosphere arriving from all directions of the sky on a unit area of horizontal surface. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the total solar energy received on a unit area of surface *directly facing the sun at all times*. The units of DNI are kWh/m^2. The direct normal irradiation is of particular interest for solar installations that track the sun and to concentrating solar technologies as only radiation coming directly from the sun may be focussed by a lens or mirror.

For modelling of solar PV plants, GHI and DHI are required for calculating the estimated energy yield. In the northern hemisphere, tilting the modules at an angle towards the south increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations.

Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo. Albedo and global tilted irradiation are described below.

Global Tilted Irradiation (GTI) – The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m^2. A transposition model is used for translating horizontal irradiation to tilted irradiation within PV modelling software.

Albedo – The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

Comparison of Resource Data

There are a variety of possible solar irradiation data sources that may be accessed. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite imagery. A minimum of 10 years of data is recommended to allow for the expected variability of resource data between years. SEI has sourced monthly horizontal plane irradiation data for the Project site from:

- ***NASA****'s Surface Meteorology and Solar Energy data set;* holds satellite derived monthly data for a grid of 0.5° × 0.5° covering the globe for a thirty-four-year period (1984-2017). The data are suitable for pre-feasibility studies of solar energy projects.

- *The* ***METEONORM (version 7.2)*** *global climatological database and synthetic weather generator;* contains a database of ground station measurements of irradiation and temperature. Where a site is over 11km from the nearest measurement station it outputs climatologic averages estimated using interpolation algorithms. Where no radiation measurement station is within 300km from the site, satellite information is used. If the site is between 50 and 300km from a measurement station a mixture of ground and satellite information is used. The accuracy of irradiation figures close to measurement stations are within a few percent. Uncertainty increases with distance between the site and the measurement station, especially in hilly and mountainous terrain.
- **SolarGIS:** SolarGIS is developed and operated by GeoModel a solar company maintaining databases of climate data to support solar energy projects and systems. Database is derived from Meteosat and Geostationary Operational Environmental Satellite system (GOES) satellite data and atmospheric parameters (aerosol and water vapour) using high performance algorithms. SolarGIS regional coverage includes Europe, Africa, Asia and parts of South America and Australia. The spatial resolution of primary parameters for European region is approximately 4km × 4km with a temporal resolution of between 15 minutes to 3 hours. SolarGIS radiation models use multispectral channels and multi-dimensional statistical treatment of ground albedo, daily values of aerosol and water vapour. SolarGIS models is validated by *IEA (International Energy Agency) SHC Collaboration Agreement, and EU FP6 project MESoR* in terms of bias and RMSE.
- **Solar and Wind Energy Resource Assessment (*SWERA)* / National Renewable Energy Laboratory *(NREL)*** data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground-based data to ensure quality of the measurements.

SEI has compared the irradiation datasets given by NASA - SSE, Meteonorm 7, SolarGIS and, NREL (SWERA) data for the site. The comparison is graphically illustrated Table6-1

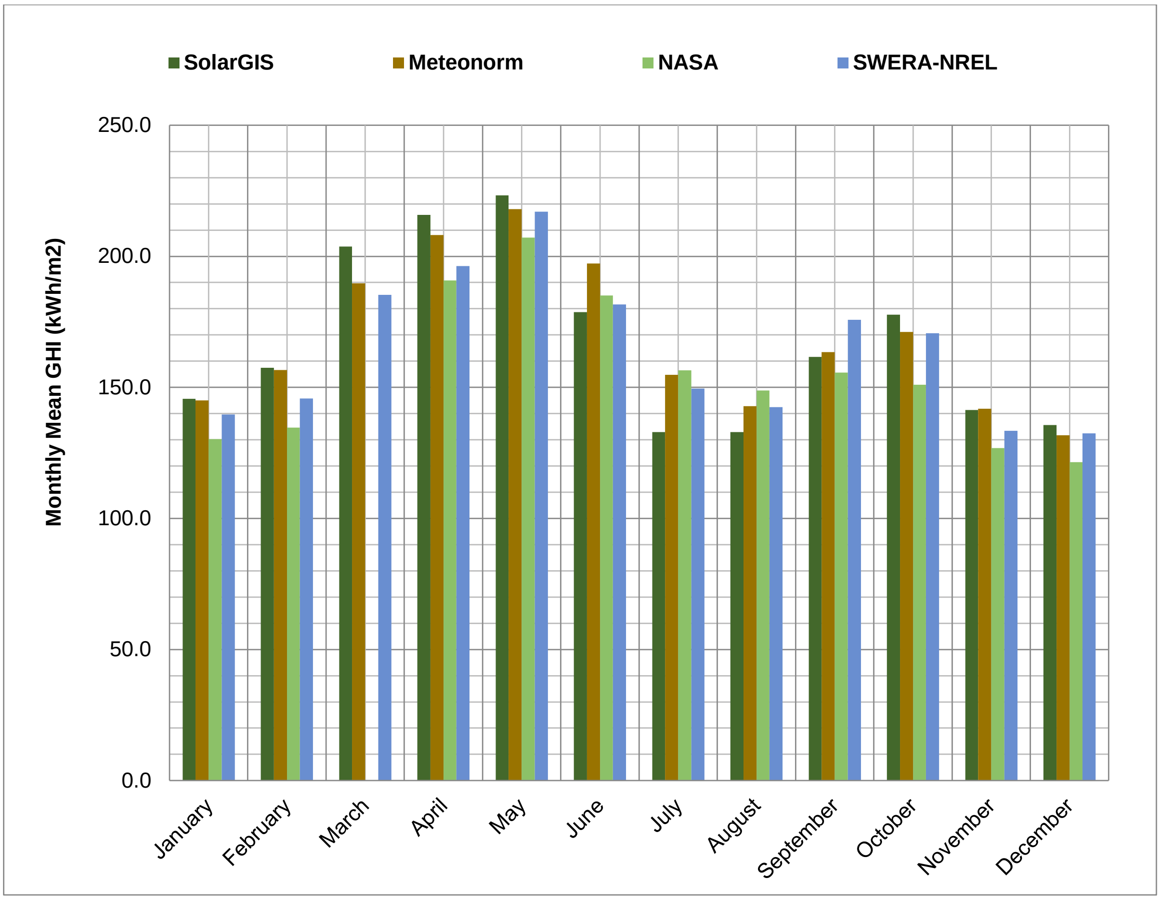

Figure 6-1: Monthly Global Horizontal Irradiation

Table6-1: Comparison of Solar Irradiation Datasets for the site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m²/annual)
SolarGIS	4km × 4km	3.9%	2,006.6
Meteonorm 7.2	14km × 14km	4.0%	2,020.4
NASA	55km × 55km	Unknown	1,708.3
NREL (SWERA)	40km × 40km	Unknown	1,970.2

The comparison of solar data for Project site location illustrated in Table6-1 indicates Meteonorm 7.2 dataset to give the highest irradiation levels. The next highest irradiation is given by SolarGIS followed by NREL (SWERA) and NASA.

The irradiation values given by Meteonorm 7.2 typically provide a combination of ground and satellite measured data. Meteonorm 7.2 has interpolated the data using satellite data for the proposed site. Uncertainty of satellite data is obtained as 6.2% for the proposed site.

The NREL (SWERA) data illustrated has been obtained for a location approximately 11.86 km away from the proposed site. SgurrEnergy performed iteration on an extensive list of NREL (SWERA) datasets to obtain appropriate coordinates that lie within the Indian boundaries. The results give only irradiation data without temperature and wind data.

The NASA-SSE data source provides purely satellite measured data for a grid covering 0.5° × 0.5° on the earth's surface and generally more suited for initial site selection.

The SolarGIS dataset has been compared with good quality ground measurements for more than 200 sites. The resulted mean bias for GHI is 0%. SolarGIS data base has also been compared with other data sources globally. The IEA (International Energy Agency) validation study conducted by University of Geneva in 2011 has resulted in SolarGIS to be the best performing database among five satellite databases. Similar IEA validation study was repeated in 2013 by University of Geneva which again resulted in SolarGIS to be the best performing database among six satellite databases. Validation study in 2013 was conducted using 18 validation sites in Europe and Mediterranean regions. Furthermore, SolarGIS has conducted its own validation for six Indian locations[8] with the following bias in GHI;

- Pantnagar (Uttarakhand)
- Kanpur (Uttar Pradesh)
- Mysore (Karnataka)
- Warangal (Telangana)
- Jaipur (Rajasthan)
- Ranchi (Jharkhand)

Comparative analysis of all the data sets available, indicate SolarGIS has been validated for India. Furthermore, SolarGIS dataset is based on the most recent long-term average that is from 1999 – 2015, while Meteonorm dataset is based on the time-period of 1991 - 2010. The uncertainty of SolarGIS is 3.9% while that of Meteonorm is 6%.

SEI is therefore of the opinion that SolarGIS dataset may be considered reasonable and a representative data source for conducting an energy yield assessment for the project location.

6.1 Global, Direct and Diffuse Irradiation on a Horizontal Plane

Horizontal plane irradiation data based on long-term monthly averages are presented in Table 6-2 and shown graphically in Figure 6-2 Diffuse irradiation accounts for 42.42% of the total irradiation. Table 6-2 illustrates direct and diffuse daily irradiation on a horizontal plane for the proposed site. SolarGIS irradiation data is presented in Table 6-2.

Table 6-2: SolarGIS Irradiation Data for the Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	145.6	46.2	7.3%
February	157.5	47.6	7.8%
March	203.7	67.6	10.2%
April	215.8	78.9	10.8%
May	223.2	94.2	11.1%
June	178.7	96.9	8.9%
July	132.9	94.2	6.6%
August	132.9	91.1	6.6%
September	161.6	78.3	8.1%

[8] https://solargis.com/docs/accuracy-and-comparisons/overview/

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
October	177.7	58.0	8.9%
November	141.4	51.9	7.0%
December	135.6	46.2	6.8%
Annual Sum	**2,006.6**	**851.2**	**-**

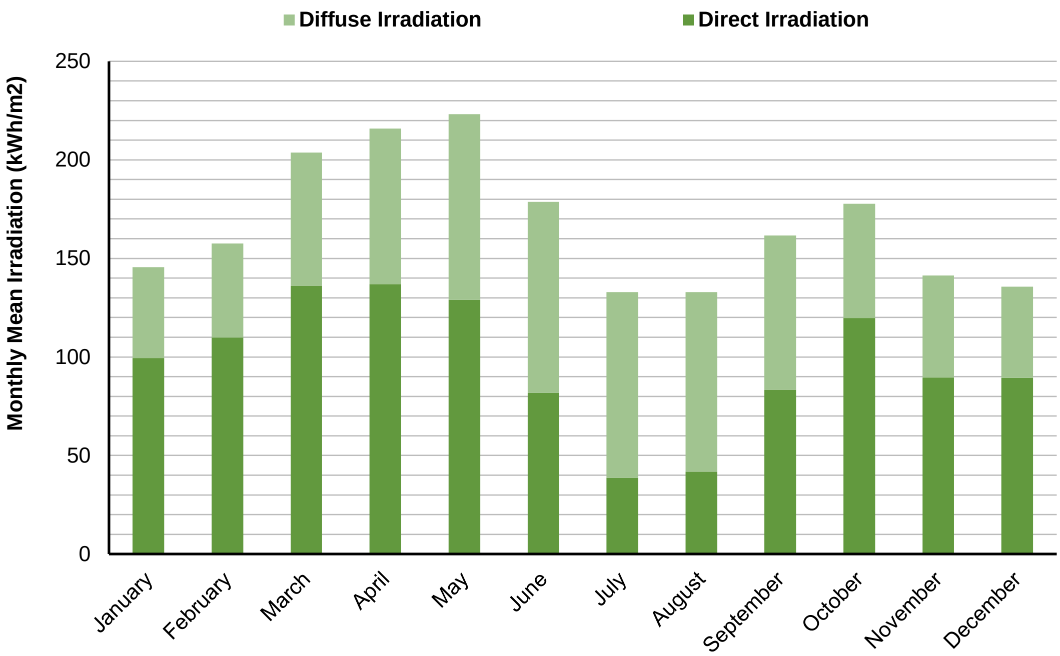

Figure 6-2: Monthly Direct and Diffuse Irradiation on a horizontal plane for the project site

6.2 Global Tilted Irradiation

Industry standard PV modelling software PVsyst (v.7.0.17), was used. An albedo of 0.2 was assumed based on the ground surface covering within and around the PV array. Table -6-3 represents the monthly GTI profile.

Table -6-3: Monthly Global Tilted Irradiation Data

Month	GTI (kWh/m^2)
January	191.10
February	191.10
March	225.30
April	219.00
May	211.80
June	165.80
July	125.20

Month	GTI (kWh/m^2)
August	129.90
September	170.80
October	208.70
November	178.20
December	179.30
Annual Sum	**2,196.20**

6.3 Climate

For wind speed analysis, data sourced from Meteonorm dataset was used and has been tabulated in Table 6-4 below. The average wind speed of 2.3 m/s was measured at 10m height from ground level for the proposed project site location.

Table 6-4: Simulated Wind Speed for site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	1.5
February	1.6
March	1.9
April	2.7
May	3.8
June	3.8
July	3.5
August	3
September	2.2
October	1.3
November	1.1
December	1.3
Yearly Average	2.3

6.4 Temperature

Temperature data has been sourced from the SolarGIS database. A typical operating temperature range for PV modules is -40°C to +85°C. Inverter operating ranges are more bounded to temperature, typically -20°C to +45°C, with the electronic equipment in the inverter degrading quicker in high temperature environments. Thus, considering the temperature range at selected site, the modules and inverters should be able to operate normally.

The effect of temperature on module performance and the corresponding plant performance may be quite significant. Typically, a reduction in efficiency of 0.40 – 0.45%/°C is noted for crystalline modules and 0.25 -0.30%/°C for thin film modules for increase in temperatures above 25°C. Therefore, during the summer months (February-June) temperature losses may be significantly high as module temperatures typically go beyond 50°C.

Table 6-5: SolarGIS Temperature Data for Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	19.7
February	22.7
March	27.9
April	32.3
May	35.1
June	34.8
July	31.3
August	30.1
September	31.6
October	30.3
November	25.5
December	21.3
Annual Average	28.6

6.5 Precipitation

The rainfall figures have been simulated using Meteonorm 7.2 as illustrated in Figure 6-3. These figures show that the identified site is situated in a region that has marginal rainfall.

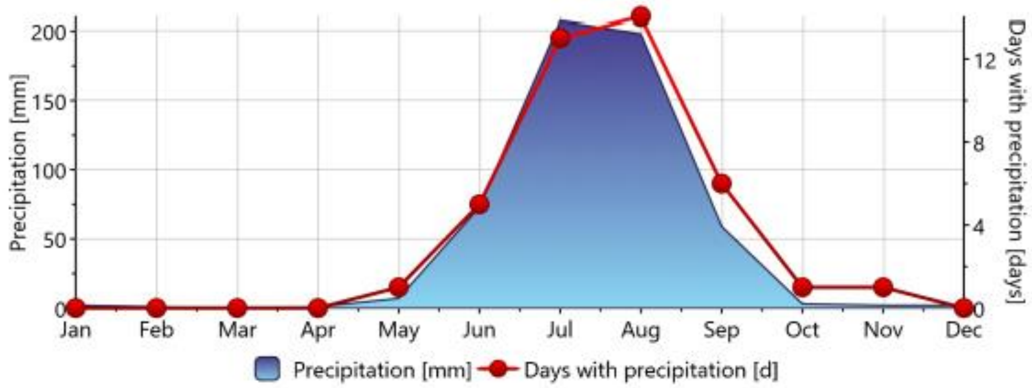

Figure 6-3 Meteonorm Predicted Precipitation for the site

PV modules are soiled by particulates of dust, dirt and bird droppings. Soiling of modules has a high impact on the energy yield thereby leading to a loss up to 3% in non-arid regions. Therefore, the modules need to be cleaned for avoiding the loss due to soiling.

Frequency of module cleaning depends on the rainfall frequency and the prevalence of dust and pollution in the local vicinity. Typical cleaning techniques include water cleaning, dry brushes or vehicle-based mechanical cleaning.

The frequency of module cleaning is primarily dependent on the amount of soiling experienced on the site. Soiling loss of 1.64%[9] has been considered by considering cleaning frequency of twice a month.

[9] The soling loss considered in simulation is 2.0% and spectral correction factor (applicable for first solar modules only) is applied to the soiling loss in PVSyst to get the corrected energy yield estimate. The soiling after applying the spectral correction factor is 1.64%.

7 Energy Yield Analysis

SgurrEnergy has computed the annual energy yields for the 13 MW$_{AC}$ Solar PV Plant using basic designs and indicative layout. Energy yields for all the PV technology configurations under evaluation is further elaborated in the following section.

Parameter	Description
Modules	First Solar 80 Wp, (FS-280)
Inverters	Power-One – (PVI-Central-500-TL) 500 kWac
Mounting System	Fixed Tilt
DC Capacity (MW$_p$)	15.0

For energy yields SgurrEnergy has:

1) Sourced average monthly horizontal irradiation, wind speed and temperature data with the other sources which included satellite image derived data. These data have been assessed for use in the energy yield simulation software.
2) Following the assessment, SgurrEnergy has selected site specific data sourced from SolarGIS to arrive at representative energy yield estimates.
3) Calculated the global incident radiation on the tilted plane, taking into account shading.
4) Applying downtime losses, AC ohmic losses, and module degradation losses to obtain energy yields that reflect twenty-five-year plant life.

Using statistical analysis of resource data for inter-annual variability to derive appropriate levels of uncertainty in the energy yield prediction, steps 2 and 3 are facilitated using industry standard photovoltaic simulation software which simulates the energy yield using hourly time steps. The software takes as input detailed specifications of:

- The solar PV modules.
- The inverter.
- Mounting system.
- Electrical configuration including number of modules in series and parallel.

7.1 Correction and Losses

Data obtained for irradiation on collector plane, PV module and inverter specifications and plant configuration are input into the PV modelling software to calculate DC energy generated from the modules in hourly time steps throughout the year. This direct current is converted to AC in the inverter.

A number of losses occur during the process of converting irradiated solar energy into AC electricity fed into the grid. The losses may be described as a yield loss factor. They are calculated within the PV modelling software and calculated from the cable dimensions. Others are nominal figures applied from knowledge of performance of similar PV plants. The losses are broadly summarised in Table 7-1 below.

Table 7-1: Description of Energy Yield Losses

Loss	Description
Shading	Three types of shading losses are considered in the PV energy yield model: horizon shading, shading between rows of modules and near shading due to trees and buildings.

Loss	Description
Incident Angle	The incidence angle loss accounts for losses in radiation penetrating the front glass of the PV modules due to angles of incidence other than perpendicular.
Low Irradiance	The conversion efficiency of a PV module reduces at low light intensities.
Module Temperature	The characteristics of a PV module are determined at standard temperature conditions of 25˚C. For every ˚C temperature rise above this, module efficiency reduces according to their temperature coefficient.
Soiling	Losses due to dust and bird droppings; soiling the module.
Module Quality	Most PV modules do not match exactly the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a given tolerance within which the actual power is guaranteed to lie.
Module Mismatch	Losses due to "mismatch" are related to the fact that the real modules in an array do not all rigorously present the same current/voltage profiles: there is a statistical variation between them.
DC Wiring Resistance	Electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).
Inverter Performance	Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.
MPP Tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the maximum power point voltage. Different inverters do this with varying efficiency.
AC Losses	This includes ohmic losses from inverter to evacuation point.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
Grid Availability and Disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Power Curtailment Losses	Curtailment loss is attributed to the utility limiting the power intake at the contracted AC capacity of the PV Plant; thus, the excess energy generated beyond the limit of 30MW$_{AC}$ at the metering level shall not be accounted
Degradation	The performance of a PV module decreases with time.

7.2 P50 Energy Yield Predictions

This section presents the SgurrEnergy's independent energy yield prediction for the 30MW$_p$ solar PV Plant with First Solar PV modules and Power One central inverters. Table 7-2 summarises the solar PV power plant, the available resource, the losses and the predicted P50 yields.

Table 7-2: Energy Yield for the 13MW$_{AC}$ Solar PV Plant

Parameters	Description
PV Module Technology	Thin Film
DC Capacity (MW$_p$)	15
AC Capacity (MVA)	13
Contracted Capacity (MW)	13
P_{NOM} Ratio	1.15
Tilt (°)	22
Pitch (m)	6.80
Annual Global Horizontal Irradiation (kWh/m^2)	2006.60
Global Irradiation Incident on Collector Plane (kWh/m^2)	2196.32
Transposition Factor	1.09
Losses	
Horizon Shading	0.00%
Incident Irradiation Below Threshold	0.00%
Near Shading	2.09%
Incident Angle	2.54%
Soiling	1.64%
Low Irradiance	1.97%
Module Temperature	9.61%
Electrical Shadings	0.03%
Module Quality	-2.30%
First year Degradation	0.00%
Module Mismatch	1.00%
DC Ohmic	0.78%
Inverter Performance	1.72%
Availability	1.00%
AC Ohmic	0.60%
Transformer (LV/MV)	1.02%
Transformer (MV/HV)	0.50%
Transmission Line	0.00%
Auxiliary Consumption	0.96%
Curtailment	
Total Annual Loss Factor	***0.804***
First Year P50 Energy Yield (MWh/annum)	**26,543.854**
Ninth Year P50 Energy Yield (MWh/annum)	**24,493.20**
Ninth Year Specific Yield (kWh/kW$_p$)	**1629.72**
Ninth Year CUF on AC Installed Capacity	**21.51%**
Ninth Year CUF on Contracted Capacity	**21.51%**

Parameters	Description
Ninth Year CUF on DC Installed Capacity	**18.60%**
Ninth Year Performance Ratio	**74.20%**

Graphical representation of the monthly generation, performance ratio and CUF for 13 MW$_{AC}$ evaluated is illustrated graphically in the Figure 7-1.

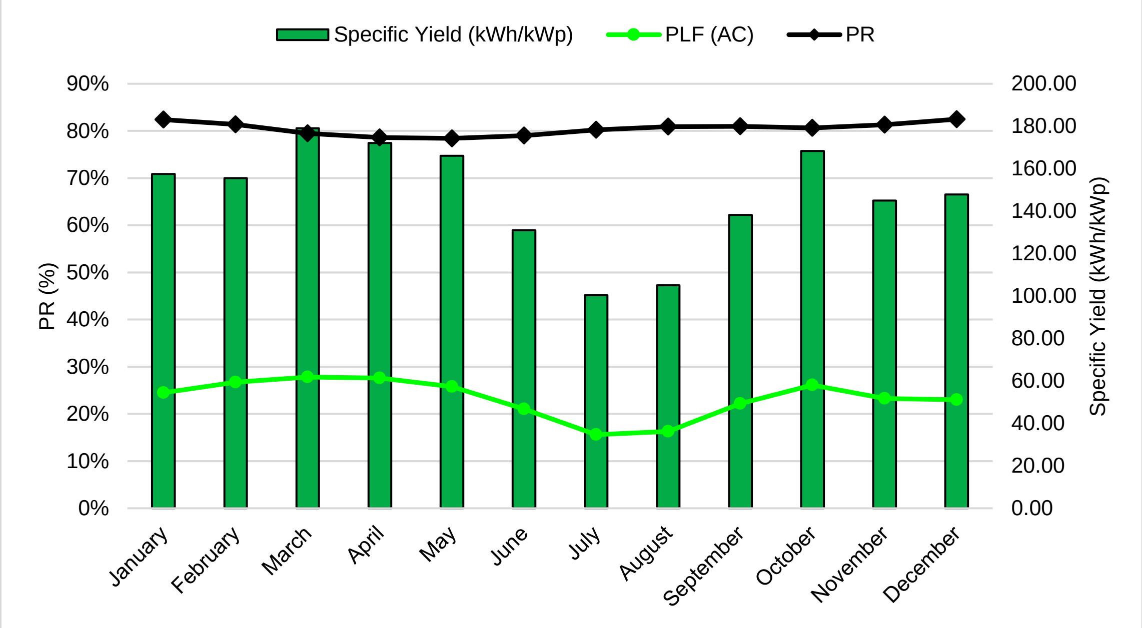

Figure 7-1: Monthly Energy Yield for 13MW$_{AC}$

7.3 Yield Uncertainty

The uncertainty in energy yield predictions is difficult to quantify as it is a function of many independent factors. The discussion below represents simplification of the estimated uncertainty which is believed to be the best approach given the uncertainty in the resource data.

7.3.1 Solar Resource Measurement Uncertainty

Energy yield prediction is based on SolarGIS database, a satellite data which is derived from Meteosat Indian Ocean Data Coverage (Meteosat IODC) and atmospheric parameters using high performance algorithms set by SolarGIS method.

The resource data for 16+ years (1999-2015) has been obtained from the SolarGIS climatological database. SolarGIS recommends an uncertainty of 3.9%.

The uncertainty in transposing the global horizontal irradiation to global tilted irradiation is dependent on the accuracy of the initial data and the characteristics of the specific location. Based on the SgurrEnergy's experience, the uncertainty associated with the transposition model is 1.5%.

7.3.2 Inter – Annual Variation in the Solar Resource

Mean global daily irradiation on a horizontal plane varies on an annual basis. This means that the plant owner does not know what energy yield to expect in any given year but can have a good idea of the expected yield in the long term.

The likely variation can be quantified based on analysis of variation in long-term irradiation data in the vicinity of site. SgurrEnergy has sourced 35 year's data from NASA database for the proposed site location which is used to estimate the standard deviation of variation in irradiation. SgurrEnergy has analysed this dataset and computed the coefficient of variation (standard deviation divided by the mean) as shown in Table 7-3.

Table 7-3: Summary of Figures for Inter-Annual Variation in Resource

Number of Years of Data	35
Coefficient of Variation	4.68

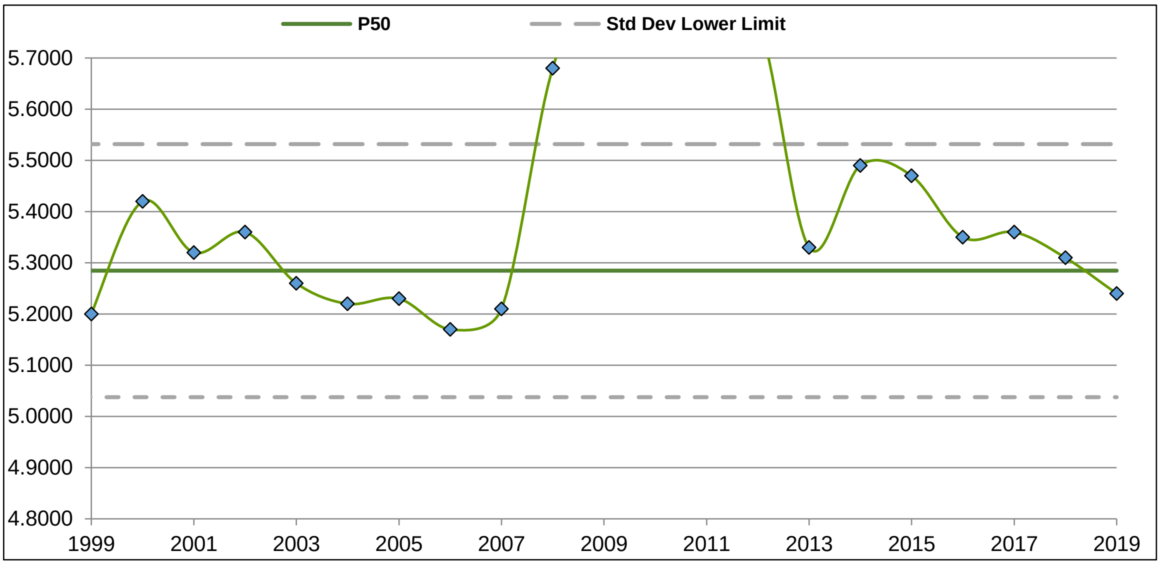

Figure 7-2: Inter-Annual Variability of GHI

Graphical illustration of inter annual variation is presented in Figure 7-2.

SgurrEnergy uses a coefficient of variation of 4.68% to quantify the inter-annual variation in the solar resource.

7.3.3 Modelling Uncertainty

The modelling uncertainty is a combination of the various uncertainties for each loss factor assessed in the modelling process. Efforts to validate the photovoltaic simulation software used data from seven grid connected systems in Europe. These indicated that the accuracy of the results of the simulation is in the order of 2 to 3%.

7.3.4 Total Uncertainty (P75 and P90 Energy Yield Predictions)

Combining the uncertainties in energy yield and inter-annual variation in the solar resource, the P50, P75 and P90 confidence interval are presented for each PV plant configuration in the table below.

Table 7-4: Life Cycle P50, P75 and P90 Generation Prediction for 13 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[10]	P90 Generation Prediction[11]
9	24,493.20	23,472.64	22,554.11

[10] The P75 values have been calculated over 10-year averages

[11] The P90 values have been calculated over 10-year averages

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[10]	P90 Generation Prediction[11]
10	24,248.27	23,237.92	22,328.57
11	24,088.23	23,084.55	22,181.20
12	23,929.25	22,932.19	22,034.81
13	23,771.31	22,780.84	21,889.38
14	23,614.42	22,630.48	21,744.91
15	23,458.57	22,481.12	21,601.39
16	23,303.74	22,332.75	21,458.82
17	23,149.94	22,185.35	21,317.19
18	22,997.15	22,038.93	21,176.50
19	22,845.37	21,893.47	21,036.73
20	22,694.59	21,748.97	20,897.89
21	22,544.80	21,605.43	20,759.97
22	22,396.01	21,462.83	20,622.95
23	22,248.19	21,321.18	20,486.84
24	22,101.36	21,180.46	20,351.62
25	21,955.49	21,040.67	20,217.30

8 Operational Analysis and Generation Comparison

To assess the operational performance of the plant, SgurrEnergy has comparatively evaluated the monthly energy yield predicted using satellite-based weather data with the plant generation SCADA values. A factor of 1.0% degradation has been considered for values after a duration of 1 year from COD (Commercial Operational Date) till ten years from COD. The variation has been evaluated with respect to the difference between the two generation figures.

Based on the information provided by the Owner, SgurrEnergy understands that the SSEGPL solar PV plant was commissioned in 17th April 2012. SgurrEnergy was provided with plant, grid availability and irradiation records from June 2016 to April 2021[12] for the solar PV plant.

SgurrEnergy has thus carried out the generation comparison for the PV project for the period from June 2016 to April 2021, henceforth referred to as 'operational period'. SgurrEnergy compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Owner.

SgurrEnergy also observed that the monthly availability figures were provided for the operational period of the solar PV plant. These availability figures were captured within the monthly energy yield predictions assessed for the site in question and were accounted for representative comparison. The average availability based on the provided data has also been specified below.

Based on the availability records provided, SgurrEnergy has analysed the trend in the plant availability and grid availability for each month as presented in the following sections.

1.1.1 Grid Availability

The ability of a PV power plant to export power is dependent on the availability of the grid transmission network and the utility grid substation. Grid unavailability is solely due to the breakdown events associated with the grid substation and substation maintenance, which is beyond the Owners control.

The monthly records of the grid availability from Jun`e 2016 to April 2021 have been graphically illustrated in Figure 8-1 below.

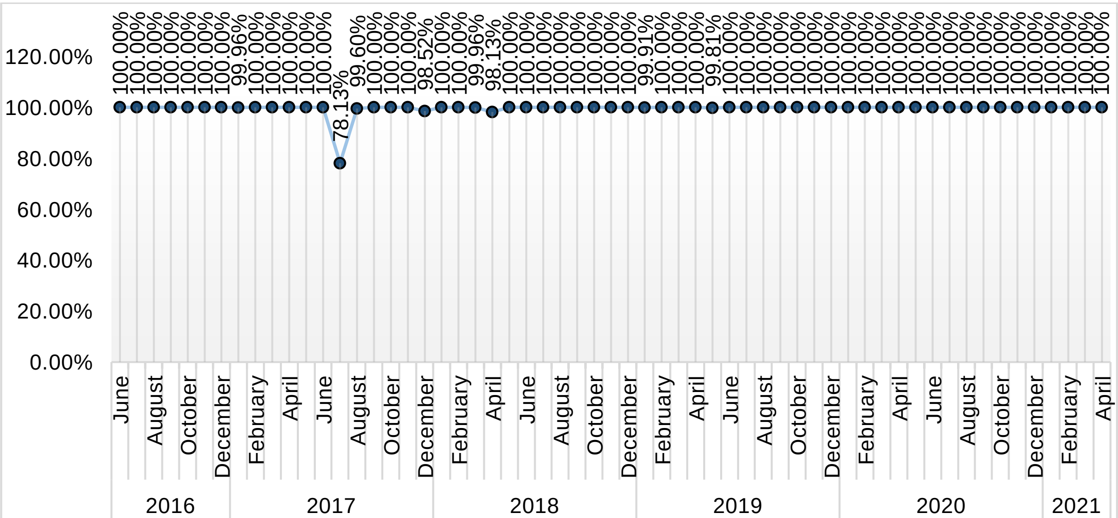

Figure 8-1: Grid Availability

[12] SgurrEnergy was provided with both the plant and grid availability records until April 2021 and hence the analysis conducted in the sections below has been done to incorporate the available data.

From the above illustration, SgurrEnergy notes that the unavailability loss experienced due grid anomalies are minimal over the operational period and are within expected range. However, for the month of July 2017 the unavailability due to grid was high when compared to other months. The downtime due to grid unavailability was close to 100% during the remaining months for which the grid availability was noted to be exceeding 98.52%.

Overall the average grid availability experienced on site for the operational period was calculated to be 99.56%

1.1.2 Plant Availability

Plant downtime is a period when the plant does not generate due to failure of equipment in plant until the injection point. The plant downtime period depends on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.

Plant availability of the SSEGPL solar PV plant is graphically illustrated below in Figure 8-2.

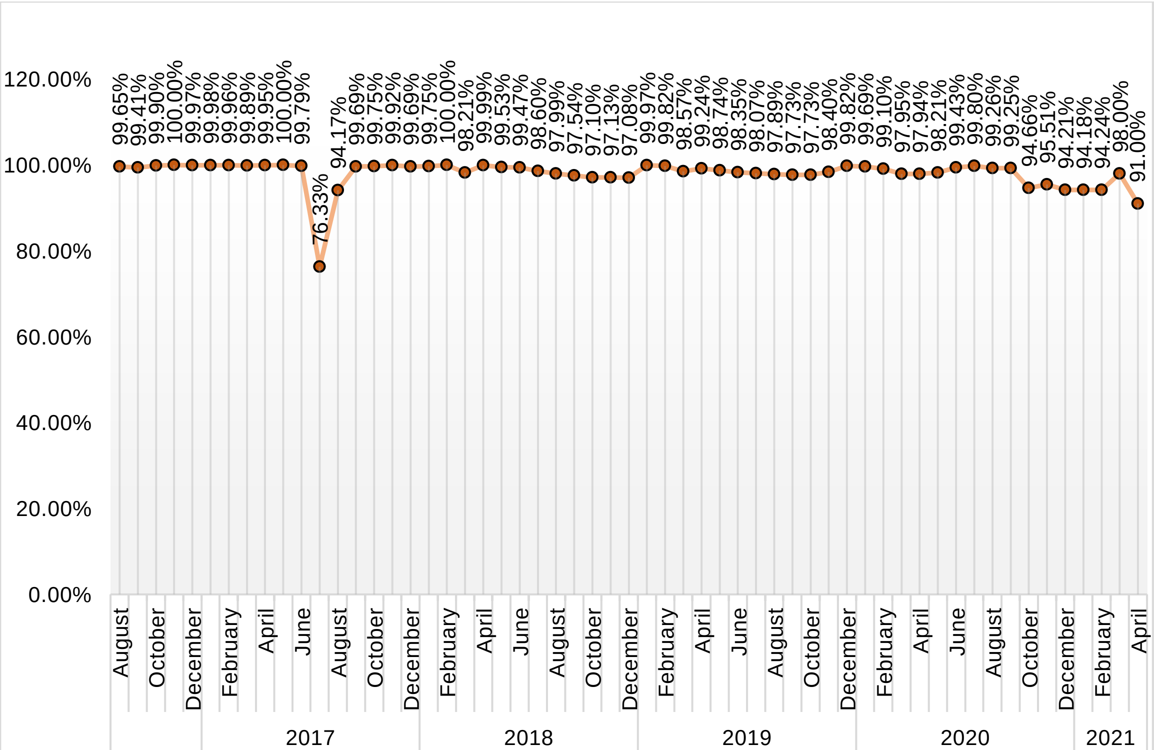

Figure 8-2: Plant Availability

Based on the above illustrations, SgurrEnergy notes the plant availability for the SSEGPL solar PV plant is notably inconsistent for all the months ranging between 76.33% to 100%. The average plant availability is noted to be 98.06% which is considered to be within the expected range.

1.2 Energy Yield Comparison

SgurrEnergy has compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Client. To make the operational energy yield predictions more representative, SgurrEnergy has applied the monthly losses due plant and grid unavailability provided by the Client. These predictions are in turn compared with the actual performance of that plant, which are the generation figures shared by the Client.

The yearly comparison of the generation data is illustrated below in Figure 8-3.

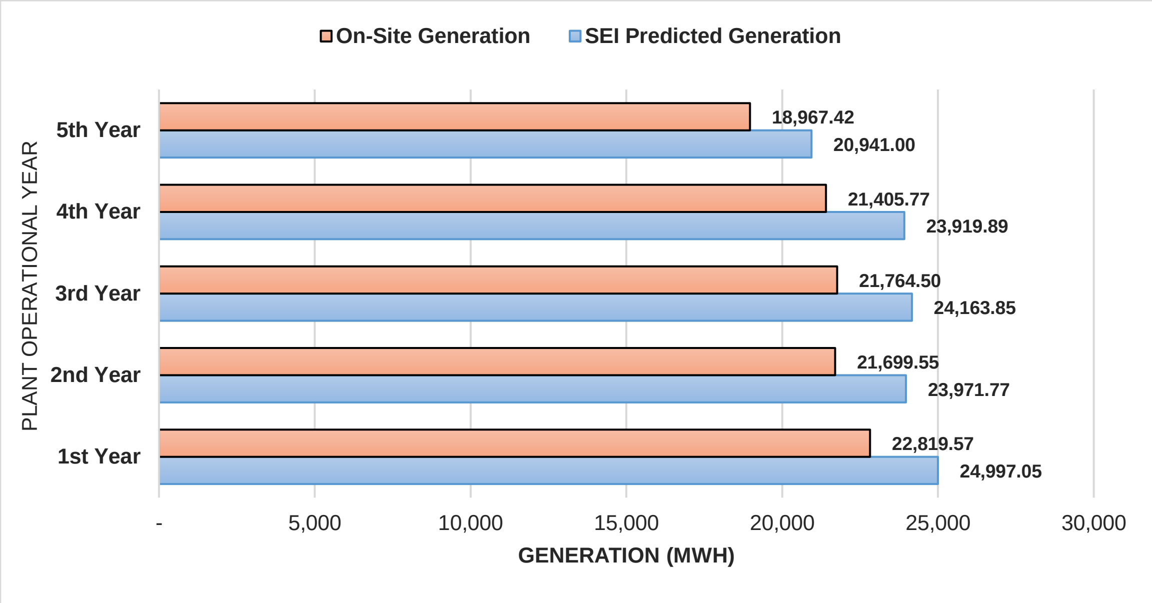

Figure 8-3: Generation Comparison

The variation of the performance of the PV plant for the period of evaluation has been tabulated below in Table 8-1

Table 8-1: PV Plant Performance – SSEGPL

PV Plant Operation Period	Predicted Generation (MWh)	Recorded Generation (MWh)	Performance Percentage[13] (%)
June 2016 -May 2017	24,997.05	22,819.57	-8.71%
June 2017 -May 2018	23,971.77	21,699.55	-9.48%
June 2018 -May 2019	24,163.85	21,764.50	-9.93%
June 2019 -May 2020	23,919.89	21,405.77	-10.51%
June 2020 -April 2021	20,941.00	18,967.42	-9.42%
Cumulative Period	**117,993.56**	**106,656.81**	**-9.61%**

Based on the above comparison, SgurrEnergy notes that the PV plant is generating lower than the expected yield. However, SgurrEnergy considers that such variations in the energy yield can be attributed to higher irradiation level experienced on the Project site. The irradiation levels significantly impact the actual generation from the PV plant as the system losses may vary significantly due to slight change in the irradiation.

In order to understand the deviation in the irradiation pattern, SgurrEnergy has compared the monthly incident irradiation data provided by the Client with the monthly incident irradiation predicted using satellite-based meteorological data for the period of evaluation.

[13] Positive values indicate higher generation, while negative values indicate lower generation

The result of the comparison is presented in the table below and the same is graphically illustrated in the Figure 8-4.

Table 8-2: Irradiation Comparison– SSEGPL

PV Plant Operation Period	Predicted Irradiation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[14] (%)
June 2016 -May 2017	2196.20	2124.77	-3.25%
June 2017 -May 2018	2196.20	1994.96	-9.16%
June 2018 -May 2019	2196.20	1991.89	-9.30%
June 2019 -May 2020	2196.20	1994.17	-9.20%
June 2020 -April 2021	1984.40	1794.64	-9.56%
Cumulative Period	10,769.20	9,900.43	-8.07%

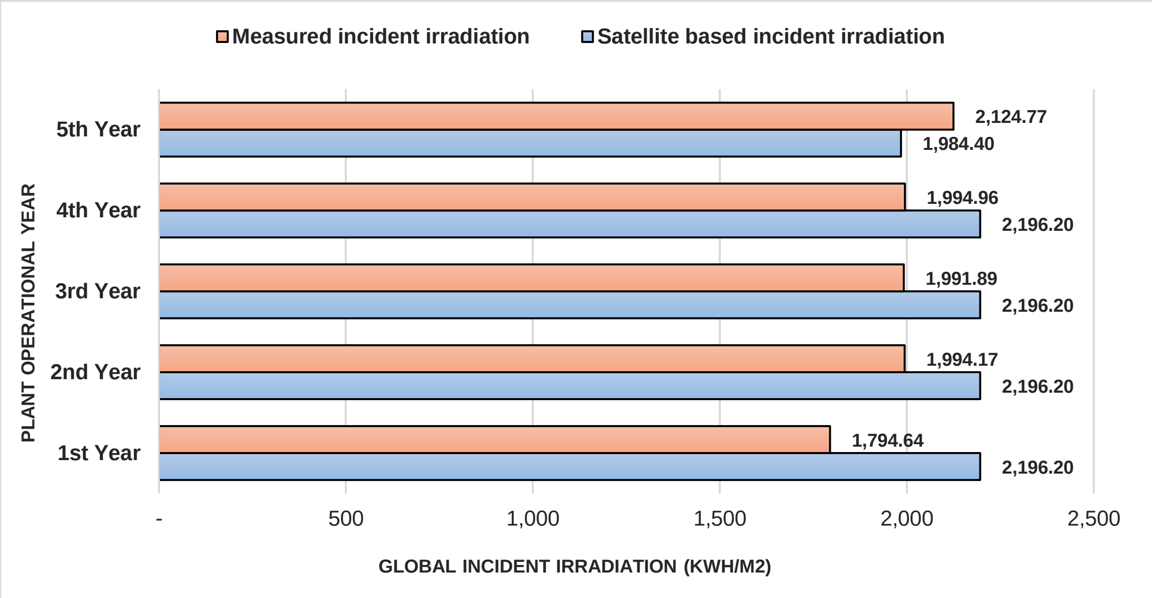

Figure 8-4: Irradiation Comparison

Based on the above illustration, it is observed that the overall recorded generation is approximately 9.61% lower than the generation predicted on site. It has also been observed that the recorded irradiation is approximately 8.07% lower than the predicted irradiation.

Based on the comparative analysis, the drop-in in generation can be attributed to the drop-in irradiation during the period of evaluation.

[14] Positive values indicate higher irradiation, while negative values indicate lower irradiation

9 Solar Plant Life beyond 25 years

The traditional life of a solar plant is 25 years, which is based primarily on solar panel warranty period. The National Renewable Energy Laboratory (NREL) in the U.S however lists solar pv plants as having a lifetime of 25-40 years[15].Most modules are expected to see a degradation rate of 0.7% for the 25 years and hence the expected power output at the end of 25 years is around 80% of the rated power. However, research from NREL[16] shows that the median degradation rates of panels are around 0.5% and power output after the 25 year term could be higher than the power output guaranteed by the module manufacturer. Hence the possibility of the module producing electricity beyond 25 years with a year on year degradation is not farfetched, however whether these degradation rates will be in a linear pattern or in an unpredictable pattern is yet discovered and hence evaluating the generation/ performance of the plant and life of the plant beyond 25 years becomes risky. The life of the plant also depends on the quality of the other components such as inverters, cables, transformers used. Over the twenty five year plant life, these component will need to be serviced and repaired, as the warranty period for all of these components are less than 10 years. The repair and service of these equipment can continue beyond 25 years and the component may be fit for use for another ten years, however the risk of equipment failure increases year on year. The life of the plant also depends on the operations and maintenance activities carried out during the plant lifecycle and hence carrying out O&M activities diligently during the lifetime of the plant can increase the life of the plant beyond 25 years.

Overall, the pv plant is expected to function beyond plant life of 25 years, however the risk associated with the plant operation increases as the panel warranties would have expired, degradation rates beyond 25 years are unknown and other components used in the plant would also need additional repair/replacement.

[15] https://www.nrel.gov/analysis/tech-footprint.html

[16] https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

Virescent Infrastructure

5MW(AC) SSEPL Solar PV Plant

Sindicatum Solar Energy Private Limited

Technical Assessment Report

July 2021

Report Details

Prepared for:	Virescent Infrastructure
Client Contact:	Atul Raaizada
Report Distribution:	
SgurrEnergy:	Ahmed Dalvi
Report Classification:	Confidential

	Name	Job-Title	Signature
Prepared by	Advisory Team		
Reviewed by	Ahmed Dalvi	Sr. Project Engineer	
Authorised by	Arif Aga	Director	
Date of Issue	20 July 2021		

Amendment Records

Revision Number	Date	Purpose of Revision	Summary of Amendments
B1	23 June 2021	Draft Issue	-
B2	28 June 2021	Minor updates	-
B3	2nd July 2021	Minor updates	-
B4	6th July 2021	Minor updates	-
B5	15th July 2021	Minor updates	-

SF/04/023

Contents

Figures

Tables

Executive Summary

Virescent Infrastructure (the Client) backed by leading global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy has been appointed by the Client to conduct a technical appraisal of 5MW$_{AC}$ SSEPL plant.The summary of the technical assessment is captured in the below table.

Table 1-1: Summary

Sr. No.	Parameter	Comment
1	Plant Overview	Review presented in Section 2
2	PV Module	According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of First Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard. Further, the warranty document was not provided for review, SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules. Regarding the certifications, the complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.
3	Inverter	SgurrEnergy has conducted review of the SMA's Sunny Central-630CP central inverter. Since the solar PV plant is operational, SgurrEnergy raises no major concern regarding the unavailability of the complete set of IEC certificates for SMA's Sunny Central-630CP central inverter used for the project. SMA offers a product warrant of 5 years which is in line with the current industry standards. In conclusion, SMA can be considered as an established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern regarding the use of SMA inverters for the Project.
4	Inverter and Auxiliary Transformer	The auxiliary transformers (100kVA) and inverter transformer (1250kVA) used within the project are manufactured by Shilchar Technologies Limited. The manufacturer has good track record of supplying transformers for solar application throughout the. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.
5	String Sizing	The V_{OC} does not exceed the inverter input voltage for the site, and therefore, SgurrEnergy considers the number of modules in series to be acceptable for the PV Project.
6	Resource Assessment	For resource analysis, SgurrEnergy has compared various satellite datasets. For the satellite databases, SgurrEnergy has compared Meteonorm 7.3, NASA, SWERA and SolarGIS data to

<table>
<tr><th>Sr. No.</th><th>Parameter</th><th>Comment</th></tr>
<tr><td></td><td></td><td>find the most suitable solar resource for long-term energy yield prediction. Owing to low uncertainty and high resolution, SgurrEnergy considers SolarGIS dataset to be the most representative satellite database among all the satellite databases for long-term energy yield assessment.</td></tr>
<tr><td>7</td><td>Operational Analysis and Generation Comparison</td><td>Review presented in Section 8</td></tr>
<tr><td>8</td><td>Allied Components and Systems</td><td>The 5MW$_{AC}$ solar PV Plant is designed with 80W$_P$ and 115W$_P$ make solar PV modules and 625kW SMA inverters. Modules are interconnected to form a string of 15 and 11 modules for 80W$_P$ and 115W$_P$ modules respectively. Five such strings forms a single output that feeds as a single input to the 16 input combiner boxes. Eight string combiner boxes are further connected to the inverter.

The 5MW$_{AC}$ solar PV plant has been configured with 8 SMA 625kW central inverters and two inverter stations. Each inverter station is of 2.5MW$_{AC}$ capacity contain four inverters of 625kW capacity, which is further connected to 0.315/0.315/33kV three-winding, 1.25MVA transformer, that steps up the voltage up to 33kV for all inverter stations. The power from the HV side of the 33kV inverter transformer is transferred to 33kV HT panel.

The output power of each 33kV HT panel is connected to 33kV main HT panel located in the main control room. Further power from main control room is fed to 33kV outdoor switchyard.

Power from 33kV switchyard is evacuated to the substation situated at a distance of 5.5km from the project site at 33kV voltage level.</td></tr>
<tr><td>9</td><td>Energy Yield Assessment</td><td>Subsequent to the solar resource assessment, SEI considers SolarGIS database as the most representative for long-term energy yield predictions. The table below summarises the energy yield predictions for third year of plant operation for the 5 MW$_{AC}$ PV plant.

<table>
<tr><td>Global Horizontal Irradiation (kWh/m2)</td><td>2044.20</td></tr>
<tr><td>Global Inclined Irradiation (kWh/m^2)</td><td>2253.77</td></tr>
<tr><td>First Year P50 Energy Yield (MWh/annum)</td><td>10,536.692</td></tr>
<tr><td>Tenth Year P50 Energy Yield (MWh/annum)</td><td>9,625.45</td></tr>
<tr><td>Tenth Specific Yield (kWh/kW$_p$)</td><td>1676.90</td></tr>
<tr><td>Tenth Performance Ratio (PR)</td><td>74.40%</td></tr>
<tr><td>Tenth PLF on Contracted Capacity (5MW$_{AC}$)</td><td>21.80%</td></tr>
</table></td></tr>
</table>

Glossary

A	Amp
AC	Alternating Current
a-Si	Amorphous Silicon
CdTe	Cadmium Telluride
c-Si	Crystalline Silicon
CIGS/CIS	Copper Indium (Gallium) Di-Selenide
CPV	Concentrated photovoltaic
CSP	Concentrating solar power
CUF	Capacity Utilization Factor
°C	Degrees Centigrade
°	Degrees
DC	Direct Current
E	East
GWh	Giga Watt hour
HV	High Voltage
Hz	Frequency, Hertz
IAM	Incident Angle Modifier
Isc	Short Circuit Current
IEC	International Electro technical Commission
kA	One Thousand Amps
km	One metric kilometre
kV	One thousand Volts
kVA	One thousand Volt Amps
kWp	One thousand Watts peak
kWh	One thousand Watt hours
LV	Low Voltage
m	Meters
m^2	Meters squared
mm	Millimetres
mm^2	Millimetres squared
m/s	Meters per second
mc-Si	Mono-crystalline Silicon

MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MTBF	Mean Time Between Failures
MV	Medium Voltage
MVA	One million Volt Amps
MW	One million Watts or Megawatt
MWp	Megawatt peak of Solar PV modules
N/m^2	Newton per meter Squared
N	North
NASA	National Aeronautics and Space Administration
NEC	National Electric Codes
O&M	Operations and Maintenance
ONAN	Oil Natural Air Natural
ONAF	Oil Natural Air Forced
%	Percentage
pc-Si	poly-crystalline Silicon
PV	Photovoltaic
REC	Renewable Energy Certificates
RPO	Renewable Purchase Obligation
STC	Standard Test Conditions
SWERA	Solar and Wind Energy Resource Assessment
TUV	TÜV Rheinland Group Testing and Standards Organisation.
V	Volts
Voc	Open Circuit Voltage
VT	Voltage Transformer
W/m^2	Watts per metres squared
Wp	Watt peak
XLPE insulation	Cross-Linked Polyethylene insulation

1 Introduction

Virescent Infrastructure (the Client) backed by global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy India (SEI) has been appointed by the Client to conduct technical appraisal for the 68MW$_{AC}$ portfolio of Solar PV projects in India. The portfolio comprises of four projects, as presented within Table 1-1.

Table 1-1: Project Key Summary

Project Name	SSEPL – 5MW$_{AC}$	SSEGPL – 13MW$_{AC}$	PLG – 20MW$_{AC}$	USUPL – 30MW$_{AC}$
Site Location	25.52"N, 72.85"E, Tiwari, Jodhpur, Rajasthan, India	23.9128°N, 71.2183°E, Santalpur, Patan, Gujarat, India	23.9°N, 71.5°E, Dahisar, Patan, Gujarat, India	25°18'52.79"N, 79°25'2.49"E, Devgaon, Mahoba, Uttar Pradesh, India
Owner	Sindicatum Solar Energy Private Limited (SSEPL)	Sindicatum Solar Energy Gujarat Private Limited (SSEGPL)	PLG Photovoltaic Private Limited (PPPL)	Universal Saur Urja Private Limited (USUPL)
DC / AC Capacity	5.745MW$_P$ / 5MW$_{AC}$	15MW$_P$ / 13MW$_{AC}$	20MW$_P$ / 20MW$_{AC}$	36.98MW$_P$ / 30MW$_{AC}$

This report presents the evaluation of the 5MW$_{AC}$ solar PV plant developed by Sindicatum Solar Energy Private Limited (SSEPL). The Solar PV plant under evaluation is located in Tiwari village, Jodhpur district in Rajasthan state. The purpose of this report is to provide a technical appraisal of PV plant under evaluation.

The report focuses on the following key parameters:

- System Design.
- Major Components.
- Engineering Design.
- Independent Solar Resource Assessment and Energy Yield Prediction.
- Plant Operational Analysis and Generation Comparison.
- Permits and Approvals.

This report presents independent technical appraisal of the Project and is based on information made available by the Client through online data room. The main Project characteristic is summarised in Table 1-2.

Figure 1-1 illustrates the project structure indicating key project participants for the 5MW$_{AC}$ solar PV plant.

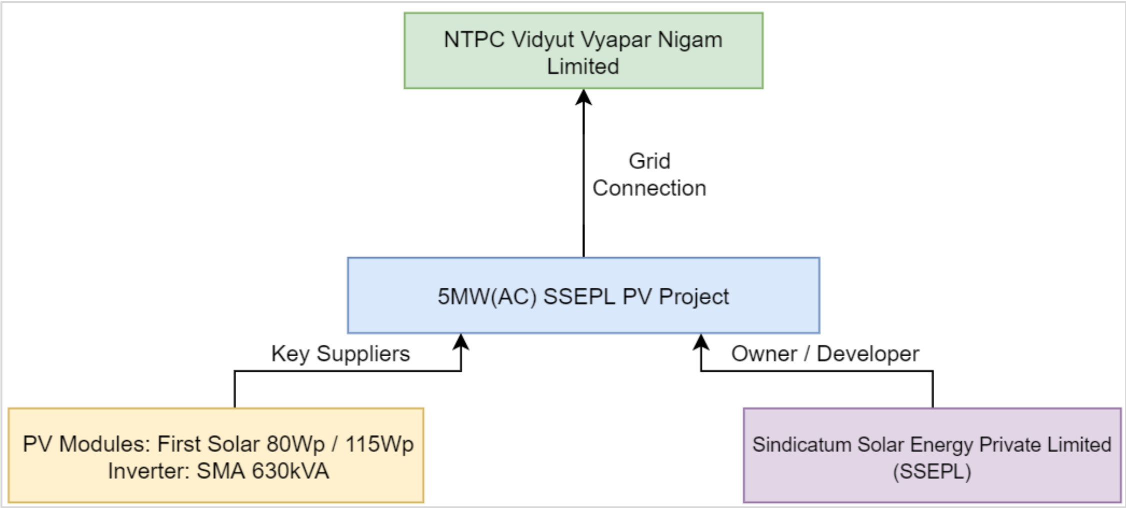

Figure 1-1: Project Structure for 5MW$_{AC}$Solar PV Plant

Table 1-2: Project Key Summary

Project Information	
Project Name	5MW$_{AC}$ SSEPL solar PV plant
Location	Tiwari, Jodhpur, Rajasthan
Developer	Sindicatum Solar Energy Private Limited
DC/ AC capacity	5MW$_{AC}$ PV Plant – 5.745MW$_{P}$ / 5MW$_{AC}$
Key Equipment Manufacturers	PV Modules: First Solar Inverters: SMA
MMS Configuration	Fixed Tilt: 20°, Azimuth: 0°
Commissioning Status	Commissioning for 5MW$_{AC}$ PV Plant was achieved on 15 October 2011.

2 5MW$_{AC}$ Solar PV Plant Overview

The project site lies around the coordinates 26.52N, 72.85 E. Satellite imageries of 5MW$_{AC}$ solar PV plants are illustrated below in Figure 2-1. The Owner has leased approximately 37.06 acres of land for the project. The Project site is located near the *Tiwari* village, in *Jodhpur* district of Rajasthan.

Project is contracted for generating 5MW$_{AC}$ power; SgurrEnergy therefore interprets 5MW$_{AC}$ as the maximum AC installed capacity for the solar PV plant.

Figure 2-1: Satellite image of 5MW$_{AC}$ plant

2.1 5MW$_{AC}$ Project Summary

Solar PV plant is modular in nature; therefore, SSEPL 5MW$_{AC}$ solar PV plants is implemented by adopting modularity in designs. 1.26MW$_{AC}$ is the typical inverter stations considered for implementing SSEPL 5MW$_{AC}$ solar PV plant.

Table 2-1 presents the summary of 5MW$_{AC}$ PV plant

Table 2-1: Summary of 5MW$_{AC}$ Plant Configurations

General	
PV Module Technology	Cd-Te Thin Film
Inverter Technology	Central Inverters
Installed DC Peak Capacity (MW$_p$)	5.745
Installed AC Capacity (MW)	5.040
Mounting Type	Fixed Tilt
Tilt Angle (°)	20°
Pitch (m)	6.01

General	
PV Modules	
PV Module Manufacturer	First Solar
Model	FS-380, FS-4115
Wattage (W_p)	80W_p / 115W_p
Number of Modules per String	11/15
Inverter	
Inverter Manufacturer / Model	SMA / Sunny Central 630CP
Inverter Nominal AC Output	630kW
Number of Inverters	8
Mounting Structure	
Mounting Structure Details (rows × columns)	5 × 11, 5 × 15
Orientation of Modules	Landscape

The 10MW$_{AC}$ plant is implemented with a total of four (4) inverter stations of capacity 1.26MW$_{AC}$ which comprising of three winding transformers to accommodate 2 × 630kVA inverters, taking the individual inverter station size to 1.26MW$_{AC}$. Inverter station is comprising of a physical block connecting 2.4MW$_p$ of installed photovoltaic array.

The output of the 1.26MW$_{AC}$ inverter stations are connected to 0.400/0.400/33kV three winding transformer of 1.25MVA for stepping up the voltage to 33kV.

The medium voltage 33kV output of the inverter stations are placed in main control room (MCR), these are combined to form a solar PV plant of 5MW$_{AC}$. The 33kV output is evacuated at the HT switchyard located in the plant premises.

The power generated by the SSEPL 5MW$_{AC}$ PV plant is fed to *Tinwari* substation located approximately 5.5km from the Project site. The point of interconnection is at the *Tinwari* substation.

3 Review of Major plant components

SgurrEnergy has conducted a desktop review of the main plant components which includes a high-level review of the company, its track record, product certifications obtained, technical characteristics and warranty conditions. SgurrEnergy has conducted a desktop review of the main plant components which includes a high-level review of the company, its track record, product certifications obtained, technical characteristics and warranty conditions.

3.1 PV modules – First Solar

SgurrEnergy has conducted a technical review of the supplier and module specification with regards to their suitability for their use in the Projects under evaluation.

3.1.1 Company Profile

First Solar Inc. is a USA based (Tempe, Arizona) producer of Cadmium Telluride (CdTe) thin-film modules and has more than 6,400[1] employees worldwide with manufacturing facilities in the USA, Malaysia, and Vietnam. Formed in 1999 the company launched production of commercial products in 2002 and was the first company to integrate thin film solar module technology into high-volume, low-cost production.

According to information available on public domain, First Solar is committed to providing a commercially attractive recycling solution for PV power plant and module owners to help them meet their module end-of-life (EOL) obligation simply, cost-effectively and responsibly.

First Solar has received the following certifications at all of its manufacturing facilities; ISO 14001:2015 environmental management systems certification, ISO 9001:2015 quality management systems certification, and ISO 45001:2018 certification for Occupational Health and Safety Management Systems.

First Solar thin film modules are used in ground-mounted and commercial rooftop applications ranging from a few kilowatts to tens of megawatts in size.

3.1.2 Experience and track record

First Solar modules have global solar PV installed capacity of 633.7GW. First Solar modules have more than 1.8GW PV modules have installed capacity and nearly 150MW capacity is under operation in India[2]. Figure 3-1 illustrates the installed capacity of first-solar modules in India.

[1]http://www.firstsolar.com/-/media/First-Solar/Documents/Corporate-Collaterals/FS_Corporate_Factsheet.ashx

[2] https://www.firstsolar.com/en-IN/PV-Plants/Project-Development

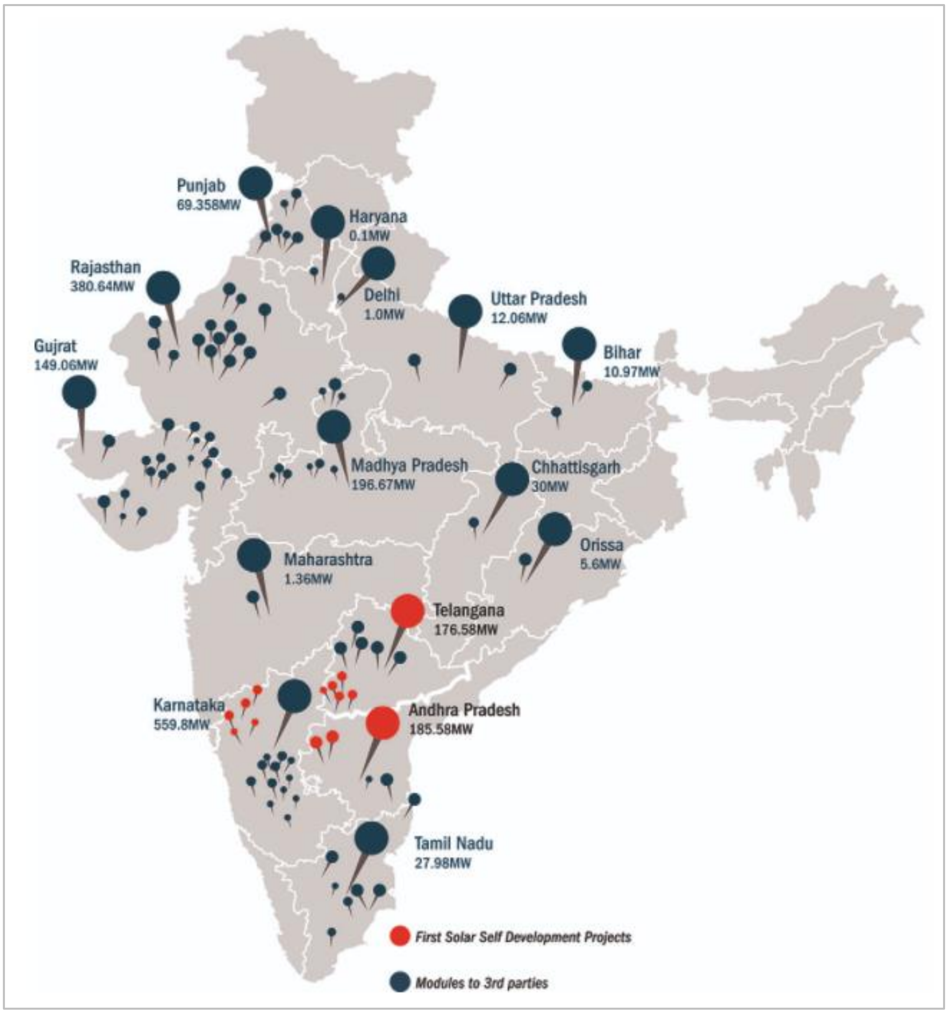

Figure 3-1: First-solar modules installed in India.

Few of the commissioned solar power plants using First Solar modules are listed in Table 3-1

Table 3-1: Track record of First Solar Modules

Sr. No.	Project	Location	Capacity (MW)	Installation Year
1	Hindupur Solar Park	Andhra Pradesh India	40.0	2016
2	Kodangal Solar Park	Telangana State India	10.0	2016
3	Mahabubnagar Solar Park	Telangana State India	10.0	2015
4	Polepally Solar Park	Telangana State India	25.0	-
5	Karoor Solar Park	Telangana State India	15.0	2016
6	Marikal Solar Parks	Telangana State India	10.0	2015
7	Hindupur Solar Park	Andhra Pradesh, India	40.0	2016

Sr. No.	Project	Location	Capacity (MW)	Installation Year
8	Topaz Solar farm	USA	550.0	-
9	Agua Caliente	USA	290.0	-
10	Copper Mountain 1	USA	48.0	-
11	Greenough River	Australia	10.0	-
12	Phalodi	Rajasthan, India	50.0	-
13	Dewa Solar plant	UAE	13.0	-

SgurrEnergy considers First solar to have an acceptable track record in delivering PV modules to PV projects worldwide.

3.1.3 Main Technical Characteristics

First Solar FS-380 and FS 4115modules of 80W$_P$ and 115W$_p$ capacity respectively have been used for the Project. The shortlisted modules have a temperature coefficient (Pmax) of -0.25%/˚C rise in temperature. This temperature coefficient is in line with SgurrEnergy's expectation for thin film. The technical characteristics of FS-380 and FS 115 are presented in the Table 3-2

Table 3-2: First Solar PV Module Technical Characteristics

Specifications	FS-380; 80W$_P$	FS 4115-3;115W$_P$
Technology	Thin Film	Thin Film
Nominal power (P_{MPP})	80W$_P$	115W$_P$
Voltage at P_{MAX} (V_{MPP})	48.5	69.3
Current at P_{MAX} (I_{MPP})	1.65	1.66
Open circuit voltage (V_{OC})	60.8	87.6
Short circuit current (I_{SC})	1.88	1.83
Maximum System Voltage	1,000	1,500
Dimensions (length × breadth × width) (mm)	1200 × 600 × 6.8	1200 × 600 × 6.8
Module area (m^2)	1200 × 600 × 6.8	1200 × 600 × 6.8
Weight (kg)	1200 × 600 × 6.8	1200 × 600 × 6.8
Temperature coefficient at P_{MAX}	-0.25%/°C	-0.28%/°C
Maximum reverse current	3.5A	4.0A
Product warranty	10 years	10 years
Power output guarantee	25 years	25 years
Module technical characteristics are given at STC (1,000W/m^2 irradiance, 25°C module temperature, Air Mass 1.5 according to module manufacturer datasheet)		

Overall, the module characteristics can be considered to be in line with market standard.

NOCT Characteristics

The nominal operating cell temperature (NOCT)[3] characteristics of selected FS-380; 80W$_P$ and FS-4115-3 ;115Wp modules are given in Table 3-3 relate to more realistic operating conditions compared to STC. It is impacted by the module materials used as well as the packing density of module materials. The NOCT for the module is 45°C. This is comparable with other manufacturers and demonstrates the module is effective at heat dissipation.

Table 3-3: PV Module NOCT Characteristics – First Solar Modules

Model	FS-380	FS-4115
Maximum Power (P_{MAX})	60W$_P$	115W$_P$
Maximum Power Voltage (V_{MP})	45.5	64.9
Maximum Power Current (I_{MP})	1.32	1.34
Open Circuit Voltage (V_{OC})	56.5	82.7
Short circuit current (I_{SC})	1.54	1.48

3.1.4 Certification of Modules

The modules are manufactured in an automated facility certified to ISO9001, ISO14001 and OHSAS18001. SgurrEnergy has summarised the certification mentioned in the datasheet provided for the module as below in Table 3-4.

Table 3-4: Certification for PV Module

Sr. No.	Certification	Description
1	IEC 61215 (Edition 2)	Quality and design requirements
2	IEC 61646	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
3	IEC 61730 (Edition 1/2)	PV module safety qualifications

It is common for PV modules to hold the design, performance and safety certifications based on IEC prescribed testing methods. However, complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.

3.1.5 Warranty

The warranty document is essentially required to understand the terms and conditions and also the warranted power performance values. Although the Client has not provided the warranty documents for review, however, referring to the datasheet provided, SgurrEnergy understands that the specified modules are provided with two forms of warranty; a 10-year Limited Product Warranty and a 25-year Limited Power Output Warranty. Both warranties are described in the sections below.

[3] Irradiance = 800W/m2, Air Mass = 1.5, Ambient temperature = 45±3°C

3.1.5.1 Product Warranty

First solar provides a limited product warranty of 10 years. During this period the modules shall be free from defects in materials and workmanship under normal use, installation, operation and service for a period of ten years.

SgurrEnergy considers ten-year product warranty provided by First Solar to be in line with the current industry standard.

3.1.5.2 Linear Power-Output Warranty

First solar warrants that the modules will not experience a power loss of greater than 10% during the first ten (10) years and 20% during twenty-five (25) years subject to the terms and conditions mentioned in the warranty document.

Since the warranty document was not provided for review, SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules.

3.2 Inverters- SMA

The Developer has utilized Sunny Central-630CP capacity central inverter for the project under evaluation.

3.2.1 Company background

SMA Solar Technology AG (System, Mess and Anlagentechnik) is a German solar energy equipment supplier founded in 1981 and headquartered in Niestetal, Northern Hesse, Germany. The company is one of the leading global specialists in photovoltaic system technology.

The company employs more than 3,000 people and has global presence in 18 countries. Since 2008, SMA has been listed on the Prime Standard of the Frankfurt Stock Exchange (S92). As of December 2020, the company has approximately 1,500 patents and utility models under its name. The company has more than 100GW installed PV system technology in more than 190 countries.[4]

SMA ranked 3rd in global solar inverter makers by increasing its market share in 2019 to 11% (as compared to 9% in 2018) generating a total revenue of €915 million. [5]

3.2.2 Track Record

Few of the noteworthy installation of SMA inverters globally are listed in Table 3-5.

Table 3-5: Inverter Global installations

Location	Capacity (MW)
Gannawarra Solar Farm, Australia	60.00
Kagoshima, Japan	70.00
Catalagan, Philippines	63.30
Tarlac City, Philippines	50.00
Sant Carlos City, Philippines	45.00
Kalkbut, South Africa	75.00

[4] https://www.sma-india.com/

[5] https://www.pv-magazine.com/2020/02/07/sma-reduced-operating-losses-in-2019/

Location	Capacity (MW)
Rawanda, East Africa	8.50
Kayes, Mali	50.00
Berden, UK	64.00
Niestetal, Germany	00.75
Wellingborough, UK	33.75
Antalya, Turkey	02.20
Templin, Germany	128.00
Palladam, Tamil Nadu, India	01.00
Nagaur, Rajasthan, India	40.00

3.2.3 Technical Characteristics

The technical specifications of SMA Sunny Central are listed in the Table 3-6. These inverters are designed to operate with DC inputs up to 1,000V. They incorporate maximum power point tracking (MPPT). The inverter is designed for outdoor use with an IP54 ingress protection class for Sunny Central-630CP inverter. It performs optimally at ambient air temperatures between -20°C to 50°C having a relative humidity of 15-95%. The technical characteristics of this inverter are illustrated in Table 3-6.

Table 3-6: SMA Inverter Characteristics

Inverter	Sunny Central-630CP
Type	**Transformer less**
Input Data	
PV voltage range, MPP (V)	500-820V
Maximum DC voltage (V)	1,000V
Maximum PV input current (A)	1,350A
Output Data	
Nominal AC power (kVA)	630kVA
Max AC current (A)	1271A
Rated output voltage (V)	315V
Normal grid frequency (Hz)	50/60Hz
Total harmonic distortion (THD)	<3%
Efficiency	
Maximum efficiency (%)	98.7%
Euro efficiency (%)	98.5%
Dimensions and Weight	
Dimensions (W × H × D) (mm)	2562 x 2279 x 956
Weight (Kg)	1800 Kg
Protection and Ambient Condition	
Operating temperature range (°C)	-20 to +50°C
Ingress Protection Degree	IP54

Inverter	Sunny Central-630CP
Relative humidity (%)	15 - 95%

The following protection devices are included within the inverter design:

- Input-side disconnection device
- Ground fault monitoring
- DC reverse polarity protection
- AC short circuit protection
- Motor driven load disconnect switch on DC side
- Overvoltage protection for auxiliary supply

SMA inverters comprise of suitable protection devices in place on both the DC and AC side to protect the PV system and inverter components.

3.2.4 Certification

SMA is certified to the internationally recognised standard for management systems and according to ISO 9001 that they conform to the latest quality standards. Inverter reliability is further enhanced via stringent quality control procedures. SMA inverter manufacturing facilities operate with the following certifications:

− ISO 9001:2015 Quality Certificate

− ISO 14001:2015 Environmental Certificate

− OHSAS 18001 Health and Safety Management System

Referring the datasheet provided by the Client, the certification of SMA inverter is enlisted in Table 3-7.

Table 3-7: Certification details for SMA inverters

Standard	Description of Standard	Certifying Agency
IEC 60529	Degree of protection provided by enclosure	Bureau Veritas
IEC 61000	Electromagnetic compatibility	Certificate not provided

Based on the information presented in Table 3-7, SgurrEnergy considers the certifications provided by SMA to be in-line with the industry standards. Since the plant is operational, SgurrEnergy raises no major concern regarding the unavailability of the complete set of IEC certificates.

3.2.5 Warranties

Referring to the extended warranty document provided by the Client for SMA inverters used for the project, SgurrEnergy understands that the inverters are under the warranty period and raises no major concern.

In case of any defect or non-conformity detected during the warranty period, resulting from a fault in workmanship or materials, the manufacturer shall replace or repair the faulty part. The SMA warranty covers any costs incurred for repair or replacement of the faulty part within the warranty period. SgurrEnergy considers the above remedial actions to be acceptable.

3.3 Transformers- Shilchar Technologies Limited

The solar PV plant is implemented with two level transformation. Power at low voltage from inverters is stepped up to 33kV using 1250kVA transformers of Shilchar make inverter transformers. Further, auxiliary transformers of 100kVA of Shilchar make is also utilized for the project.

3.3.1.1 Company Profile

The inverter transformer used for the project are manufactured by Shilchar Technologies Limited.

Established in 1990 and headquartered in Gujrat, India, Shilchar is one of the prominent manufacturers of Power & Distribution transformers. As of April 2020, the Company has commissioned the manufacturing facility capable of manufacturing up to 50MVA, 132KV class transformer and up to 4000MVA transformers annually.

Shilchar Technologies is an ISO 90001:2015, ISO 14001:2015 and ISO 45001:2018 certified company providing services to wide range of industries across the world including utility sector to renewable energy. The Company has a dedicated marketing team to cater services required in 20 different countries in the world. Since 2011, 40% of the revenue generated by Shilchar is through export.

The Company manufactures and has type tested various 3-winding, 4-winding, and 5-winding transformer with copper and aluminium conductor. The highest rating type tested by Shilchar is 12.5MVA, 5 winding Inverter Duty Transformer (IDT). The Company has supplied nearly 4GWs of transformers for solar application throughout the world including in Philippines, Egypt, Kenya, and Chile.

3.3.1.2 Technical Specifications

The 100kVA auxiliary transformer used in the project is outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

The 1250kVA inverter transformer used in the project is outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

SgurrEnergy is satisfied that both the transformers have been designed to adhere local and country specific grid codes and relevant IS codes (IS-2026). The transformers technical characteristics are presented in Table 3-8.

Table 3-8: Technical Specification of Shilchar Transformer

Technical Parameters	Auxiliary transformer; 100kVA	Inverter transformer; 1250kVA
Rated Power	100kVA	1250kVA
Rated HV	33kV	33kV
Rated LV	433V	315V
Tapping on HV	-5% to +5% (steps of 2.5%)	-5% to +5% (steps of 2.5%)
Phases	3	3
Frequency	50Hz	50Hz
Vector group	Dyn11	Dyn11yn11
Impedance	3.95% (with IS TOL.)	5.24%

Technical Parameters	Auxiliary transformer; 100kVA	Inverter transformer; 1250kVA
Cooling Strategy	ONAN	ONAN
Oil temperature rise	50°C	-
Winding temperature rise	55°C	-
Winding material	Copper	-

SgurrEnergy considers the overall the technical specifications to be adequate for the PV projects and in line with the industry accepted standards.

3.3.1.3 Temperature Rise Detection and Protection

Inverter transformers have been provided with standard temperature sensing systems. These comprise of an analogue oil temperature indicating (OTI) unit and winding temperature indicating (WTI) unit. Both the units have been adequately provided with alarm/trip contacts and wired to relay units located at HT panel.

The transformers are adequately provided with the Buchholz Relay that essentially serves as a critical protective device in case of excessive gas pressure released in the event of higher transformer loadings and faults.

3.3.1.4 Warranties and Guaranties

Based on the information available in public domain, SgurrEnergy understands the Shilchar transformers have been provided with a warranty of 60 months from date of dispatch. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards.

3.4 Conclusion on Major Plant Components

PV Modules

According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of First Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard.

Further, the warranty document was not provided for review, SgurrEnergy is unable to comment on warranty terms and conditions and suggests getting clarity from the manufacturer regarding the warranty offered for the PV modules. Regarding the certifications, the complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.

Inverters

SgurrEnergy has conducted review of the SMA's Sunny Central-630CP central inverter. Since the solar PV plant is operational, SgurrEnergy raises no major concern regarding the unavailability of the complete set of IEC certificates for SMA's Sunny Central-630CP central inverter used for the project. SMA offers a product warrant of 5 years which is in line with the current industry standards.

In conclusion, SMA can be considered as an established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern regarding the use of SMA inverters for the Project.

Transformers

The auxiliary transformers (100kVA) and inverter transformer (1250kVA) used within the project are manufactured by Shilchar Technologies Limited. The manufacturer has good track record of supplying transformers for solar application throughout the. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

3.5 Module Support Structures

The Array Layout provided by the Client for the 5MW(AC) SSELP Solar PV Plant indicates the fixed tilt module mounting structure is inclined at 20° tilt angle.

Although the as-built MMS GA drawing for the 5MW$_{AC}$ SSELP Solar PV Plant site has not been provided for review. Material used for MMS member, type of foundation and details provided for MMS is unavailable for review. The general arrangement is as shown in below figure.

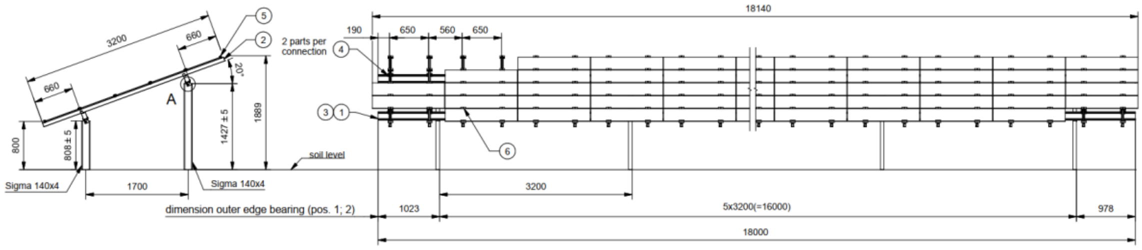

Figure 3-2: MMS general arrangement

4 Allied Components and Systems

4.1 Civil Structures

Based on the review of Plant layout, SgurrEnergy observed that the inverter stations are placed at centre of each block module to minimise cable losses.

4.2 PV Power Transfer

SgurrEnergy has reviewed the electrical schematic provided by the Client. The electrical schematic describes the overall connection of the PV modules, inverters, transformers, switchgear, and plant substation as well as providing the ratings of all the components.

SgurrEnergy has been provided with the following electrical schematic for the Project.

- *3b AES_40011002 40 05_AC SLDs_R5(As built)-Over all SLD*.
- *1z AES_40001002 42 05_DC SLD_R5(As built) - INVETER STATION-1*
- *1zAES_40001002 42 05_DC SLD_R5(As built) - INVETER STATION-2*.

The 5MW$_{AC}$ solar PV Plant is designed with 80W$_{P}$ and 115W$_{P}$ *make* solar PV modules and 625kW SMA inverters. Modules are interconnected to form a string of 15 and 11 modules for 80W$_{P}$ and 115W$_{P}$ modules respectively. Five such strings forms a single output that feeds as a single input to the 16 input combiner boxes. Eight string combiner boxes are further connected to the inverter.

The 5MW$_{AC}$ solar PV plant has been configured with 8 SMA 625kW central inverters and two inverter stations. Each inverter station is of 2.5MW$_{AC}$ capacity contain four inverters of 625kW capacity, which is further connected to 0.315/0.315/33kV three-winding, 1.25MVA transformer, that steps up the voltage up to 33kV for all inverter stations. The power from the HV side of the 33kV inverter transformer is transferred to 33kV HT panel.

The output power of each 33kV HT panel is connected to 33kV main HT panel located in the main control room. Further power from main control room is fed to 33kV outdoor switchyard.

Power from 33kV switchyard is evacuated to the substation situated at a distance of 5.5km from the project site at 33kV voltage level. Transmission line details not provided to SgurrEnergy.

Figure below illustrates a power flow summary for the 5MW$_{AC}$ Solar PV plant.

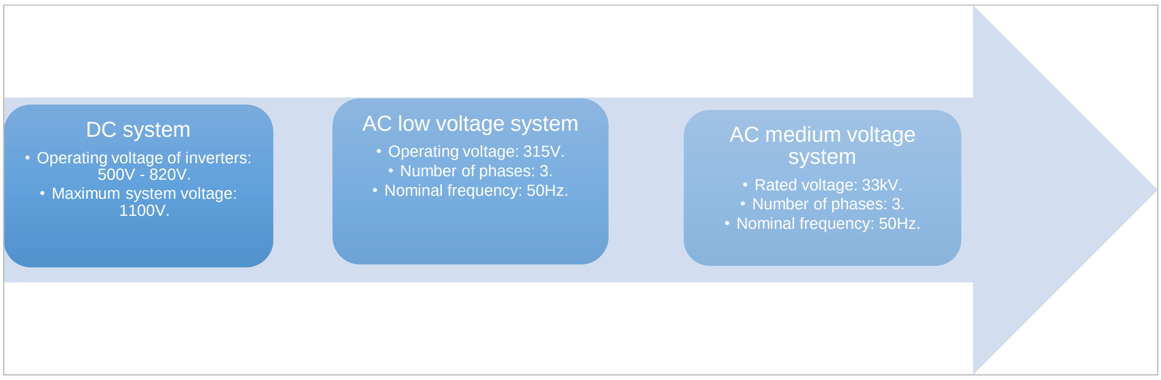

Figure 4-1: Power flow of 5MW$_{AC}$ PV plant

4.3 Cabling

4.3.1 DC Cabling

DC cabling comprises of PV module leads, string cables connecting the PV module strings to combiner box and main DC cables connecting the combiner box to the inverter fuse and then to the inverter. Modules are interconnected in series with solar grade cables that are tied along with the module mounting structures. Modules are interconnected in daisy chain to form a string of 15 PV modules connected in series.

The 5 in 1 out cable harness has been used to pre-combine the string of PV module. Single core 6mm^2 multi-stranded copper PV cables connect cable harness output to String Combiner Box (SCB).

These combiner boxes are equipped with 16A fuse for each of the string connection and a disconnector switch on output side. Power from string combiner box is further transferred to the inverter using 1 runs, 1C, 120mm^2 cables. Detailed Cable specifications has not been provided.

4.3.2 AC Cabling

Three phase AC output from inverter is connected to the LV winding of a three-winding 1.25MVA transformers, using 4 Runs/phase single core 240mm^2 Aluminium Armoured XLPE cable. The inverter transformers step up the voltage to 33kV.

Power is fed from the high voltage side of each transformers using 1R,3C, 95mm^2, 33kV Al XLPE armoured cable to the 33kV HT panel in the 2.5MW$_{AC}$ inverter stations using a radial feeder arrangement.

The 33kV output from HT panel of first inverter station is transmitted to 33kV HT panel located at second Inverter Station. Output from both IDTs of second Inverter station shall be connected to the 33kV HT panel in a radial manner. Combined 5MW output from second HT Panel shall be connected to main HT panel located at Main control room using 1R,3C, 120mm^{2,} 33kV(E) Al XLPE armoured HT cable.

The power from the Main HT panel is transferred to 33kV outdoor switchyard using 1R,3C, 120mm^{2,} 33kV(E) Al XLPE armoured HT cable. Further the output power of 33kV Switchyard is transferred to GSS through overhead line.

4.4 Inverter Station

The 5MW$_{AC}$ solar PV plant has been configured with 8 inverters and two inverter stations. Each inverter station is of 2.5MW$_{AC}$ capacity consist of four inverters of 625kW capacity.

The 2.5MW$_{AC}$ inverter station consists of four inverters connected to two 1250kVA three-winding transformers. Each transformer, along with allied switchgears, steps up the voltage to 33kV for all inverter stations. Further the power from the HV side of the transformer is fed to the 33kV outdoor type HT panel through radial feeder arrangement.

33kV outdoor type HT panel comprises of 30/5-5A current transformer, 33kV/110V fixed type line potential transformer, 33kV EDO TP, 630A SF6 Circuit Breaker and other electrical protection system. The power from inverter duty transformer is transferred to aforesaid MV panel.

4.5 LV/MV Transformers

SgurrEnergy has reviewed the SLD and observed 1.25MVA, 33kV/2x0.3150kV, Dy11y11 three-winding transformers have been used in the project. These inverter duty transformers step up the voltage to 33kV.

The 1.25MVA inverter duty transformers output is connected to 33kV HT panels located within inverter station. The energy from 33kV HT panel of first Inverter station is connected radially at HT panel of second Inverter station. The combined 5MW power from second Inverter Station shall be connected to 33kV main HT panel located within main control room.

4.6 33kV Main HT Panel

A 33kV main HT panel comprises of inverter station incoming feeders and one outgoing feeder. Each feeder comprises of dedicated VCB, instrument transformer with metering and protection class. All feeders have been provided with relay and metering unit. The 33kV main HT panel outgoing and incoming feeders are provided with instantaneous overcurrent and earth fault i.e. 50/50N and IDMT overcurrent & earth fault i.e. 51/51N protections. The 33kV outgoing feeder from main HT panel is provided with 0.2 class instrument transformers.

Power is fed from 33kV main HT panel to and 33kV outdoor Switchyard. Further power from 33kV Switchyard is transferred to GSS through overhead line.

4.7 33kV Metering Yard

Revenue metering at 33kV has been considered at Kinwari GSS.

4.8 Auxiliary Power Supply

SgurrEnergy had reviewed the electrical schematics shared for the projects to evaluate auxiliary system. One 100kVA 33/0.415kV Auxiliary Transformer has been considered cater the load of entire 5MWac plant. Main ACDB panel has been considered at main control room from where tapping's for ACDBs located at Inverter stations has been provided.

4.9 Circuit Breakers

Circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal and abnormal circuit conditions. The circuit breakers are three poles type with electrically and mechanically operated trip-free with anti-pumping facility suitable for remote electrical closing and tripping. The circuit breakers are normally mounted on individual structures.

Following the review of 33kV SLD, SgurrEnergy observed 33kV, 630A, 25kA/1sec SF6 type circuit breaker has been used in the project.

4.10 Isolators

Isolators are used to transfer load from one bus to another and also to isolate equipment for maintenance.

Based on the review of 33kV SLD, SgurrEnergy observed 33kV, 630A isolator without earth switch has been used in the project.

4.11 Instrument Transformers

Current transformers (CT) and voltage/potential transformers (VT) are known to be as instrument transformers. Instrument transformers are devices used to transform the values of current and voltage in the primary system to values suitable for the measuring instruments, meters, protective relays, etc.

The current transformers with accuracy class of 0.2 for metering and class 5P for protection has been used in 5MW$_{AC}$ solar PV plant. The potential transformers with accuracy class of 0.2 for metering and class 3P for protection has been used in the project.

4.12 Surge Arrestors and Lightning Arresters

The substation equipment has to be protected against travelling waves due to lightning strokes on the lines entering the substation. The apparatus most commonly used for this purpose is the surge arrester. Transformer is the costliest equipment in substation, and it is normal practice to install surge arrester near to the transformer. Additional surge arresters shall be provided either on bus or on various lines for protection of the equipment.

Following the review, SgurrEnergy observed that surge arrester has not been provided near Transformers rather only one 33kV, 10kA surge arrester has been provided in outdoor Switchyard line side.

4.13 Metering

In addition to the metering and monitoring arrangement in inverters, monitoring of voltage, current and energy will be provided at the medium voltage switchboards for each of the feeder sections. These meters will be digital with an RS 485 port for remote monitoring. These usually have an accuracy class of 0.5.

Similarly, HV side shall also be equipped with voltage, current, power and energy meters in order to correlate the energy generation and losses. Class of meters at the evacuation point shall be 0.2S.

5 System Design Appraisal

SgurrEnergy has performed a detailed analysis to evaluate the string sizing and compatibility of the inverters with PV modules used for the Project. The following sections discuss the results obtained from the analysis.

5.1 Plant Layout Design

SgurrEnergy was provided with electrical schematics and pv syst report. Based on these documents it is noted that the PV plant has been implemented using First Solar (80W$_P$ and 115W$_P$) PV modules. The total DC installed capacity stands at 5.8MW$_P$. The AC installed capacity stands at 5.04MW$_{AC}$ with 8 inverters of capacity 630kW each.

The selected tilt for the 5.04 MW$_{AC}$ plant is 20°. The 5.04 MW$_{AC}$ plant is designed with a pitch of 6.01m.

15 and 11 modules are connected in series to form a string. The nominal plant power ratio (DC to AC) of the Project is 1.14. Typically, PV plants are designed to have a nominal power ratio upto 1.45 in India; a higher ratio leads to greater overload losses during peak irradiance conditions. However, PV module temperature losses are substantial at the high ambient temperatures corresponding to the higher nominal power ratio.

5.2 String Sizing

The plant layout provided by the Developer indicate Fifteen 80W$_p$ and Eleven 115W$_p$ First Solar CdTe modules to be connected in series to form a string for the plant.

As the string voltage is dependent on temperature and irradiation, open circuit voltage (V$_{OC}$) of the string must be corrected using the temperature co-efficient for the PV modules. Therefore, it becomes necessary to ensure that the maximum voltage input (i.e. the maximum V$_{OC}$ of string at minimum temperature) to inverter does not exceed the inverter maximum operating D.C voltage and hence is a critical value considered by SgurrEnergy in validating string configuration. Subsequent to calculating open circuit voltage (V$_{OC}$ max), maximum power voltage (V$_{mp}$ min) is calculated to ensure that it is within the maximum power point (MPP) range of the implemented inverters.

SgurrEnergy considers the maximum and minimum ambient temperature of 45°C and 9°C respectively for system design validation to be fair and representative for the PV plants' site.

The results of string sizing validation are presented in Table 5-1. Results indicate that V$_{OC}$ max at the minimum ambient temperature is within the maximum system voltage of 1,000V for the selected SMA (Sunny Central 630CP) inverters.

Table 5-1: String Sizing for First Solar PV Modules

Parameters	First Solar 115W$_p$
PV module power (W$_p$)	115
Modules per string	11
Inverters	SMA (Sunny Central 630CP)
Maximum Open-circuit voltage (V$_{OC}$ max) at minimum ambient temperature of 9°C	943.8V
Minimum power voltage (V$_{mp}$ min) at maximum ambient temperature of 45°C	718.3

5.3 Inverter Compatibility

SgurrEnergy performed a detailed analysis on plant sizing to assess the compatibility of inverters with the PV modules used in the projects. The electrical design compatibility summary with First Solar and SMA inverter is presented in Table 5-2. SgurrEnergy has selected First Solar module (110W$_p$) for checking compatibility with SMA inverter, as SgurrEnergy considers this to be representative for all the First Solar PV modules installed on site.

Table 5-2: Inverter Compatibility with First Solar 110 W$_p$ Modules

Parameters	Inverter Compatibility	
PV module	**First Solar 110 Wp (FS-4115)**	
Modules per string	15	Acceptable
Strings per inverter	420	Acceptable
Maximum power, P_{mpp} at STC (kWp)	531	Nominal power ratio is 0.84, this is within the inverter bus current carrying capacity.
Maximum power voltage, V_{mpp} at STC (V)	762.3	Acceptable.
Maximum power current, I_{mpp} at STC (A)	929.6	Acceptable
Open-circuit voltage, V_{oc} at STC (V)	963.6	Acceptable.
Minimum MPP voltage at 45ºC ambient temperature (V)	718.3	Acceptable: Inverter MPPT ranges 500 - 820V.
Maximum MPP voltage at 9ºC ambient temperature (V)	795.3	Acceptable: Inverter MPPT ranges 500 - 820V.
Maximum open circuit voltage, V_{oc} at 9ºC (V)	943.8	Acceptable: Maximum inverter voltage 1000V.

Overall, SgurrEnergy does not raise any concerns regarding the string sizing and inverter compatibility.

6 Resource assessment

The accuracy of any solar energy yield prediction is heavily dependent on the accuracy of the solar resource dataset used. Solar irradiation data is currently not being measured at the location of the proposed power plant and it is therefore necessary to use alternative data sources to obtain estimates of the irradiation figures for the site.

The solar resource of a location may be defined by values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation is the total solar energy received on a unit area of horizontal surface. It includes energy received from the sun in a direct beam and energy that is received from radiation scattered off the atmosphere arriving from all directions of the sky (diffuse irradiation). The units of GHI are given in kWh/m2. Values are often provided for a period of a day, a month or a year.

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the energy received from radiation scattered off the atmosphere arriving from all directions of the sky on a unit area of horizontal surface. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the total solar energy received on a unit area of surface *directly facing the sun at all times*. The units of DNI are kWh/m^2. The direct normal irradiation is of particular interest for solar installations that track the sun and to concentrating solar technologies as only radiation coming directly from the sun may be focussed by a lens or mirror.

For modelling of solar PV plants, GHI and DHI are required for calculating the estimated energy yield. In the northern hemisphere, tilting the modules at an angle towards the south increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations.

Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo. Albedo and global tilted irradiation are described below.

Global Tilted Irradiation (GTI) – The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m^2. A transposition model is used for translating horizontal irradiation to tilted irradiation within PV modelling software.

Albedo – The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

Comparison of Resource Data

There are a variety of possible solar irradiation data sources that may be accessed. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite imagery. A minimum of 10 years of data is recommended to allow for the expected variability of resource data between years. SEI has sourced monthly horizontal plane irradiation data for the Project site from:

- ***NASA****'s Surface Meteorology and Solar Energy data set;* holds satellite derived monthly data for a grid of 0.5° × 0.5° covering the globe for a thirty-four-year period (1984-2017). The data are suitable for pre-feasibility studies of solar energy projects.

- *The* ***METEONORM (version 7.2)*** *global climatological database and synthetic weather generator;* contains a database of ground station measurements of irradiation and temperature. Where a site is over 11km from the nearest measurement station it outputs climatologic averages estimated using interpolation algorithms. Where no radiation measurement station is within 300km from the site, satellite information is used. If the site is between 50 and 300km from a measurement station a mixture of ground and satellite information is used. The accuracy of irradiation figures close to measurement stations are within a few percent. Uncertainty increases with distance between the site and the measurement station, especially in hilly and mountainous terrain.
- **SolarGIS:** SolarGIS is developed and operated by GeoModel a solar company maintaining databases of climate data to support solar energy projects and systems. Database is derived from Meteosat and Geostationary Operational Environmental Satellite system (GOES) satellite data and atmospheric parameters (aerosol and water vapour) using high performance algorithms. SolarGIS regional coverage includes Europe, Africa, Asia and parts of South America and Australia. The spatial resolution of primary parameters for European region is approximately 4km × 4km with a temporal resolution of between 15 minutes to 3 hours. SolarGIS radiation models use multispectral channels and multi-dimensional statistical treatment of ground albedo, daily values of aerosol and water vapour. SolarGIS models is validated by *IEA (International Energy Agency) SHC Collaboration Agreement, and EU FP6 project MESoR* in terms of bias and RMSE.
- **Solar and Wind Energy Resource Assessment (*SWERA) /* National Renewable Energy Laboratory *(NREL)*** data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground-based data to ensure quality of the measurements.

SEI has compared the irradiation datasets given by NASA - SSE, Meteonorm 7, SolarGIS and, NREL (SWERA) data for the site. The comparison is graphically illustrated Table6-1

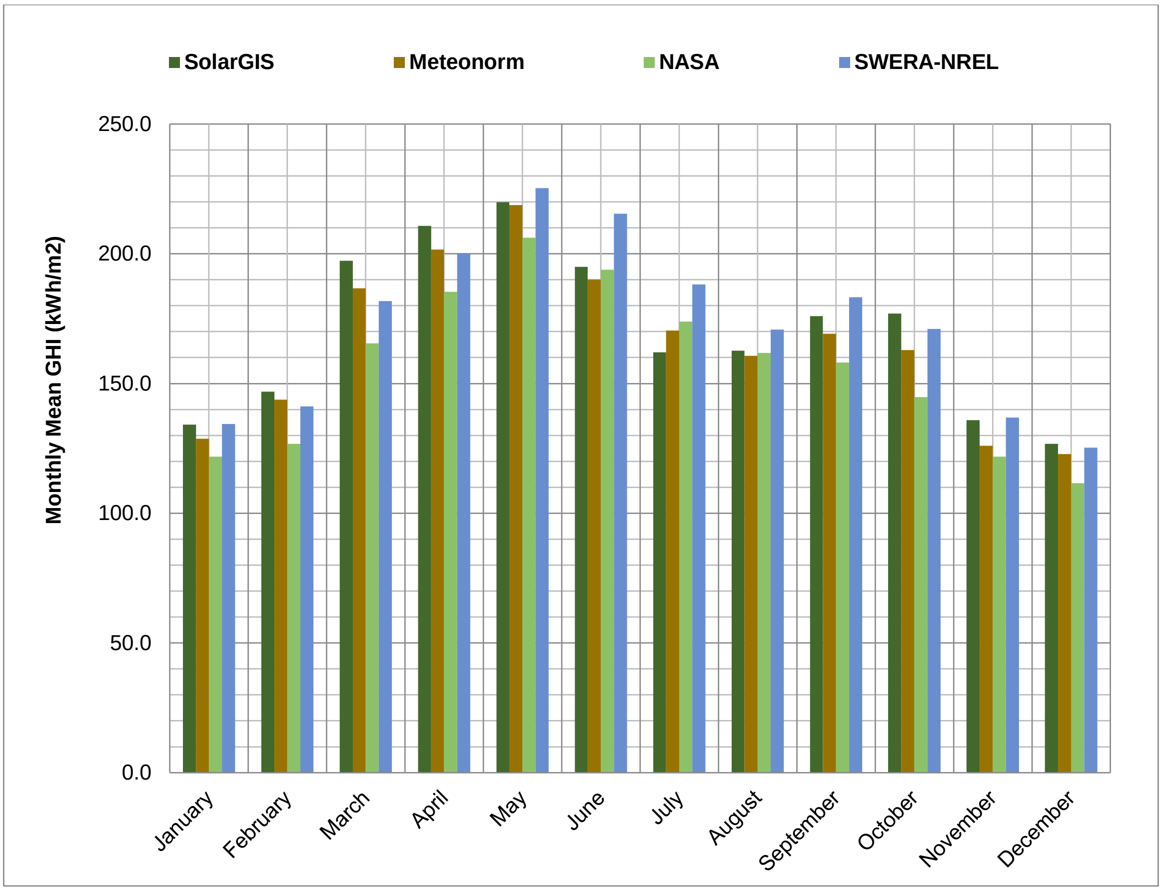

Figure 6-1: Monthly Global Horizontal Irradiation

Table6-1: Comparison of Solar Irradiation Datasets for the site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m^2/annual)
SolarGIS	4km × 4km	3.9%	2044.2
Meteonorm 7.3	14km × 14km	4.0%	1981.6
NASA	55km × 55km	Unknown	1871.5
NREL (SWERA)	40km × 40km	Unknown	2073.6

The comparison of solar data for Project site location illustrated in Table6-1 indicates NREL (SWERA) dataset to give the highest irradiation levels. The next highest irradiation is given by SolarGIS followed by Meteonorm 7.2 and NASA.

The irradiation values given by Meteonorm 7.2 typically provide a combination of ground and satellite measured data. Meteonorm 7.2 has interpolated the data using satellite data for the proposed site. Uncertainty of satellite data is obtained as 6.8% for the proposed site.

The NREL (SWERA) data illustrated has been obtained for a location approximately 3.54 km away from the proposed site. SgurrEnergy performed iteration on an extensive list of NREL (SWERA) datasets to obtain appropriate coordinates that lie within the Indian boundaries. The results give only irradiation data without temperature and wind data.

The NASA-SSE data source provides purely satellite measured data for a grid covering 0.5° × 0.5° on the earth's surface and generally more suited for initial site selection.

The SolarGIS dataset has been compared with good quality ground measurements for more than 200 sites. The resulted mean bias for GHI is 0%. SolarGIS data base has also been compared with other data sources globally. The IEA (International Energy Agency) validation study conducted by University of Geneva in 2011 has resulted in SolarGIS to be the best performing database among five satellite databases. Similar IEA validation study was repeated in 2013 by University of Geneva which again resulted in SolarGIS to be the best performing database among six satellite databases. Validation study in 2013 was conducted using 18 validation sites in Europe and Mediterranean regions. Furthermore, SolarGIS has conducted its own validation for six Indian locations[6] with the following bias in GHI;

- Pantnagar (Uttarakhand)
- Kanpur (Uttar Pradesh)
- Mysore (Karnataka)
- Warangal (Telangana)
- Jaipur (Rajasthan)
- Ranchi (Jharkhand)

Comparative analysis of all the data sets available, indicate SolarGIS has been validated for India. Furthermore, SolarGIS dataset is based on the most recent long-term average that is from 1999 – 2015, while Meteonorm dataset is based on the time-period of 1991 - 2010. The uncertainty of SolarGIS is 3.9% while that of Meteonorm is 6%.

SEI is therefore of the opinion that SolarGIS dataset may be considered reasonable and a representative data source for conducting an energy yield assessment for the project location.

6.1 Global, Direct and Diffuse Irradiation on a Horizontal Plane

Horizontal plane irradiation data based on long-term monthly averages are presented in Table 6-2 and shown graphically in Figure 6-2 Diffuse irradiation accounts for 40.52% of the total irradiation. Table 6-2 illustrates direct and diffuse daily irradiation on a horizontal plane for the proposed site. SolarGIS irradiation data is presented in Table 6-2.

Table 6-2: SolarGIS Irradiation Data for the Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	134.2	42.5	6.6%
February	146.9	44.8	7.2%
March	197.3	63.6	9.7%
April	210.7	81.6	10.3%
May	219.9	101.7	10.8%
June	195.0	99.0	9.5%
July	162.0	98.6	7.9%
August	162.6	89.0	8.0%
September	176.0	68.7	8.6%

6 https://solargis.com/docs/accuracy-and-comparisons/overview/

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
October	177.0	51.5	8.7%
November	135.9	46.2	6.6%
December	126.7	41.2	6.2%
Annual Sum	**2,044.2**	**828.2**	**-**

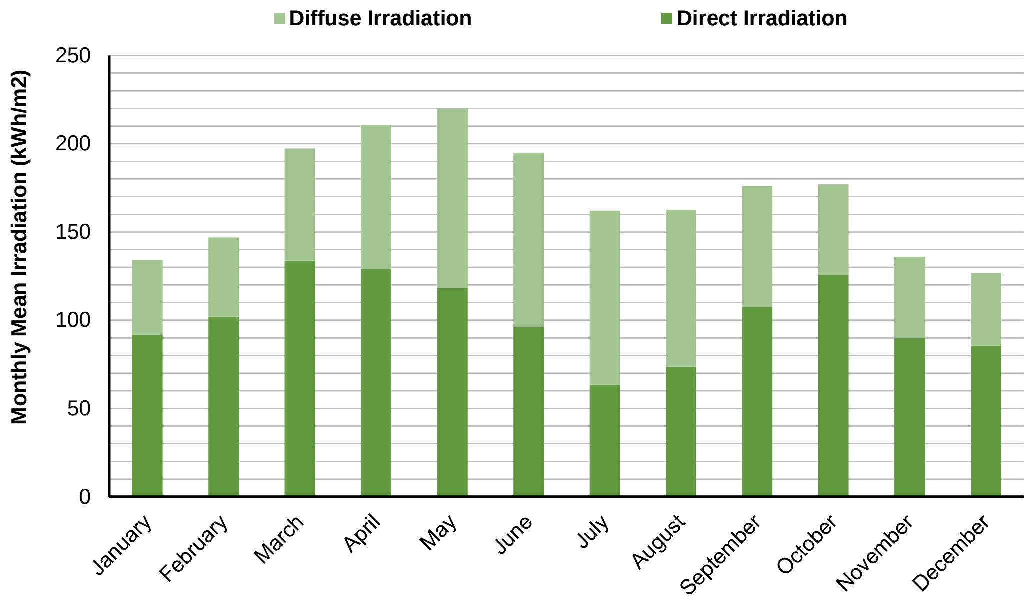

Figure 6-2: Monthly Direct and Diffuse Irradiation on a horizontal plane for the project site

6.2 Global Tilted Irradiation

Industry standard PV modelling software PVsyst (v.7.0.17), was used. An albedo of 0.2 was assumed based on the ground surface covering within and around the PV array. Table -6-3 represents the monthly GTI profile.

Table -6-3: Monthly Global Tilted Irradiation Data

Month	GTI (kWh/m^2)
January	176.20
February	179.80
March	221.20
April	217.60
May	213.20
June	184.70
July	154.80

Month	GTI (kWh/m^2)
August	162.10
September	190.30
October	210.00
November	173.60
December	170.10
Annual Sum	**2,253.60**

6.3 Climate

For wind speed analysis, data sourced from Meteonorm dataset was used and has been tabulated in Table 6-4 below. The average wind speed of 1.1 m/s was measured at 10 m height from ground level for the proposed project site location.

Table 6-4: Simulated Wind Speed for site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	0.9
February	0.9
March	1
April	1.2
May	2.1
June	2
July	1.6
August	1.3
September	1
October	0.4
November	0.5
December	0.8
Yearly Average	1.1

6.4 Temperature

Temperature data has been sourced from the SolarGIS database. A typical operating temperature range for PV modules is -40°C to +85°C. Inverter operating ranges are more bounded to temperature, typically -20°C to +45°C, with the electronic equipment in the inverter degrading quicker in high temperature environments. Thus, considering the temperature range at selected site, the modules and inverters should be able to operate normally.

The effect of temperature on module performance and the corresponding plant performance may be quite significant. Typically, a reduction in efficiency of 0.40 – 0.45%/°C is noted for crystalline modules and 0.25 -0.30%/°C for thin film modules for increase in temperatures above 25°C. Therefore, during the summer months (February-

June) temperature losses may be significantly high as module temperatures typically go beyond 50°C.

Table 6-5: SolarGIS Temperature Data for Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	15.3
February	18.4
March	24.1
April	29.6
May	33.8
June	35.0
July	32.5
August	31.1
September	30.7
October	26.9
November	21.3
December	16.8
Annual Average	26.3

6.5 Precipitation

The rainfall figures have been simulated using Meteonorm 7.3 as illustrated in Figure 6-3. These figures show that the identified site is situated in a region that has marginal rainfall.

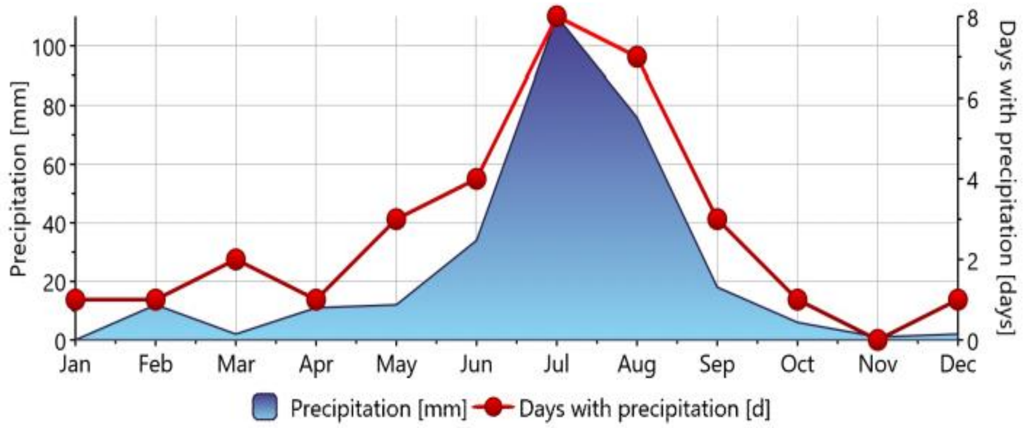

Figure 6-3 Meteonorm Predicted Precipitation for the site

PV modules are soiled by particulates of dust, dirt and bird droppings. Soiling of modules has a high impact on the energy yield thereby leading to a loss up to 3% in non-arid regions. Therefore, the modules need to be cleaned for avoiding the loss due to soiling.

Frequency of module cleaning depends on the rainfall frequency and the prevalence of dust and pollution in the local vicinity. Typical cleaning techniques include water cleaning, dry brushes or vehicle-based mechanical cleaning.

The frequency of module cleaning is primarily dependent on the amount of soiling experienced on the site. Soiling loss of 2.37%[7] has been considered by considering cleaning frequency of twice a month.

[7] The soling loss considered in simulation is 2.0% and spectral correction factor (applicable for first solar modules only) is applied to the soiling loss in PVSyst to get the corrected energy yield estimate. The soiling after applying the spectral correction factor is 2.37%.

7 Energy Yield Analysis

SgurrEnergy has computed the annual energy yields for the 5 MW$_{AC}$ Solar PV Plant using basic designs and indicative layout. Energy yields for all the PV technology configurations under evaluation is further elaborated in the following section.

Parameter	Description
Modules	First Solar 80 W$_p$, (FS-380) First Solar 115 W$_p$ (FS-4115)
Inverters	Sunny Central Inverters – 630 KW$_{AC}$ (Sunny Central 630CP)
Mounting System	Fixed Tilt
DC Capacity (MW$_p$)	5.7

For energy yields SgurrEnergy has:

1) Sourced average monthly horizontal irradiation, wind speed and temperature data with the other sources which included satellite image derived data. These data have been assessed for use in the energy yield simulation software.
2) Following the assessment, SgurrEnergy has selected site specific data sourced from SolarGIS to arrive at representative energy yield estimates.
3) Calculated the global incident radiation on the tilted plane, taking into account shading.
4) Applying downtime losses, AC ohmic losses, and module degradation losses to obtain energy yields that reflect twenty-five-year plant life.

Using statistical analysis of resource data for inter-annual variability to derive appropriate levels of uncertainty in the energy yield prediction, steps 2 and 3 are facilitated using industry standard photovoltaic simulation software which simulates the energy yield using hourly time steps. The software takes as input detailed specifications of:

- The solar PV modules.
- The inverter.
- Mounting system.
- Electrical configuration including number of modules in series and parallel.

7.1 Correction and Losses

Data obtained for irradiation on collector plane, PV module and inverter specifications and plant configuration are input into the PV modelling software to calculate DC energy generated from the modules in hourly time steps throughout the year. This direct current is converted to AC in the inverter.

A number of losses occur during the process of converting irradiated solar energy into AC electricity fed into the grid. The losses may be described as a yield loss factor. They are calculated within the PV modelling software and calculated from the cable dimensions. Others are nominal figures applied from knowledge of performance of similar PV plants. The losses are broadly summarised in Table 7-1 below.

Table 7-1: Description of Energy Yield Losses

Loss	Description
Shading	Three types of shading losses are considered in the PV energy yield model: horizon shading, shading between rows of modules and near shading due to trees and buildings.
Incident Angle	The incidence angle loss accounts for losses in radiation penetrating the front glass of the PV modules due to angles of incidence other than perpendicular.
Low Irradiance	The conversion efficiency of a PV module reduces at low light intensities.
Module Temperature	The characteristics of a PV module are determined at standard temperature conditions of 25˚C. For every ˚C temperature rise above this, module efficiency reduces according to their temperature coefficient.
Soiling	Losses due to dust and bird droppings; soiling the module.
Module Quality	Most PV modules do not match exactly the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a given tolerance within which the actual power is guaranteed to lie.
Module Mismatch	Losses due to "mismatch" are related to the fact that the real modules in an array do not all rigorously present the same current/voltage profiles: there is a statistical variation between them.
DC Wiring Resistance	Electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).
Inverter Performance	Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.
MPP Tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the maximum power point voltage. Different inverters do this with varying efficiency.
AC Losses	This includes ohmic losses from inverter to evacuation point.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
Grid Availability and Disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Power Curtailment Losses	Curtailment loss is attributed to the utility limiting the power intake at the contracted AC capacity of the PV Plant; thus, the excess energy generated beyond the limit of 30MW$_{AC}$ at the metering level shall not be accounted
Degradation	The performance of a PV module decreases with time.

7.2 P50 Energy Yield Predictions

This section presents the SgurrEnergy's independent energy yield prediction for the 5 MW$_p$ solar PV Plant with First solar PV modules and Sunny central inverters. Table 7-2 summarises the solar PV power plant, the available resource, the losses and the predicted P50 yields.

Table 7-2: Energy Yield for the 5 MW$_{AC}$ Solar PV Plant

Parameters	Description
PV Module Technology	Thin Film
DC Capacity (MW$_p$)	5.7
AC Capacity (MVA)	5.0
Contracted Capacity (MW)	5.0
P_{NOM} Ratio	1.14
Tilt (°)	20
Pitch (m)	6.01
Annual Global Horizontal Irradiation (kWh/m^2)	1957.60
Global Irradiation Incident on Collector Plane (kWh/m^2)	2096.84
Transposition Factor	1.07
Losses	
Horizon Shading	0.00%
Incident Irradiation Below Threshold	0.00%
Near Shading	1.57%
Incident Angle	2.60%
Soiling	2.37%
Low Irradiance	0.35%
Module Temperature	6.64%
Electrical Shadings	0.02%
Module Quality	-0.90%
First year Degradation	0.00%
Module Mismatch	1.00%
DC Ohmic	0.36%
Inverter Performance	1.81%
Availability	1.00%
AC Ohmic	0.92%
Transformer (LV/MV)	1.01%
Transformer (MV/HV)	0.50%
Transmission Line	0.75%
Auxiliary Consumption	0.56%
Curtailment	
Total Annual Loss Factor	***0.814***
First Year P50 Energy Yield (MWh/annum)	**10,536.692**
Tenth Year P50 Energy Yield (MWh/annum)	**9,625.45**
Tenth Year Specific Yield (kWh/kW$_p$)	**1676.90**

Parameters	Description
Tenth Year CUF on AC Installed Capacity	**21.80%**
Tenth Year CUF on Contracted Capacity	**21.80%**
Tenth Year CUF on DC Installed Capacity	**19.14%**
Tenth Year Performance Ratio	**74.40%**

Graphical representation of the monthly generation, performance ratio and CUF for 5MW$_{AC}$ evaluated is illustrated graphically in the Figure 7-1.

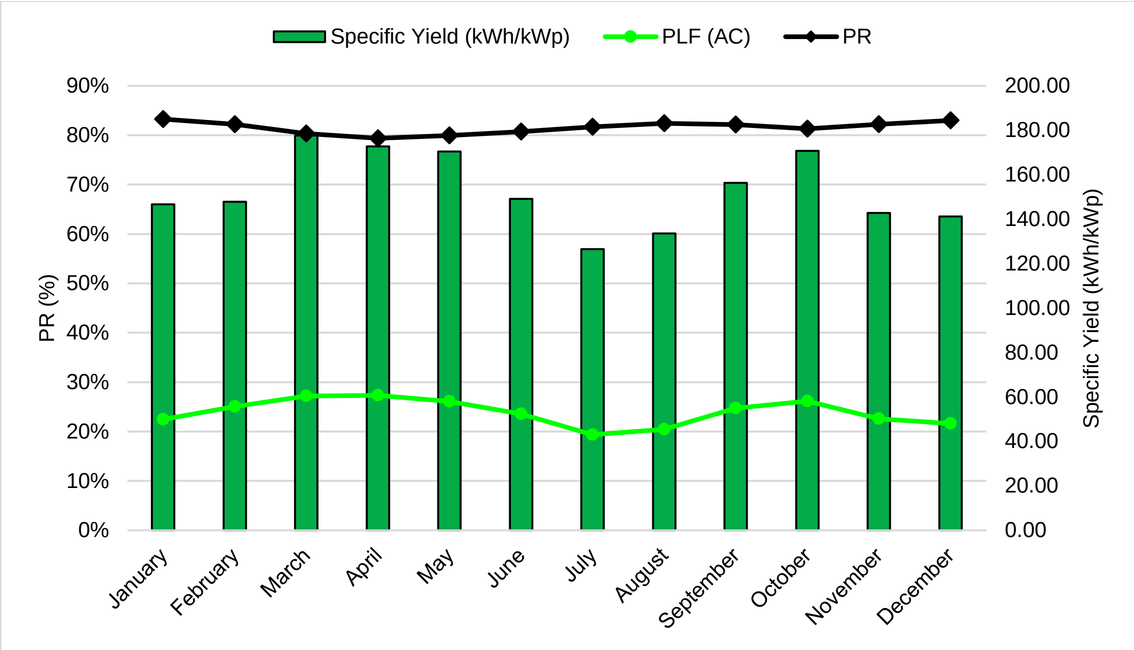

Figure 7-1: Monthly Energy Yield for 5 MW$_{AC}$

7.3 Yield Uncertainty

The uncertainty in energy yield predictions is difficult to quantify as it is a function of many independent factors. The discussion below represents simplification of the estimated uncertainty which is believed to be the best approach given the uncertainty in the resource data.

7.3.1 Solar Resource Measurement Uncertainty

Energy yield prediction is based on SolarGIS database, a satellite data which is derived from Meteosat Indian Ocean Data Coverage (Meteosat IODC) and atmospheric parameters using high performance algorithms set by SolarGIS method.

The resource data for 16+ years (1999-2015) has been obtained from the SolarGIS climatological database. SolarGIS recommends an uncertainty of 3.9%.

The uncertainty in transposing the global horizontal irradiation to global tilted irradiation is dependent on the accuracy of the initial data and the characteristics of the specific location. Based on the SgurrEnergy's experience, the uncertainty associated with the transposition model is 1.5%.

7.3.2 Inter – Annual Variation in the Solar Resource

Mean global daily irradiation on a horizontal plane varies on an annual basis. This means that the plant owner does not know what energy yield to expect in any given year but can have a good idea of the expected yield in the long term.

The likely variation can be quantified based on analysis of variation in long-term irradiation data in the vicinity of site. SgurrEnergy has sourced 35 year's data from NASA database for the proposed site location which is used to estimate the standard deviation of variation in irradiation. SgurrEnergy has analysed this dataset and computed the coefficient of variation (standard deviation divided by the mean) as shown in Table 7-3.

Table 7-3: Summary of Figures for Inter-Annual Variation in Resource

Number of Years of Data	35
Coefficient of Variation	5.60

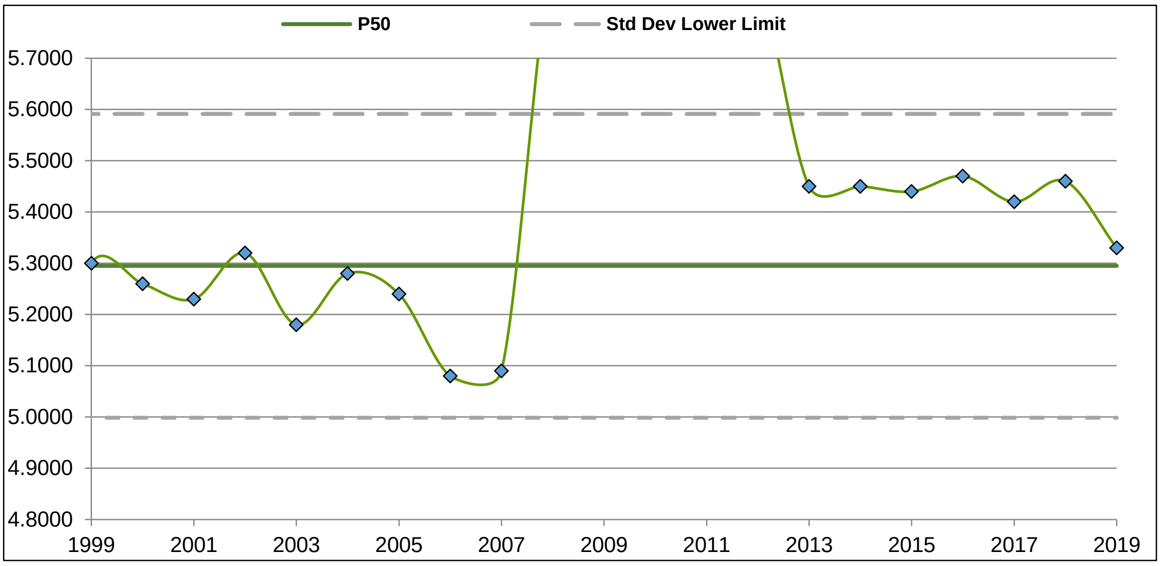

Figure 7-2: Inter-Annual Variability of GHI

Graphical illustration of inter annual variation is presented in Figure 7-2.

SgurrEnergy uses a coefficient of variation of 5.60 % to quantify the inter-annual variation in the solar resource.

7.3.3 Modelling Uncertainty

The modelling uncertainty is a combination of the various uncertainties for each loss factor assessed in the modelling process. Efforts to validate the photovoltaic simulation software used data from seven grid connected systems in Europe. These indicated that the accuracy of the results of the simulation is in the order of 2 to 3%.

7.3.4 Total Uncertainty (P75 and P90 Energy Yield Predictions)

Combining the uncertainties in energy yield and inter-annual variation in the solar resource, the P50, P75 and P90 confidence interval are presented for each PV plant configuration in the table below.

Table 7-4: Life Cycle P50, P75 and P90 Generation Prediction for 5 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[8]	P90 Generation Prediction[9]
10	9,625.45	9,219.45	8,854.03
11	9,561.92	9,158.60	8,795.60
12	9,498.81	9,098.15	8,737.55
13	9,436.12	9,038.11	8,679.88
14	9,373.84	8,978.45	8,622.59
15	9,311.98	8,919.20	8,565.68
16	9,250.52	8,860.33	8,509.15
17	9,189.46	8,801.85	8,452.99
18	9,128.81	8,743.76	8,397.20
19	9,068.56	8,686.05	8,341.78
20	9,008.71	8,628.72	8,286.72
21	8,949.25	8,571.77	8,232.03
22	8,890.19	8,515.20	8,177.70
23	8,831.51	8,459.00	8,123.72
24	8,773.22	8,403.17	8,070.11
25	8,715.32	8,347.71	8,016.84

[8] The P75 values have been calculated over 10-year averages

[9] The P90 values have been calculated over 10-year averages

8 Operational Analysis and Generation Comparison

To assess the operational performance of the plant, SgurrEnergy has comparatively evaluated the monthly energy yield predicted using satellite-based weather data with the plant generation SCADA values. A factor of 1.0% degradation has been considered for values after a duration of 1 year from COD (Commercial Operational Date) till ten years from COD. The variation has been evaluated with respect to the difference between the two generation figures.

Based on the information provided by the Owner, SgurrEnergy understands that the SSEPL solar PV plant was commissioned in 15th October 2011. SgurrEnergy was provided with plant, grid availability and irradiation records from April 2016 to April 2021[10] for the solar PV plant.

SgurrEnergy has thus carried out the generation comparison for the PV project for the period from April 2016 to April 2021, henceforth referred to as 'operational period'. SgurrEnergy compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Owner.

SgurrEnergy also observed that the monthly availability figures were provided for the operational period of the solar PV plant. These availability figures were captured within the monthly energy yield predictions assessed for the site in question and were accounted for representative comparison. The average availability based on the provided data has also been specified below.

Based on the availability records provided, SgurrEnergy has analysed the trend in the plant availability and grid availability for each month as presented in the following sections.

1.1.1 Grid Availability

The ability of a PV power plant to export power is dependent on the availability of the grid transmission network and the utility grid substation. Grid unavailability is solely due to the breakdown events associated with the grid substation and substation maintenance, which is beyond the Owners control.

The monthly records of the grid availability from April 2016 to April 2021 have been graphically illustrated in Figure 8-1 below.

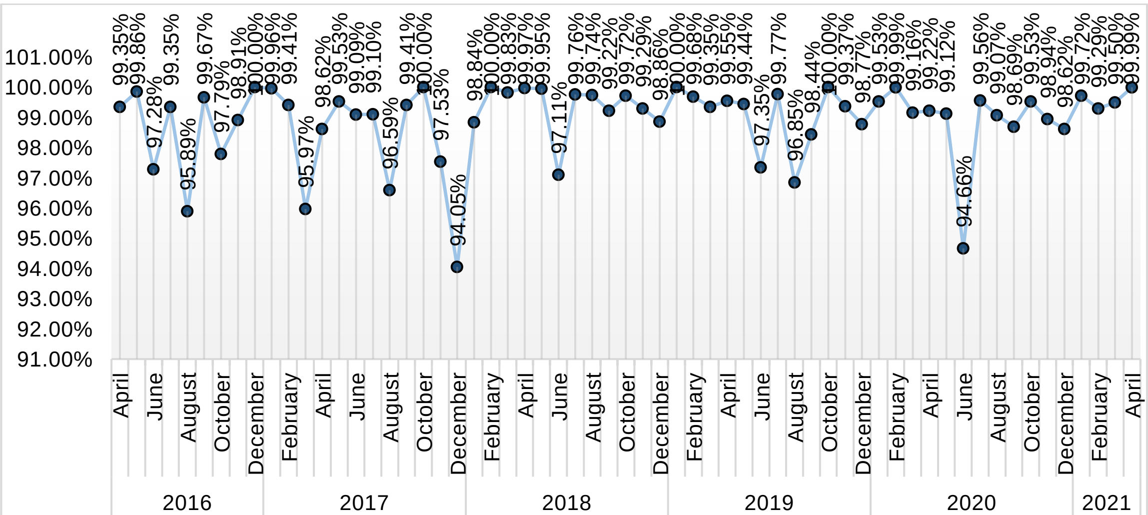

Figure 8-1: Grid Availability

[10] SgurrEnergy was provided with both the plant and grid availability records until April 2021 and hence the analysis conducted in the sections below has been done to incorporate the available data.

From the above illustration, SgurrEnergy notes that the unavailability loss experienced due grid anomalies are high over the operational period. For the months of August 2016,March 2017,August 2017, December 2017,June 2018,June 2019,August 2019 and June 202 the unavailability due to grid was high when compared to other months. The downtime due to grid unavailability was above 98% during the remaining months.

Overall the average grid availability experienced on site for the operational period was calculated to be 98.90%

1.1.2 Plant Availability

Plant downtime is a period when the plant does not generate due to failure of equipment in plant until the injection point. The plant downtime period depends on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.

Plant availability of the SSEPL solar PV plant is graphically illustrated below in Figure 8-2.

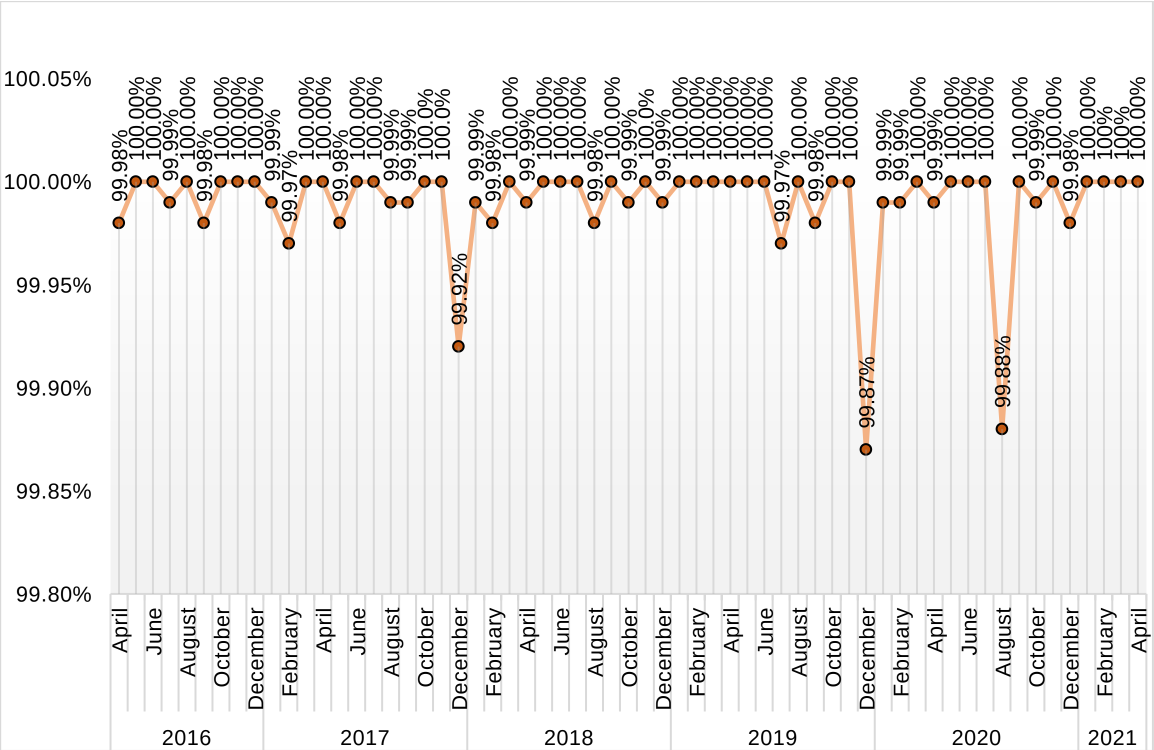

Figure 8-2: Plant Availability

Based on the above illustrations, SgurrEnergy notes the plant availability for the SSEPL solar PV plant is consistently above 99.87% for all the months ranging between 99.87% to 100%. The average plant availability is noted to be 99.99% which is considered to be well above the expected range.

1.2 Energy Yield Comparison

SgurrEnergy has compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Client. To make the operational energy yield predictions more representative, SgurrEnergy has applied the monthly losses due plant and grid unavailability provided by the Client. These predictions are in turn compared with the actual performance of that plant, which are the generation figures shared by the Client.

The yearly comparison of the generation data is illustrated below in Figure 8-3.

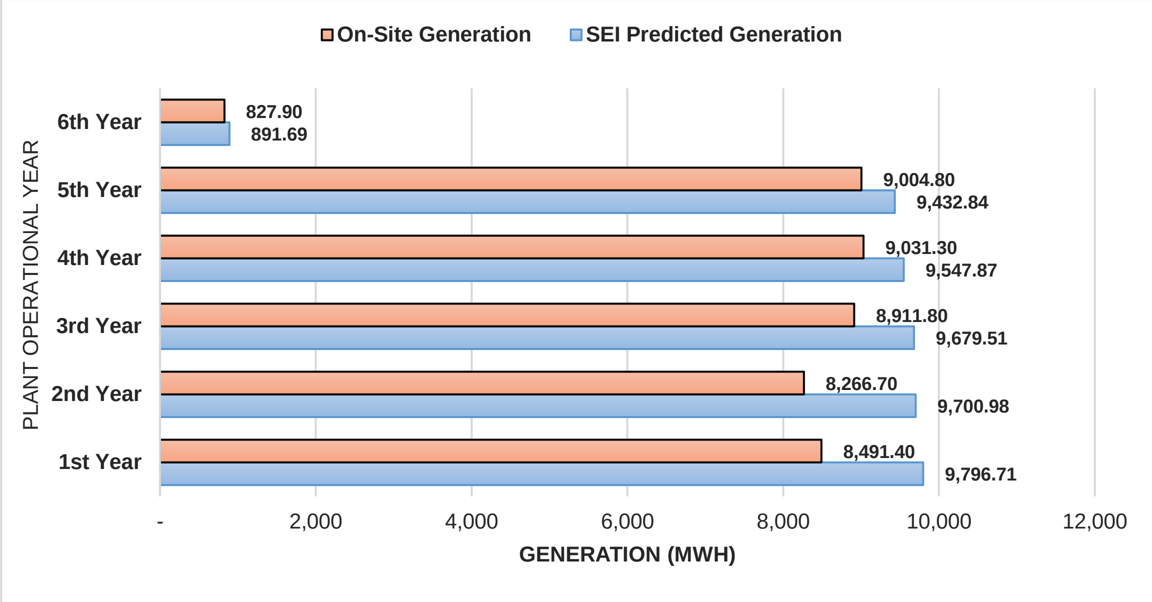

Figure 8-3: Generation Comparison

The variation of the performance of the PV plant for the period of evaluation has been tabulated below in Table 8-1

Table 8-1: PV Plant Performance – SSEPL

PV Plant Operation Period	Predicted Generation (MWh)	Recorded Generation (MWh)	Performance Percentage[11] (%)
April 2016 -March 2017	9,796.71	8,491.40	-13.32%
April 2017 - March 2018	9,700.98	8,266.70	-14.78%
April 2018 - March 2019	9,679.51	8,911.80	-7.93%
April 2019 - March 2020	9,547.87	9,031.30	-5.41%
April 2020 - March 2021	9,432.84	9,004.80	-4.54%
April 2021	891.69	827.90	-7.15%
Cumulative Period	**49,049.60**	**44,533.90**	**-9.21%**

Based on the above comparison, SgurrEnergy notes that the PV plant is generating lower than the expected yield. However, SgurrEnergy considers that such variations in the energy yield can be attributed to higher irradiation level experienced on the Project site. The irradiation levels significantly impact the actual generation from the PV plant as the system losses may vary significantly due to slight change in the irradiation.

In order to understand the deviation in the irradiation pattern, SgurrEnergy has compared the monthly incident irradiation data provided by the Client with the monthly incident irradiation predicted using satellite-based meteorological data for the period of evaluation. The result of the comparison is presented in the table below and the same is graphically illustrated in the Figure 8-4.

[11] Positive values indicate higher generation, while negative values indicate lower generation

Table 8-2: Irradiation Comparison– SSEPL

PV Plant Operation Period	Predicted Irradiation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[12] (%)
April 2016 -March 2017	2,253.60	2,139.39	-5.07%
April 2017 - March 2018	2,253.60	2,131.70	-5.41%
April 2018 - March 2019	2,253.60	2,094.71	-7.05%
April 2019 - March 2020	2,253.60	2,151.96	-4.51%
April 2020 - March 2021	2,253.60	1,987.31	-11.82%
April 2021	217.60	198.83	-6.74
Cumulative Period	**11,485.60**	**10,703.91**	**-6.81%**

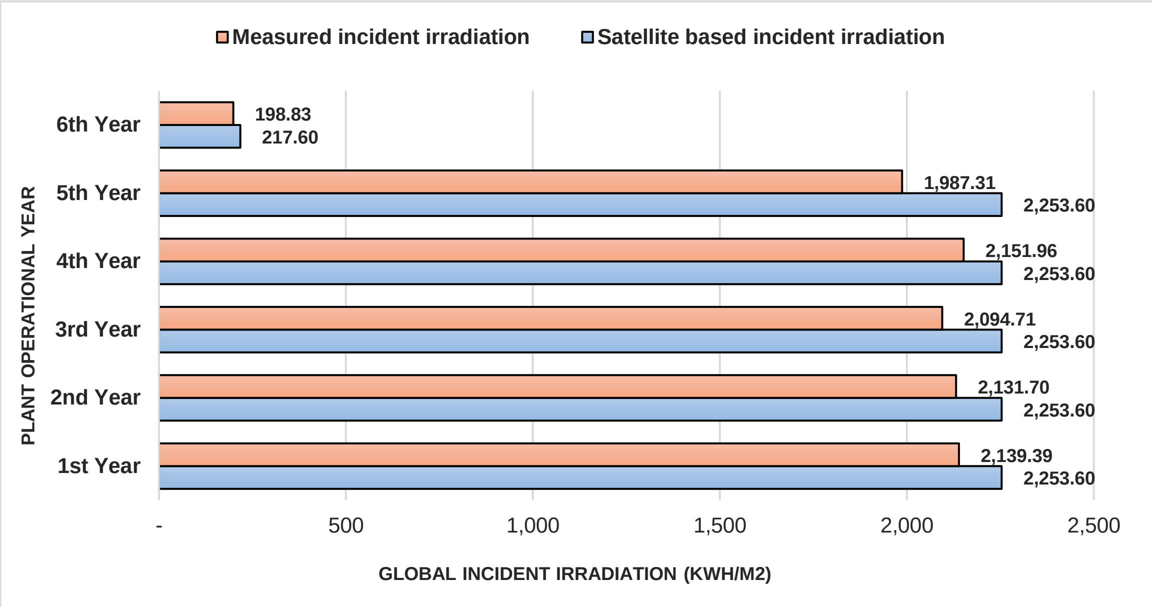

Figure 8-4: Irradiation Comparison

Based on the above illustration, it is observed that the overall recorded generation is approximately 9.21% lower than the generation predicted on site. It has also been observed that the recorded irradiation is 6.81% lower than thee predicted irradiation.

Based on the comparative analysis, the drop-in generation can be attributed to the drop in irradiation during the evaluation period.

[12] Positive values indicate higher irradiation, while negative values indicate lower irradiation

9 Solar Plant Life beyond 25 years

The traditional life of a solar plant is 25 years, which is based primarily on solar panel warranty period. The National Renewable Energy Laboratory (NREL) in the U.S however lists solar pv plants as having a lifetime of 25-40 years[13].Most modules are expected to see a degradation rate of 0.7% for the 25 years and hence the expected power output at the end of 25 years is around 80% of the rated power. However, research from NREL[14] shows that the median degradation rates of panels are around 0.5% and power output after the 25 year term could be higher than the power output guaranteed by the module manufacturer. Hence the possibility of the module producing electricity beyond 25 years with a year on year degradation is not farfetched, however whether these degradation rates will be in a linear pattern or in an unpredictable pattern is yet discovered and hence evaluating the generation/ performance of the plant and life of the plant beyond 25 years becomes risky. The life of the plant also depends on the quality of the other components such as inverters, cables, transformers used. Over the twenty five year plant life, these component will need to be serviced and repaired, as the warranty period for all of these components are less than 10 years. The repair and service of these equipment can continue beyond 25 years and the component may be fit for use for another ten years, however the risk of equipment failure increases year on year. The life of the plant also depends on the operations and maintenance activities carried out during the plant lifecycle and hence carrying out O&M activities diligently during the lifetime of the plant can increase the life of the plant beyond 25 years.

Overall, the pv plant is expected to function beyond plant life of 25 years, however the risk associated with the plant operation increases as the panel warranties would have expired, degradation rates beyond 25 years are unknown and other components used in the plant would also need additional repair/replacement.

[13] https://www.nrel.gov/analysis/tech-footprint.html

[14] https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

Virescent Infrastructure

20MW(AC) PLG Solar PV Plant
PLG Photovoltaic Private Limited
Technical Assessment Report

July 2021

Report Details

Prepared for:	Virescent Infrastructure
Client Contact:	Atul Raaizada
Report Distribution:	
SgurrEnergy:	Ahmed Dalvi
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	Name	Job-Title	Signature
Prepared by	Advisory Team		
Reviewed by	Ahmed Dalvi	Sr. Project Engineer	[signature]
Authorised by	Arif Aga	Director	[signature]
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Amendment Records

Revision Number	Date	Purpose of Revision	Summary of Amendments
B1	23 June 2021	Draft Issue	-
B2	28 June 2021	Minor Updates	-
B3	2 July 2021	Minor Updates	-
B4	6 July 2021	Minor Updates	-
B5	21 July 2021	Minor Updates	-

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Executive Summary

Virescent Infrastructure (the Client) backed by leading global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy has been appointed by the Client to conduct a technical appraisal of 20MW$_{AC}$ PLG Photovoltaic Private Limited (PLG). The Project is located in Patan district of Gujarat.

The summary of the technical assessment is captured in the below table.

Table 1-1: Summary

Sr. No.	Parameter	Comment
1	Plant Overview	Review presented in Section 2
2	PV Module	According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of Kyocera Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard. Further, according to the warranty documents available in public domain for the module manufacturer, SgurrEnergy considers the warranty terms and conditions offered by Kyocera to be in-line with the industry standard and raises no major concern regarding the warranties offered. However, SgurrEnergy suggests getting clarity on the limited product warranty, first-year degradation and general degradation offered by the manufacturer for the PV modules used for the project. Referring the datasheet provided, SgurrEnergy observed that the Kyocera PV modules used for the project are IEC 61215 and IEC 61730 certified, which is in-line with the industry standard. In conclusion, SgurrEnergy does not raise any major concerns about the modules used in the project.
3	Inverter	SgurrEnergy has conducted review of the ABB's PV800-57-500kW and Power-one's PVI-500.0-TL-CN -500kVA central inverter. Both the central inverter makes have the required certification for use in solar PV plants. The technical characteristics of both the inverters are in-line with the industry standard. ABB and Power-one offer a product warrant of 63 and 66 months, respectively, which is in line with the current industry standards. In conclusion, ABB and Power-one can be considered as established and reputable inverter manufacturers and are known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern in the utilization of ABB and Power-one inverters for the project.
4	Inverter and Power Transformer	The inverter transformers (1250kVA) and power transformer (12.5MVA) used within the project are manufactured by Voltamp. The manufacturers have good track record of supplying transformers for solar application throughout the world. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for

Sr. No.	Parameter	Comment
		the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.
5	String Sizing	The V_{OC} does not exceed the inverter input voltage for the site, and therefore, SgurrEnergy considers the number of modules in series to be acceptable for the PV Project.
7	Resource Assessment	For resource analysis, SgurrEnergy has compared various satellite datasets. For the satellite databases, SEI has comparedMeteonorm 7.3, NASA, SWERA and SolarGIS data to find the most suitable solar resource for long-term energy yield prediction. Owing to low uncertainty and high resolution, SEI considers SolarGIS dataset to be the most representative satellite database among all the satellite databases for long-term energy yield assessment.
8	Operational Analysis and Generation Comparison	Review presented in Section 8
9	Allied Components and Systems	Review presented in Section 4
10	Energy Yield Assessment	Subsequent to the solar resource assessment, SEI considers SolarGIS database as the most representative for long-term energy yield predictions. The table below summarises the energy yield predictions for ninth year of plant operation for the 20MW$_{AC}$ PV plant.

Global Horizontal Irradiation (kWh/m2)	2015.00
Global Inclined Irradiation (kWh/m^2)	2211.81
First Year P50 Energy Yield (MWh/annum)	32,542.19
Ninth Year P50 Energy Yield (MWh/annum)	31,263.05
Ninth Specific Yield (kWh/kW$_p$)	1563.15
Ninth Performance Ratio (PR)	70.67%
Ninth PLF on Contracted Capacity (20 MW$_{AC}$)	17.84%

Glossary

A	Amp
AC	Alternating Current
a-Si	Amorphous Silicon
CdTe	Cadmium Telluride
c-Si	Crystalline Silicon
CIGS/CIS	Copper Indium (Gallium) Di-Selenide
CPV	Concentrated photovoltaic
CSP	Concentrating solar power
CUF	Capacity Utilization Factor
°C	Degrees Centigrade
°	Degrees
DC	Direct Current
E	East
GWh	Giga Watt hour
HV	High Voltage
Hz	Frequency, Hertz
IAM	Incident Angle Modifier
Isc	Short Circuit Current
IEC	International Electro technical Commission
kA	One Thousand Amps
km	One metric kilometre
kV	One thousand Volts
kVA	One thousand Volt Amps
kWp	One thousand Watts peak
kWh	One thousand Watt hours
LV	Low Voltage
m	Meters
m^2	Meters squared
mm	Millimetres
mm^2	Millimetres squared
m/s	Meters per second
mc-Si	Mono-crystalline Silicon

MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MTBF	Mean Time Between Failures
MV	Medium Voltage
MVA	One million Volt Amps
MW	One million Watts or Megawatt
MWp	Megawatt peak of Solar PV modules
N/m^2	Newton per meter Squared
N	North
NASA	National Aeronautics and Space Administration
NEC	National Electric Codes
O&M	Operations and Maintenance
ONAN	Oil Natural Air Natural
ONAF	Oil Natural Air Forced
%	Percentage
pc-Si	poly-crystalline Silicon
PV	Photovoltaic
REC	Renewable Energy Certificates
RPO	Renewable Purchase Obligation
STC	Standard Test Conditions
SWERA	Solar and Wind Energy Resource Assessment
TUV	TÜV Rheinland Group Testing and Standards Organisation.
V	Volts
Voc	Open Circuit Voltage
VT	Voltage Transformer
W/m^2	Watts per metres squared
Wp	Watt peak
XLPE insulation	Cross-Linked Polyethylene insulation

1 Introduction

Virescent Infrastructure (the Client) backed by global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy India (SEI) has been appointed by the Client to conduct technical appraisal for the 68MW$_{AC}$ portfolio of Solar PV projects in India. The portfolio comprises of four projects, as presented within Table 1-1.

Table 1-1: Project Key Summary

Project Name	SSEPL – 5MW$_{AC}$	SSEGPL – 13MW$_{AC}$	PLG – 20MW$_{AC}$	USUPL – 30MW$_{AC}$
Site Location	26.52N, 72.85 E, Tiwari, Jodhpur, Rajasthan, India	23.9128°N, 71.2183°E, Santalpur, Patan, Gujarat, India	23.922758°N 71.523231°E, Dahisar, Patan, Gujarat, India	25°18'52.79"N, 79°25'2.49"E, Devgaon, Mahoba, Uttar Pradesh, India
Owner	Sindicatum Solar Energy Private Limited (SSEPL)	Sindicatum Solar Energy Gujarat Private Limited (SSEGPL)	PLG Photovoltaic Private Limited (PPPL)	Universal Saur Urja Private Limited (USUPL)
DC / AC Capacity	5.745MW$_P$ / 5MW$_{AC}$	15MW$_P$ / 13MW$_{AC}$	20MW$_P$ / 20MW$_{AC}$	36.98MW$_P$ / 30MW$_{AC}$

This report presents the evaluation of the 20MW$_{AC}$ solar PV plant developed PLG Photovoltaic Private Limited (PPPL). The Solar PV plant under evaluation is located in Dahisar village, Patan district in Gujarat state. The purpose of this report is to provide a technical appraisal of PV plant under evaluation.

The report focuses on the following key parameters:

- System Design.
- Major Components.
- Engineering Design.
- Independent Solar Resource Assessment and Energy Yield Prediction.
- Plant Operational Analysis and Generation Comparison.
- Permits and Approvals.

This report presents independent technical appraisal of the Project and is based on information made available by the Client through online data room. The main Project characteristic is summarised in Table 1-2.

Figure 1-1 illustrates the project structure indicating key project participants for the 5MW$_{AC}$ solar PV plant.

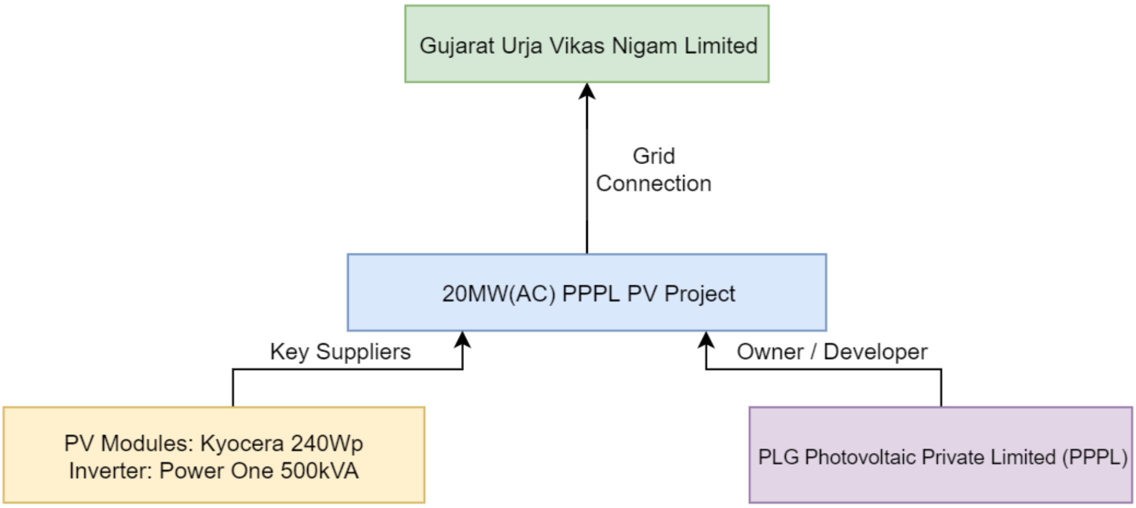

Figure 1-1: Project Structure for 20MW$_{AC}$Solar PV Plant

Table 1-2: Project Key Summary

Project Information	
Project Name	20MW$_{AC}$ PPPL solar PV plant
Location	Dahisar, Patan, Gujarat
Developer	PLG Photovoltaic Private Limited (PPPL)
DC/ AC capacity	20MW$_{AC}$ PV Plant – 20MW$_{P}$ / 20MW$_{AC}$
Key Equipment Manufacturers	PV Modules: Kyocera Inverters: SMA
MMS Configuration	Fixed Tilt: 23°, Azimuth: 0°
Commissioning Status	Commissioning for 20MW$_{AC}$ PV Plant was achieved on 26 January 2012.

2 20MW$_{AC}$ Solar PV Plant Overview

The project site lies around the coordinates 23.922758°N and 71.523231°E. Satellite imageries of 20MW$_{AC}$ solar PV plants are illustrated below in Figure 2-1. The Owner owns approximately 107 acres of land for the project. The Project site is located near the *Dahisar* village, in *Patan* district of Gujarat.

Project is contracted for generating 20MW$_{AC}$ power; SEI therefore interprets 20MW$_{AC}$ as the maximum AC installed capacity for the solar PV plant.

Figure 2-1: Satellite image of 20MW$_{AC}$ plant

2.1 20MW$_{AC}$ Project Summary

Solar PV plant is modular in nature; therefore, PPPL 20MW$_{AC}$ solar PV plants is implemented by adopting modularity in designs. 1MW$_{AC}$ is the typical inverter stations considered for implementing PPPL 20MW$_{AC}$ solar PV plant.

Table 2-1 presents the summary of 20MW$_{AC}$ PV plant

Table 2-1: Summary of 20MW$_{AC}$ Plant Configurations

General	
PV Module Technology	Poly-crystalline
Inverter Technology	Central Inverters
Installed DC Peak Capacity (MW$_p$)	20.0
Installed AC Capacity (MW)	20.0
Mounting Type	Fixed Tilt

General	
Tilt Angle (°)	23°
Pitch (m)	7.2
PV Modules	
PV Module Manufacturer	Kyocera
Model	KD240GH-2PB
Wattage (W_p)	240W_p
Number of Modules per String	24
Inverter	
Inverter Manufacturer / Model	Power-One / PVI-500.0-TL-CN
Inverter Nominal AC Output	500kW
Number of Inverters	40
Mounting Structure	
Mounting Structure Details (rows × columns)	4 × 3
Orientation of Modules	Landscape

The 20MW$_{AC}$ plant is implemented with a total of twenty inverter stations of capacity 1MW$_{AC}$ which comprise of three winding transformers to accommodate 2 × 500kVA inverters, taking the individual inverter station size to 1MW$_{AC}$. Inverter station is comprising of a physical block connecting 1MW$_p$ of installed photovoltaic array.

The output of the 1MW$_{AC}$ inverter stations are combined and connected to two 66/11kV for stepping up the voltage to 66kV. The 66kV output is evacuated at the HT switchyard located in the plant premises.

The power generated by the PPPL 20MW$_{AC}$ PV plant is fed to Gujarat Electricity Transmission Company (GETCO) substation located approximately 0.5km from the Project site. Point of interconnection and utility metering lies within the 20MW$_{AC}$ ZIPL PV Plant premises.

3 Review of Major plant components

SgurrEnergy has conducted a technical review of the supplier and module specification with regards to their suitability for their use in the Projects under evaluation.

3.1.1 Company Profile

Established as Kyoto Ceramic Company Limited in 1959, Kyocera Corporation is a multinational ceramics and electronics manufacturer headquartered in Kyoto, Japan. The company manufacturers industrial ceramics, solar power generating systems, telecommunications equipment, electronic components, semiconductor packages, cutting tools, etc.

With the experience of more than 40 years, Kyocera is a vertically integrated producer and supplier of solar-powered solutions providing services in both developed and developing nations across the globe.[1] According to a report published by GTM Researcher module reliability scorecard in June 2014, Kyocera was the only solar module manufacturer to rank as a performance leader in all six categories in independent testing by PV Evolution Labs.[2]

Kyocera's polycrystalline silicon solar modules were the first in the world to pass all "Long-term Sequential Tests"* performed by TUV Rheinland Japan Ltd. Since its inception, the company has produced more than 8GW of solar power generating equipment.

Kyocera solar have three manufacturing units based in Japan and one in China along with regional offices in U.S.A., Singapore, India, Taiwan, Germany and China.

Few of the commissioned solar power plants using Kyocera modules are listed in Table 3-1.

Table 3-1: Track record of Kyocera Modules

Sr. No.	Project	Capacity (MW)
1	Fushimi-ku, Kyoto city	25.00
2	Yamaguchi Prefecture, Japan	21.10
3	Ichihara city, Chiba Prefecture, Japan	13.40
4	Changshu Dongyang Beverage	3.14
5	Tianjin Toyoda Gosei	2.18
6	Tianjin Qinwei industry, China	2.02
7	Tianjin Fengjin Automobile transmission	1.61
8	Alvarado Water Treatment facility, San Diego	1.20
9	Suzhou Zixiang Electronics, China	1.01
10	PPL Renewable Energy Park, Camden	0.50
11	Gatorade Distribution Facility, Tolleson	0.50
12	Integrity Building Corporation, Mesa	0.02

Kyocera is considered a Tier 1 supplier by Bloomberg (Q1, 2021). A Tier 1 supplier is defined as a module manufacturer who has *'provided products to five different projects,*

[1] https://global.kyocera.com/prdct/solar/spirit/example/industrial.html

[2] https://www.solarelectricsupply.com/solar-panels/kyocera-solar-modules

which have been financed non-recourse by five different (non-development) banks, in the past two years'.

Whilst the Bloomberg tiering system does not reflect on a product's technical or quality aspects, it does provide an indication of acceptability in the marketplace. SgurrEnergy considers Canadian solar to have a strong track record in delivering PV modules to utility-scale projects worldwide).

3.1.1.1 Main Technical Characteristics

The Kyocera KD240GH-2PB modules of 240W$_P$ capacity has been utilized for the project. The 24W$_P$ modules have efficiencies of 16% and power tolerance of +5/-3%. The selected series has a temperature coefficient (Pmax) of -1.10W/°C. This temperature coefficient is in line with SgurrEnergy's expectation for c-Si technology. The technical characteristic of the shortlisted modules is presented in Table 3-2.

Table 3-2: Technical specifications of KD240GH-2PB

Specifications	KD240GH-2PB
Technology	Polycrystalline
Nominal power (P_{MPP})	240W
Voltage at P_{MAX} (V_{MPP})	29.80V
Current at P_{MAX} (I_{MPP})	8.06A
Open circuit voltage (V_{OC})	36.90V
Short circuit current (I_{SC})	8.59A
Efficiency (%)	14.50%
Maximum System Voltage	1,000V
Power tolerance (%)	+5/-3%
Dimensions (length × breadth × width) (mm)	1662 × 990 × 46 mm
Module area (m^2)	1.65m^2
Weight (kg)	21.00kg
Temperature coefficient at P_{MAX} (%/°C)	-0.46%/°C
Maximum reverse current (A)	15A
Operation temperature (°C)	-40°C to +90°C
Maximum mechanical load (N/m^2)	5,400Pa
Product warranty	10 years
Power output guarantee	10/ 20 years
Module technical characteristics are given at STC (1,000W/m^2 irradiance, 25°C module temperature, Air Mass 1.5 according to module manufacturer datasheet)	

Modules have a power tolerance of +5/-3%. The module temperature coefficients are average compared with those typically seen for multi-crystalline silicon modules. The maximum system voltage is 1,000V which is standard and compatible with the Project system design. Maximum mechanical loading specifications is in line with industry norms.

NOCT Characteristics

The nominal operating cell temperature (NOCT)[3] characteristics of selected KD240GH-2PB modules of 240W$_P$ capacity is given in Table 3-3 corresponding to realistic operating conditions as compared to STC. It is affected by module materials used as well as the packing density of module materials. The NOCT for the module is 45°C.

Table 3-3: PV Module NOCT Characteristics of KD240GH-2PB

Model	KD240GH-2PB
Maximum Power (P_{MAX})	172W$_P$
Max Power Voltage (V_{MPP})	26.7V
Max Power Current (I_{MPP})	6.5A
Open Circuit Voltage (V_{OC})	33.7V
Short Circuit Current (I_{SC})	6.9A

3.1.1.2 Certification of Modules

General review of datasheet indicates Kyocera Solar PV modules manufactured in facilities with the following certifications:

- ISO 14001 certification for environmental management systems
- ISO 9001 Certification for quality management systems
- OHSAS 18001 certification for Occupational Health and Safety Management Systems

Further, SgurrEnergy has summarised the certification mentioned in the datasheet of the modules under evaluation within Table 3-4.

Table 3-4: Certification for PV Module- Kyocera Solar Modules

Certification	Description
IEC 61215	Crystalline silicon PV modules – Design qualification and type approval
IEC 61730	PV module safety qualification

It is common for PV modules to hold the design, performance and safety certifications based on IEC prescribed testing methods. However, complete set of certifications of the installed modules was not made available for SgurrEnergy's review. Since the solar PV plant is already operational, SgurrEnergy raises no major concern regarding the unavailability of IEC certifications.

3.1.1.3 Warranty

As is standard within the industry, the specified modules are provided with two forms of warranty; a Limited Product Warranty and a Limited Peak Power Warranty. Both warranties are described further below and start at the earlier of the date of installation or 90 days from the delivery date.

3.1.1.4 Product Warranty

Referring the warranty document provided, SgurrEnergy understands that Kyocera has offered a limited product warranty of 2 years. During this period the modules shall be free

[3] Irradiance = 800W/m^2, Air Mass = 1.5, Ambient temperature = 45±3°C.

from defects in materials and workmanship that affects the performance of the module. If the PV modules fail to conform to the warranty terms, Kyocera will repair or replace the PV modules at it's sole option.

Although the warranty terms are in-line with the industry standard, SgurrEnergy considers two-year product warranty offered by Kyocera to be lower than industry standard of 10-years. Hence, SgurrEnergy suggests getting clarity from the manufacturer on the product warranty period offered for the PV modules used for the Project.

3.1.1.5 Linear Power-Output Warranty

According to the datasheet provided, Kyocera warrants that the nominal power output at the end of 10 years and 20 years of operation shall not be less than 90% and 80% of the minimally specified power under standard test conditions (STC), respectively. However, the power loss of in the first year of operation and degradation in each year thereafter is not mentioned in the datasheet provided. Hence, SgurrEnergy suggests getting clarity from the manufacturer on the first-year degradation and the general degradation of the PV modules used for the Project.

3.2 Inverters

The project has utilized ABB PVS800-57-500kW and Power one PVI-500.0-TL-CN - 500kVA central inverters for the project under evaluation.

3.2.1 Company background- ASEA Brown Boveri (ABB)

ABB is a global leader in power and automation technologies. Based in Zurich, Switzerland, ABB is one of the largest engineering companies as well as one of the largest conglomerates in the world. ABB has operations in around 100 countries, with approximately 147,000 employees[4]. Company reported global revenue of around $34,312 million for 2017.[5]

The firm's shares are traded on the stock exchanges of Zurich, Stockholm, and New York. ABB is a multinational corporation headquartered in Zurich, Switzerland, operating mainly in robotics and power and automation technology.

On July 9, 2019, the Italian company FIMER acquired ABB's solar inverter business. The takeover of ABB's solar inverter business included 800 employees in 26 countries as well as two manufacturing plants, in Italy and in India, and a R&D facility in Finland.

FIMER was founded in 1942, headquartered in Vimercate, Italy, has been actively working in inverter technology since 1983. As of 2020, the company employs more than 1,100 employees across its three manufacturing facilities and three R&D centres across the globe. As a result of acquisition of ABB's PV inverter line, FIMER ranked the fifth-largest PV inverter globally in 2019.

3.2.1.1 Track Record

ABB India commenced local manufacturing of solar inverters in 2012 and partnered with several customers. ABB is the solar inverter market leader in India holding approximately 24% market share in 2018. ABB has approximately 3,590MW in operation across more than 350 sites in India. ABB India manages close to 40% of the installed bases in India. As on 30 August 2017, ABB India crossed the 5GW threshold for the supply of inverters in the country.

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[4] https://new.abb.com/news/detail/26838/abb-to-exit-solar-inverter-business

[5] https://new.abb.com/investorrelations/company-profile/facts-figures

Table 3-5 lists the state-wise installed capacity of ABB inverters in India. However, it is to be noted that the table below doesn't not comprise of the installed capacities till date.

Table 3-5: ABB Inverter Track Record

Location	Capacity (MW)
Punjab	227
Haryana	62
Uttar Pradesh	106
Bihar	225
Rajasthan	371
Madhya Pradesh	271
Chhattisgarh	28
Odisha	20
Andhra Pradesh	647
Maharashtra	261
Tamil Nadu	747
Karnataka	305
Kerala	50

ABB India has strategically located it headquarter in Bangalore and offices other cities Pune, Ahmedabad, Jaipur, Faridabad, Hyderabad, Tamil Nadu, and Bhopal in order to facilitate quick spare part availability and minimal response time. ABB aims to provide first response to its customers within 4 hours on weekdays and within 24 hours on weekends and holidays. ABB also provides a Turn-Around-Time of 48 and 72 hours on weekdays and weekends respectively, hence maintaining an average uptime of over 99%.

3.2.1.2 Technical Characteristics

ABB PV800-57-500kW inverter has been selected for technical feasibility of the Project. The technical specification of 500kW ABB inverter is listed in Table 3-6.

The PV800-57-500kW Series of central inverters designed ideal for large PV Power Plants. These inverters are designed to operate with DC inputs up to 1,100 V PV800-57-500kW inverter is designed for outdoor use with an IP42 ingress protection class. They perform optimally at ambient air temperatures between -15°C to 50°C and relative humidity in the range of 15% to 95% with maximum noise level of less than 75dBA.

The PV800-57-500kW inverter has peak efficiency of 98.6% and a European efficiency of 98.2%.

The main technical characteristics of these inverters are illustrated in Table 3-6.

Table 3-6: ABB inverter specifications

ABB Central Inverter Specifications	
Inverter	PV800-57-500kW
Type	Central Inverter
Input Data	
PV voltage range, MPP (V)	450 to 825V
Maximum DC voltage (V)	1,100V

ABB Central Inverter Specifications	
Maximum input current (A)	1,145A
Output Data	
Nominal AC power (kW)	500kW
Maximum AC current (A)	965A
Nominal AC voltage (V)	300V
AC grid frequency (Hz)	50/60Hz
Maximum THD	< 3%
Operating Performance	
Maximum efficiency (%)	98.60%
Euro efficiency (%)	98.20%
Power consumption	
Own consumption in operation (W)	490W
Standby operation consumption (W)	65W
Other	
Dimensions (W × H × D) (mm)	2630mm x 2130mm x 708mm
Weight (kg)	1800kg
Environmental Protection Rating	IP42
Operating temperature range (°C)	-15 to +50°C
Relative humidity (%)	15% to 95%

The following protection devices are included within the inverter design:

- Ground fault monitoring
- Grid Monitoring
- Anti-islanding protection
- DC reverse-polarity protection
- AC and DC short circuit and over current protection
- AC and DC over voltage and temperature protection

ABB inverters comprise of suitable protection devices in place on both the DC and AC side to protect the PV system and inverter components.

3.2.1.3 Certification

ABB is certified to the internationally recognised standard for management systems and according to ISO 9001 that they conform to the latest quality standards.

Inverter reliability is further enhanced via stringent quality control procedures. ABB inverter manufacturing facilities operate with the following certifications:

- ISO 9001:2015 Quality Certificate
- ISO 14001:2015 Environmental Certificate
- OHSAS 18001 Health and Safety Management System

Based on information available in public domain, SgurrEnergy has summarized the certification of the ABB inverter within Table 3-7.

Table 3-7: Description of Certification of ABB inverters

Certification	Description
IEC 60068-2-6/29	Environmental testing of inverters to assess their ability to perform and survive under conditions such as transportation, storage, operational environments, extreme cold and heat
IEC 61683:1999	Procedure for measuring efficiency
IEC 62109-2:2011	Safety of Power Converters
IEC 62116:2014	Islanding prevention measures

3.2.1.4 Warranties

According to the warranty documents provided, ABB has offered the inverter warranty of 60 months from commissioning of last inverter or 63 months from the date of supply of last inverter, whichever is earlier. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards and do not raise any concern over the use of inverter for the project.

3.2.2 Company background- Power-one

Founded in Chatsworth, California, in 1972 as an AC/DC power supplies manufacturer, Power-one was incorporated in late 1970s and shifted its headquarters to Camarillo. Power-one was one of the leading providers of renewable energy and energy-efficient power conversion and power management solutions and a leading designer and manufacturer of photovoltaic inverters, in the late 1990s.

The company provided services in sales, manufacturing, and R&D across Asia, Europe, and the Americas. In addition to its manufacturing units in Dominican Republic and Mexico, the company also had research and development centre in Limerick, Ireland.[6] In 2013, Power-one had over 40-years of experience of providing services for variety of industries including renewable energy, servers, storage and networking, industrial and network power systems, etc. In 2012, Power-one employed nearly 3,300 people, mainly in China, Italy, the USA and Slovakia and generated USD120million in earnings.

However, due to poor business conditions at the start of the 21st century, the company suffered significant losses. On April 22, 2013, the ABB acquired Power-one's solar inverter business.

ABB is a global leader in power and automation technologies. Based in Zurich, Switzerland, ABB is one of the largest engineering companies as well as one of the largest conglomerates in the world. ABB has operations in around 100 countries, with approximately 147,000 employees[7]. Company reported global revenue of around $34,312 million for 2017.[8]

3.2.2.1 Track Record

Table 3-5 lists the state-wise installed capacity of Power-one (ABB) inverters in India. However, it is to be noted that the table below doesn't not comprise of the installed capacities till date.

Table 3-8: Power-one (ABB) Inverter Track Record

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[6] https://www.encyclopedia.com/books/politics-and-business-magazines/power-one-inc

[7] https://new.abb.com/news/detail/26838/abb-to-exit-solar-inverter-business

[8] https://new.abb.com/investorrelations/company-profile/facts-figures

Location	Capacity (MW)
Punjab	227
Haryana	62
Uttar Pradesh	106
Bihar	225
Rajasthan	371
Madhya Pradesh	271
Chhattisgarh	28
Odisha	20
Andhra Pradesh	647
Maharashtra	261
Tamil Nadu	747
Karnataka	305
Kerala	50

3.2.2.2 Technical Characteristics

Power-one PVI-500.0-TL-CN inverter has been selected for technical feasibility of the Project. The technical specification of 500kW Power One inverter is listed in Table 3-6.

The PVI-500.0-TL-CN -500kVA Series of central inverters designed ideal for large PV Power Plants. These inverters are designed to operate with DC inputs up to 1,000 V. PVI-500.0-TL-CN -500kVA inverter is designed for outdoor use with an IP20 ingress protection class. They perform optimally at ambient air temperatures between -20°C to 55°C and relative humidity in the range of 0% to 95% with maximum noise level of less than 62dBA.

The PVI-500.0-TL-CN -500kVA inverter has peak efficiency of 98.5% and a European efficiency of 98.2%.

The main technical characteristics of these inverters are illustrated in Table 3-6.

Table 3-9: Power-one inverter specifications

ABB Central Inverter Specifications	
Inverter	PVI-500.0-TL-CN -500kVA
Type	Central Inverter
Input Data	
PV voltage range, MPP (V)	475 to 900V
Maximum DC voltage (V)	1,000V
Maximum input current (A)	1,100A
Output Data	
Nominal AC power (kW)	500kW
Maximum AC current (A)	900A
AC voltage range (V)	272 to 352V
AC grid frequency (Hz)	50Hz±5%
Maximum THD	< 4%

ABB Central Inverter Specifications	
Operating Performance	
Maximum efficiency (%)	98.50%
Euro efficiency (%)	98.20%
Power consumption	
Night-time power loss (W)	<66W
Standby operation consumption (W)	<66W
Other	
Dimensions (W × H × D) (mm)	2280mm x 2000mm x 800mm
Weight (kg)	<1400kg
Environmental Protection Rating	IP20
Operating temperature range (°C)	-20 to+55°C
Relative humidity (%)	0% to 95%

The following protection devices are included within the inverter design:

- Anti-islanding protection
- Reverse polarity protection
- AC and DC short circuit and over current protection
- AC and DC over voltage and temperature protection

Power-one inverters comprise of suitable protection devices in place on both the DC and AC side to protect the PV system and inverter components.

3.2.2.3 Certification

Power-one is certified to the internationally recognised standard for management systems and according to ISO 9001 that they conform to the latest quality standards.

Inverter reliability is further enhanced via stringent quality control procedures. Power-one inverter manufacturing facilities operate with the following certifications:

- ISO 9001:2015 Quality Certificate
- ISO 14001:2015 Environmental Certificate
- OHSAS 18001 Health and Safety Management System

Based on information available in public domain, SgurrEnergy has summarized the certification of the Power-one inverter within Table 3-7.

Table 3-10: Description of Certification of Power-one inverters

Certification	Description
IEC 61000-6-2	Electromagnetic compatibility
IEC 62109-2:2011	Safety of Power Converters
IEC 62116:2014	Islanding prevention measures

3.2.2.4 Warranties

According to the warranty documents available on public domain[9], the standard warranty offered by Power-one for central is for a period of 66 months from the date of invoice. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards and do not raise any concern over the use of inverter for the project.

3.3 Transformers- Voltamp Transformers Ltd.

The solar PV plant is implemented with two level transformation. Power at low voltage from inverters is stepped up to 11kV using 1250kVA transformers of Voltamp make inverter transformers, and further to 66kV using 12.5MVA power transformer manufactured by Voltamp.

3.3.1 Company Profile

The inverter transformer used is manufactured by Voltamp Transformers limited (Voltamp).

Voltamp was founded in 1963 in Vadodara, Gujarat and now has a PAN India presence. The company initially started off by manufacturing small transformers by 1975 the largest transformer manufactured was for 132kV networks. This limit rose to 220kV class of transformers in 2008. The company employs more than 300 personnel (including 60 engineers) and has branch offices in Mumbai, New Delhi, Chennai, Bangalore, Secundrabad, Pune, Bhubaneshwar, etc.

The company has four manufacturing plants and the current manufacturing capacity totals to 13000 MVA per year. These facilities boast of manufacturing Oil filled Power and Distribution Transformers up to 160MVA, 220kV. The company got its ISO 9001 certification in 1998 and was listed on the NSE and BSE stock exchange in 2006.

Notable designs include:

- 75MVA 11/138kv GT
- 20MVA 33-22/11kV (DZ10)
- 50MVA 132-110/33kV transformer
- 6 MVA 1-ph transformer
- 15MVA 11/1.3-1.3kV (24 pulse)
- 100MVA 22kV

The company also manufacturers two types of dry transformers, i.e. resin impregnated (25KVA-5000KVA up to 11kV) and cast resin transformers (50kVA-12500kVA up to 33kV). Prominent clients include ABB, Exide, Adani, BHEL, BPCL, Suzlon etc.

3.3.2 Technical Specifications

The 1250kVA rated Inverter transformers and 12.5MVA rated Power transformers, used in the project are outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

SgurrEnergy is satisfied that the transformer has been designed to adhere local and country specific grid codes and relevant IS codes (IS-2026). The transformer technical characteristics are presented in Table 3-11.

[9] https://www.renvu.com/site/downloads/Power-One%20Aurora%20Warranty%20Services%20Description%20for%20String%20Inverters%20for%20RENVU.pdf

Table 3-11: Technical Specification of Voltamp Transformer

Technical Parameters	Description	
Rated Power	1250kVA	12.5MVA
Rated HV	11kV	66kV
Rated LV	2*0.625kV	11kV
Tapping on HV	+10% to -10% (steps of 2.5%)	+12.5% to -12.5% (steps of 1.5625%)
Phases	3	
Frequency	50Hz	
Vector group	Dyn11yn11	Dyn11
Impedance	4.9%	10%
Cooling Strategy	ONAN	
Oil temperature rise	50°C	
Winding temperature rise	55°C	
Winding material	Electrolytic Copper	

SgurrEnergy considers the overall the technical specification to be adequate for the PV projects and in line with the industry accepted standards.

3.3.3 Temperature Rise Detection and Protection

Inverter transformers and Power transformers have been provided with standard temperature sensing systems. These comprise of an analogue oil temperature indicating (OTI) unit and winding temperature indicating (WTI) unit. Both the units have been adequately provided with alarm/trip contacts and wired to relay units located at HT panel.

The transformers are adequately provided with the Buchholz Relay that essentially serves as a critical protective device in case of excessive gas pressure released in the event of higher transformer loadings and faults.

3.3.4 Warranties and Guaranties

Based on the review of the standard warranty certificate sourced from public domain, SgurrEnergy understands the Voltamp transformers are provided with a warranty of 60 months from date of dispatch. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards.

3.4 Conclusion on Major Plant Components

PV Modules

According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of Kyocera Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard.

Further, according to the warranty documents available in public domain for the module manufacturer, SgurrEnergy considers the warranty terms and conditions offered by Kyocera to be in-line with the industry standard and raises no major concern regarding the warranties offered. However, SgurrEnergy suggests getting clarity on the limited product warranty, first-year degradation and general degradation offered by the manufacturer for the PV modules used for the project.

Referring the datasheet provided, SgurrEnergy observed that the Kyocera PV modules used for the project are IEC 61215 and IEC 61730 certified, which is in-line with the industry standard. In conclusion, SgurrEnergy does not raise any major concerns about the modules used in the project.

Inverters

SgurrEnergy has conducted review of the ABB's PV800-57-500kW and Power-one's PVI-500.0-TL-CN -500kVA central inverter. Both the central inverter makes have the required certification for use in solar PV plants. The technical characteristics of both the inverters are in-line with the industry standard. ABB and Power-one offer a product warrant of 63 and 66 months, respectively, which is in line with the current industry standards.

In conclusion, ABB and Power-one can be considered as established and reputable inverter manufacturers and are known for producing good quality and high-performance inverters. SgurrEnergy raises no major concern in the utilization of ABB and Power-one inverters for the project.

Transformers

The inverter transformers (1250kVA) and power transformer (12.5MVA) used within the project are manufactured by Voltamp. The manufacturers have good track record of supplying transformers for solar application throughout the world. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

3.5 Module support structures

The Array Layout provided by the Client for the 20MW(AC) PLG Solar PV Plant indicates the fixed tilt module mounting structure is inclined at 23° tilt angle.

Although the as-built MMS GA drawing for the 20MW$_{AC}$ PLG Solar PV Plant site has not been provided for review. Material used for MMS member, type of foundation and details provided for MMS is unavailable for review. The general arrangement is as shown in below figure.

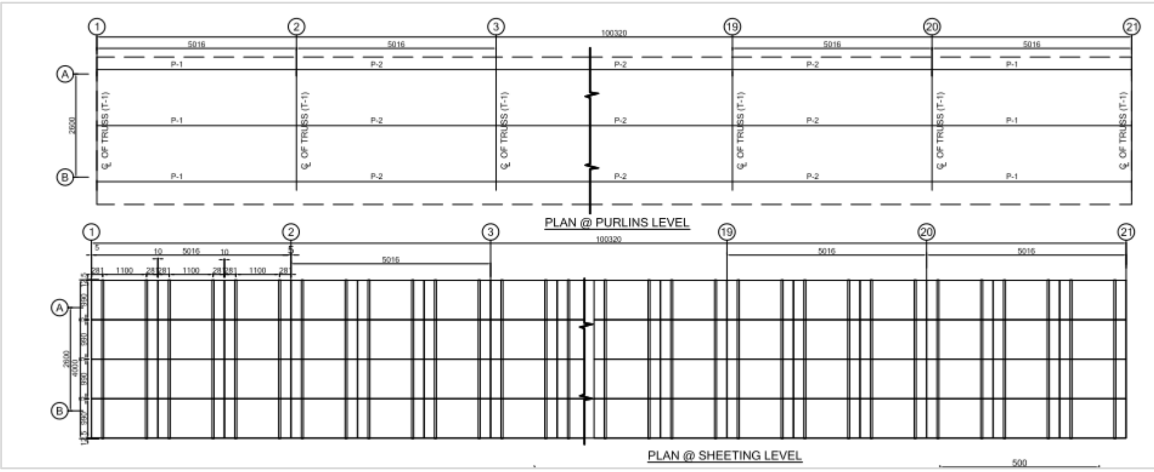

Figure 3-1: MMS General Arrangement

4 Allied Components and Systems

4.1 Civil Structures

Based on the review of Plant layout, SgurrEnergy observed that the inverter stations are placed at centre of each block module to minimise cable losses.

4.2 PV Power Transfer

SgurrEnergy has gone through the electrical schematic provided by the Client. The electrical schematic describes the overall connection of the PV modules, inverters, transformers, switchgear, and plant substation as well as providing the ratings of all the components.

SgurrEnergy has been provided with the following electrical schematic for the Project.

- *AC side electrical SLD of Solar plant-R2*.
- *Typical DC SLD for 500kW$_p$ PV unit-R2.*

The 20MW$_{AC}$ solar PV Plant is designed with 240W$_p$ *Kyocera* make solar PV modules and 500kW *Power one* make central inverters. PV modules are interconnected in series to form a string of 24 modules; eight such strings are further connected to 8 input string combiner boxes as inputs. The output of seven string combiner boxes is further connected to central inverter.

The 20MW$_{AC}$ solar PV plant has been configured with 40 *Power one* make 500kW central inverters and 20 inverter stations. Each inverter station comprises of one three winding inverter duty transformers (IDT) to accommodate two 500kW inverters. The inverter duty transformer is connected with two Inverters, taking the individual inverter station size to 1MW$_{AC}$. Inverter station comprises of a physical block connecting to 1MW$_p$ of installed photovoltaic array. The output of 500kW inverters are connected to 1.25MVA, 11/0.320-0.320kV, ONAN three winding transformer for stepping up the voltage to 11kV.

The medium voltage output from inverter duty transformer is connected with 11kV RMU (Ring Main Unit) panel placed at inverter station. The five such 11kV RMU (Ring Main Unit) panels are connected in ring philosophy and connected with 11kV switchgear panel located in control room. The 11kV output from main MV Switchgear panel shall be further connected to 11/66kV switchyard.

Power from 66kV switchyard is evacuated to the grid substation at 66kV voltage level via 0.5km overhead transmission line; however the switchyard details is not provided to SgurrEnergy.

Figure below illustrates a power flow summary for the 20MW$_{AC}$ Solar PV plant.

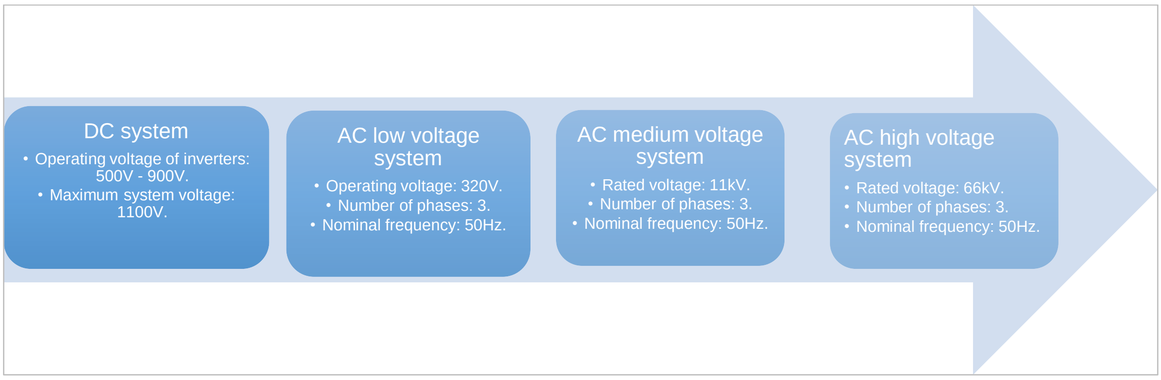

Figure 4-1: Power flow of 20MW$_{AC}$ PV plant

4.3 Cabling

4.3.1 DC Cabling

DC cabling comprises of PV module leads, string cables connecting the PV module strings to combiner box and main DC cables connecting the combiner box to the inverter fuse and then to the inverter. Modules are interconnected in series with 4mm^2 solar grade cables. PV modules are interconnected in daisy chain scheme to form a string of 24 PV modules connected in series. Single core 4mm^2 multi-stranded copper PV cables connect string output to String Combiner Box (SCB).

These combiner boxes are equipped with 25A fuse for each of the string connection. Power from string combiner box is further transferred to the inverter using 2C, 95mm^2, 1.1kV aluminium XLPE cables.

4.3.2 AC Cabling

Three phase AC output from inverter is connected to the LV winding of a 1.25MVA three-winding transformers using 3C, 300mm^2 Aluminium Armoured XLPE cable. The inverter transformers step up the voltage to 11kV.

The inverter duty transformer output is connected to 11kV RMU panel located in inverter station 3C, 300mm^2, 11kV Al XLPE armoured cable. The five such RMU panels are interconnected in ring philosophy using 3C, 300mm^2, 11kV Al XLPE armoured cables.

The 11kV output from RMU panels is transmitted to 11kV switchgear panel located in main control room using 3C, 300mm^2, 11kV Al XLPE armoured cables.

The power from the Main switchgear panel is transferred to 11/66kV outdoor switchyard using 3R of 3C, 300mm^2, 11kV Al XLPE armoured cable. Further the output power of 11/66kV Switchyard is transferred to GSS.

4.4 Inverter Station

The 20MW$_{AC}$ solar PV plant has been configured with 40 inverters and 20 inverter stations. Each inverter station is of 1MW$_{AC}$ capacity consist of two 500kW inverters and one 1.25MVA inverter duty transformer.

The 1MW$_{AC}$ inverter station consists of two inverters connected to 1.25MVA, 11/0.320-0.320kV, three winding transformers. The inverter duty transformer steps up the voltage to 11kV for all inverter stations. Further the power from the HV side of the transformer is fed to the 11kV RMU panel through underground cable.

The 11kV RMU panel comprises of 100/1A current transformer, 630A SF6/VCB Circuit Breaker, two 630A load break switches and other electrical protection system. The power from inverter duty transformer is transferred to aforesaid RMU panel.

4.5 LV/MV Transformers

SgurrEnergy has reviewed the SLD and observed that 1.25MVA, 11kV/2x0.320kV, Dyn11yn11 three winding transformers have been used in the project. These inverter duty transformers step up the voltage to 11kV.

The 1.25MVA inverter duty transformers output is connected to 11kV RMU panels located within inverter station. The energy from 11kV RMU panels of five Inverter stations is connected in ring philosophy. The combined 5MW power from five Inverter Stations is transmitted to 11kV switchgear over ring philosophy which located within main control room.

4.6 11kV RMU Panel

The 11kV RMU panel comprises of inverter duty transformer incoming feeder, inverter station RMU panel incoming feeder and one outgoing feeder to nearest inverter station RMU panel or 11kV switchgear panel located in main control room. Each RMU panel comprises of 100/1A current transformer, 630A SF6/VCB Circuit Breaker, two 630A load break switches and other electrical protection system.

4.7 11kV Switchgear Panel

The 11kV main switchgear panels outgoing and incoming feeders are provided with instrument transformers for protection and metering system, VCB for isolation/protection. The Class 1.0 instrument transformers for metering and class 5P10 instrument transformers for protection have been considered.

Power from 11kV switchgear panel is transmitted to 11/66kV outdoor Switchyard. Further power from 66kV Switchyard is transferred to GSS.

4.8 Auxiliary Power Supply

SgurrEnergy had reviewed the electrical schematics shared for the projects to evaluate auxiliary system. One 100kVA, 11/0.430kV auxiliary transformer for control room and two, 5kVA, 320/415V auxiliary transformers have been considered to cater the auxiliary loads. ACDB panels have been considered at main control room and inverter stations.

4.9 Circuit Breakers

Circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal and abnormal circuit conditions. The circuit breakers are three poles type with electrically and mechanically operated trip-free with anti-pumping facility suitable for remote electrical closing and tripping. The circuit breakers are mounted within the panels as well as on individual structures.

Following the review of 11kV SLD, SgurrEnergy observed 11kV, 630A and 1250A, 25kA/1sec SF6/VCB type circuit breaker has been used in the project.

4.10 Load break switch

Load break switches are used to isolate the equipment during load condition for maintenance.

Based on the review of 11kV SLD, SgurrEnergy observed 11kV, 630A load break switches switch has been used in the project.

4.11 Instrument Transformers

Current transformers (CT) and voltage/potential transformers (VT) are known to be as instrument transformers. Instrument transformers are devices used to transform the values of current and voltage in the primary system to values suitable for the measuring instruments, meters, protective relays, etc.

The current transformers with accuracy class of 1.0 for metering and class 5P10 for protection has been used in 20MW$_{AC}$ solar PV plant.

4.12 Surge Arrestors and Lightning Arresters

The substation equipment has to be protected against travelling waves due to lightning strokes and switching surges from incoming lines. The apparatus most commonly used for this purpose is the surge arrester. Transformer is the costliest equipment in substation, and it is normal practice to install surge arrester near to the transformer. Additional surge arresters shall be provided either on bus or on various lines for protection of the equipment.

Following the review, SgurrEnergy observed that surge arrester has not been provided fro 11kV system.

4.13 Metering

In addition to the metering and monitoring arrangement in inverters, monitoring of voltage, current and energy will be provided at the medium voltage switchboards for each of the feeder sections. These meters will be digital with an RS 485 port for remote monitoring. These usually have an accuracy class of 0.5.

Similarly, HV side shall also be equipped with voltage, current, power and energy meters in order to correlate the energy generation and losses. Class of meters at the evacuation point shall be 0.2S. However, SgurrEnergy has not provided with 11/66kV switchyard SLD and metering details.

5 System Design Appraisal

SgurrEnergy has performed a detailed analysis to evaluate the string sizing and compatibility of the inverters with PV modules used for the Project. The following sections discuss the results obtained from the analysis.

5.1 Plant Layout Design

SgurrEnergy was provided with as built plant layout and electrical schematics. SgurrEnergy has verified the plant configuration with electrical schematics provided by the Client. The PV plant is designed with Kyocera 240Wp PV modules. The total DC installed capacity stands at 20MW$_p$. The AC installed capacity stands at 20MW$_{AC}$ with 40 inverters of capacity 500kW each. The 20MW$_{AC}$ PV plant is illustrated below in the Figure 5-1.

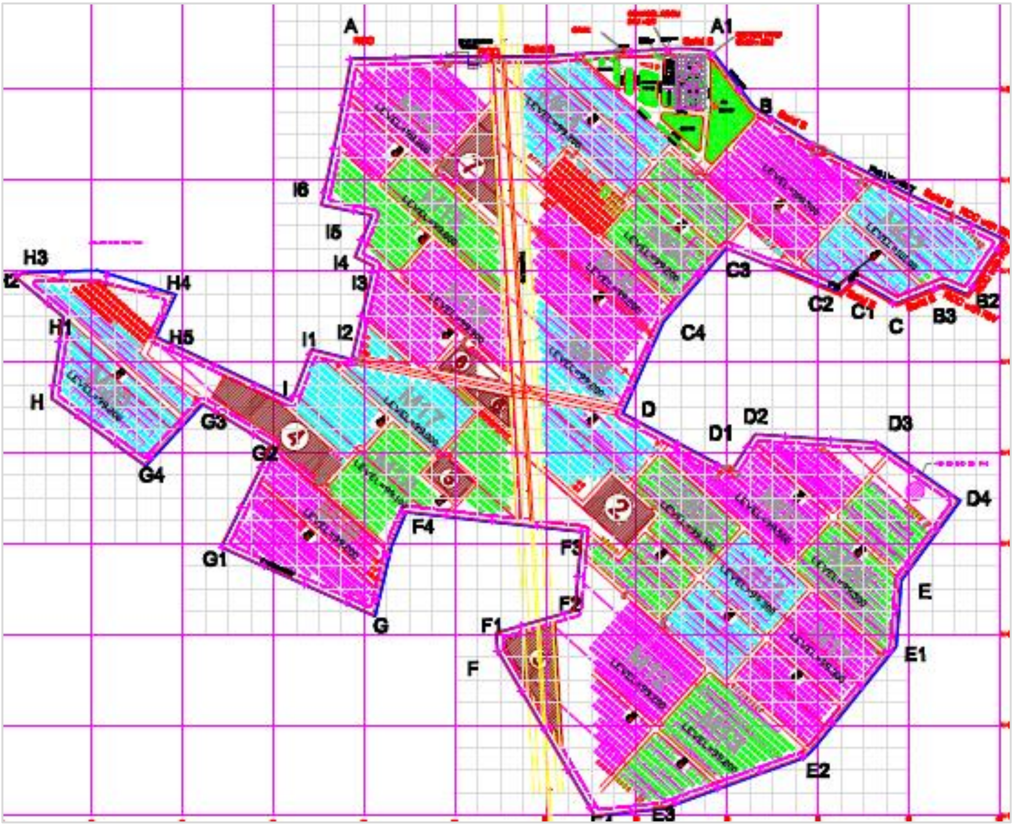

Figure 5-1: Plant layout

All the PV modules are orientated towards South. The selected tilt for the 20MW$_{AC}$ plant is 23°. The 20MW$_{AC}$ plant is designed with a pitch of 7.00m.

24 modules are connected in series to form a string. The nominal plant power ratio (DC to AC) of the Project is 1.01. Typically, PV plants are designed to have a nominal power ratio upto 1.50 in India; a higher ratio leads to greater overload losses during peak irradiance conditions. However, PV module temperature losses are substantial at the high ambient temperatures corresponding to the higher nominal power ratio.

5.2 String Sizing

The plant layout provided by the Owner indicate twenty four 240 W$_p$ polycrystalline PV modules to be connected in series to form a string for the plant.

As the string voltage is dependent on temperature and irradiation, open circuit voltage (V$_{OC}$) of the string must be corrected using the temperature co-efficient for the PV modules. Therefore, it becomes necessary to ensure that the maximum voltage input (i.e. the maximum V$_{OC}$ of string at minimum temperature) to inverter does not exceed the inverter maximum operating D.C voltage and hence is a critical value considered by SgurrEnergy in validating string configuration. Subsequent to calculating open circuit voltage (V_{OC} max), maximum power voltage (V_{mp} min) is calculated to ensure that it is within the maximum power point (MPP) range of the implemented inverters.

SgurrEnergy considers the maximum and minimum ambient temperature of 45°C and 10°C respectively for system design validation to be fair and representative for the PV plants' site.

The results of string sizing validation are presented in Table 5-1. Results indicate that V_{OC} max at the minimum ambient temperature is within the maximum system voltage of 1,000V for the selected Power One 500kW inverters.

Table 5-1: String Sizing for Kyocera PV Modules

Parameters	Kyocera 240W$_p$
PV module power (W$_p$)	240
Modules per string	24
Inverters	Power One PVI 500TL
Maximum Open-circuit voltage (V_{OC} max) at minimum ambient temperature of 10°C	861.6
Minimum power voltage (V_{mp} min) at maximum ambient temperature of 45°C	650.4

5.3 Inverter Compatibility

SgurrEnergy performed a detailed analysis on plant sizing to assess the compatibility of inverters with the PV modules used in the projects. The electrical design compatibility summary with Kyocera and Power One inverter are presented in Table 5-2.

Table 5-2: Inverter Compatibility with Kyocera 240W$_p$ Modules

Parameters	Inverter Compatibility	
PV module	**Kyocera 240**	
Modules per string	24	Acceptable
Strings per inverter	87	Acceptable
Maximum power, P_{mpp} at STC (kWp)	505	Nominal power ratio is 1.01, this is within the inverter bus current carrying capacity.
Maximum power voltage, V_{mpp} at STC (V)	715.2	Acceptable.
Maximum power current, I_{mpp} at STC (A)	902.72	Acceptable
Open-circuit voltage, V_{oc} at STC (V)	885.6	Acceptable.
Minimum MPP voltage at 45ºC ambient temperature (V)	650.4	Acceptable: Inverter MPPT ranges 475 -900V.
Maximum MPP voltage at 10ºC ambient temperature (V)	734.4	Acceptable: Inverter MPPT ranges 475 -900V.
Maximum open circuit voltage, V_{oc} at 10ºC (V)	861.6	Acceptable: Maximum inverter voltage 1000V.

Overall, SgurrEnergy does not raise any concerns regarding the string sizing and inverter compatibility.

6 Resource assessment

The accuracy of any solar energy yield prediction is heavily dependent on the accuracy of the solar resource dataset used. Solar irradiation data is currently not being measured at the location of the proposed power plant and it is therefore necessary to use alternative data sources to obtain estimates of the irradiation figures for the site.

The solar resource of a location may be defined by values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation is the total solar energy received on a unit area of horizontal surface. It includes energy received from the sun in a direct beam and energy that is received from radiation scattered off the atmosphere arriving from all directions of the sky (diffuse irradiation). The units of GHI are given in kWh/m2. Values are often provided for a period of a day, a month or a year.

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the energy received from radiation scattered off the atmosphere arriving from all directions of the sky on a unit area of horizontal surface. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the total solar energy received on a unit area of surface *directly facing the sun at all times*. The units of DNI are kWh/m^2. The direct normal irradiation is of particular interest for solar installations that track the sun and to concentrating solar technologies as only radiation coming directly from the sun may be focussed by a lens or mirror.

For modelling of solar PV plants, GHI and DHI are required for calculating the estimated energy yield. In the northern hemisphere, tilting the modules at an angle towards the south increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations.

Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo. Albedo and global tilted irradiation are described below.

Global Tilted Irradiation (GTI) – The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m^2. A transposition model is used for translating horizontal irradiation to tilted irradiation within PV modelling software.

Albedo – The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

Comparison of Resource Data

There are a variety of possible solar irradiation data sources that may be accessed. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite imagery. A minimum of 10 years of data is recommended to allow for the expected variability of resource data between years. SEI has sourced monthly horizontal plane irradiation data for the Project site from:

- ***NASA****'s Surface Meteorology and Solar Energy data set;* holds satellite derived monthly data for a grid of 0.5° × 0.5° covering the globe for a thirty-four-year period (1984-2017). The data are suitable for pre-feasibility studies of solar energy projects.

- *The* ***METEONORM (version 7.2)*** *global climatological database and synthetic weather generator;* contains a database of ground station measurements of irradiation and temperature. Where a site is over 11km from the nearest measurement station it outputs climatologic averages estimated using interpolation algorithms. Where no radiation measurement station is within 300km from the site, satellite information is used. If the site is between 50 and 300km from a measurement station a mixture of ground and satellite information is used. The accuracy of irradiation figures close to measurement stations are within a few percent. Uncertainty increases with distance between the site and the measurement station, especially in hilly and mountainous terrain.
- **SolarGIS:** SolarGIS is developed and operated by GeoModel a solar company maintaining databases of climate data to support solar energy projects and systems. Database is derived from Meteosat and Geostationary Operational Environmental Satellite system (GOES) satellite data and atmospheric parameters (aerosol and water vapour) using high performance algorithms. SolarGIS regional coverage includes Europe, Africa, Asia and parts of South America and Australia. The spatial resolution of primary parameters for European region is approximately 4km × 4km with a temporal resolution of between 15 minutes to 3 hours. SolarGIS radiation models use multispectral channels and multi-dimensional statistical treatment of ground albedo, daily values of aerosol and water vapour. SolarGIS models is validated by *IEA (International Energy Agency) SHC Collaboration Agreement, and EU FP6 project MESoR* in terms of bias and RMSE.
- **Solar and Wind Energy Resource Assessment (*SWERA)* / National Renewable Energy Laboratory *(NREL)*** data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground-based data to ensure quality of the measurements.

SEI has compared the irradiation datasets given by NASA - SSE, Meteonorm 7, SolarGIS and, NREL (SWERA) data for the site. The comparison is graphically illustrated Table6-1

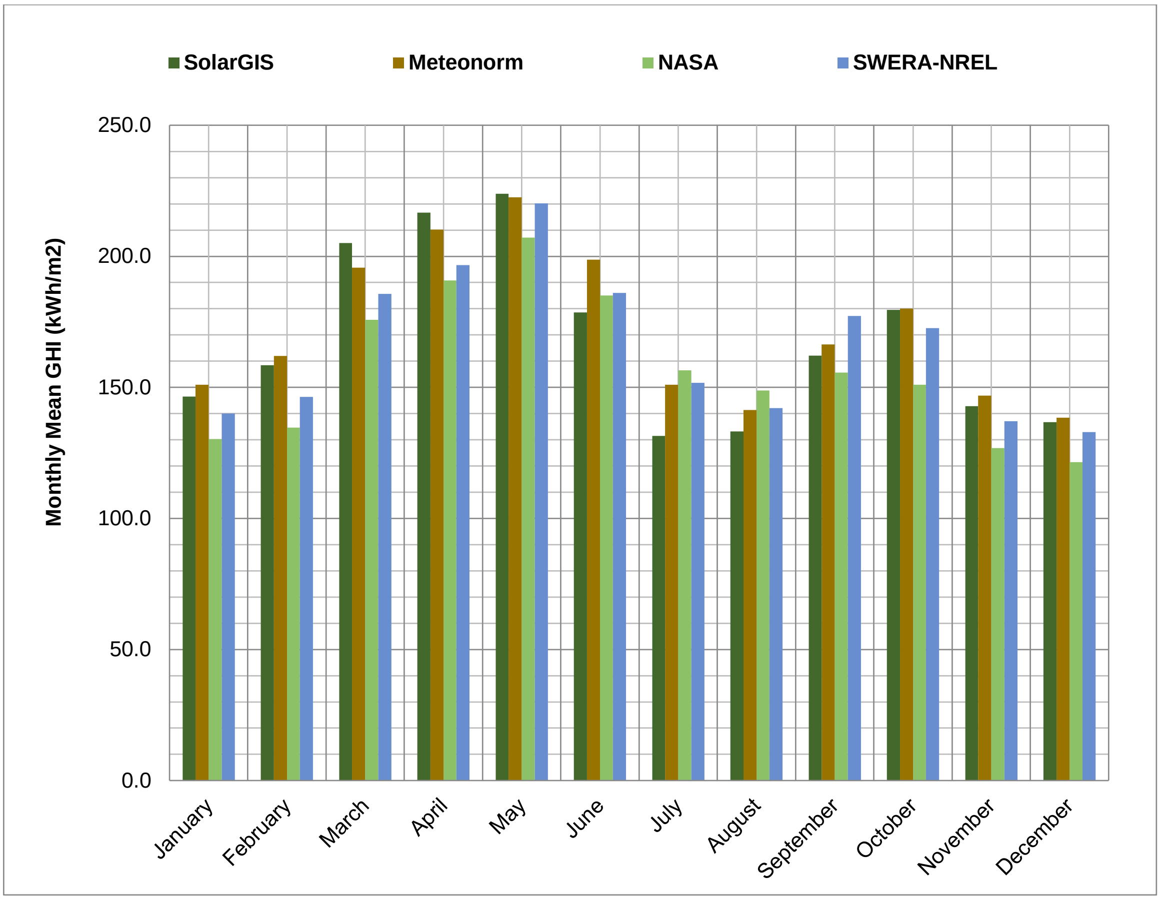

Figure 6-1: Monthly Global Horizontal Irradiation

Table6-1: Comparison of Solar Irradiation Datasets for the site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m²/annual)
SolarGIS	4km × 4km	3.9%	2,015.0
Meteonorm 7.2	14km × 14km	4.0%	2,064.1
NASA	55km × 55km	Unknown	1,864.1
NREL (SWERA)	40km × 40km	Unknown	1,988.5

The comparison of solar data for Project site location illustrated in Table6-1 indicates Meteonorm 7.2 dataset to give the highest irradiation levels. The next highest irradiation is given by SolarGIS followed by NREL (SWERA) and NASA.

The irradiation values given by Meteonorm 7.2 typically provide a combination of ground and satellite measured data. Meteonorm 7.2 has interpolated the data using satellite data for the proposed site. Uncertainty of satellite data is obtained as 6.8% for the proposed site.

The NREL (SWERA) data illustrated has been obtained for a location approximately 8.76 km away from the proposed site. SgurrEnergy performed iteration on an extensive list of NREL (SWERA) datasets to obtain appropriate coordinates that lie within the Indian boundaries. The results give only irradiation data without temperature and wind data.

The NASA-SSE data source provides purely satellite measured data for a grid covering 0.5° × 0.5° on the earth's surface and generally more suited for initial site selection.

The SolarGIS dataset has been compared with good quality ground measurements for more than 200 sites. The resulted mean bias for GHI is 0%. SolarGIS data base has also been compared with other data sources globally. The IEA (International Energy Agency) validation study conducted by University of Geneva in 2011 has resulted in SolarGIS to be the best performing database among five satellite databases. Similar IEA validation study was repeated in 2013 by University of Geneva which again resulted in SolarGIS to be the best performing database among six satellite databases. Validation study in 2013 was conducted using 18 validation sites in Europe and Mediterranean regions. Furthermore, SolarGIS has conducted its own validation for six Indian locations[10] with the following bias in GHI;

- Pantnagar (Uttarakhand)
- Kanpur (Uttar Pradesh)
- Mysore (Karnataka)
- Warangal (Telangana)
- Jaipur (Rajasthan)
- Ranchi (Jharkhand)

Comparative analysis of all the data sets available, indicate SolarGIS has been validated for India. Furthermore, SolarGIS dataset is based on the most recent long-term average that is from 1999 – 2015, while Meteonorm dataset is based on the time-period of 1991 - 2010. The uncertainty of SolarGIS is 3.9% while that of Meteonorm is 6%.

SEI is therefore of the opinion that SolarGIS dataset may be considered reasonable and a representative data source for conducting an energy yield assessment for the project location.

6.1 Global, Direct and Diffuse Irradiation on a Horizontal Plane

Horizontal plane irradiation data based on long-term monthly averages are presented in Table 6-2 and shown graphically in Figure 6-2 Diffuse irradiation accounts for 41.31% of the total irradiation. Table 6-2 illustrates direct and diffuse daily irradiation on a horizontal plane for the proposed site. SolarGIS irradiation data is presented in Table 6-2.

Table 6-2: SolarGIS Irradiation Data for the Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	146.5	44.6	7.3%
February	158.4	45.6	7.9%
March	205.1	65.4	10.2%
April	216.7	77.4	10.8%
May	223.9	92.4	11.1%
June	178.6	96.6	8.9%
July	131.5	93.6	6.5%
August	133.2	90.2	6.6%
September	162.1	76.8	8.0%

[10] https://solargis.com/docs/accuracy-and-comparisons/overview/

Month	Monthly GHI (kWh/m²)	Monthly Diffuse (kWh/m²)	Proportion of GHI to Annual
October	179.5	55.2	8.9%
November	142.8	49.8	7.1%
December	136.7	44.6	6.8%
Annual Sum	**2,015.0**	**832.3**	**-**

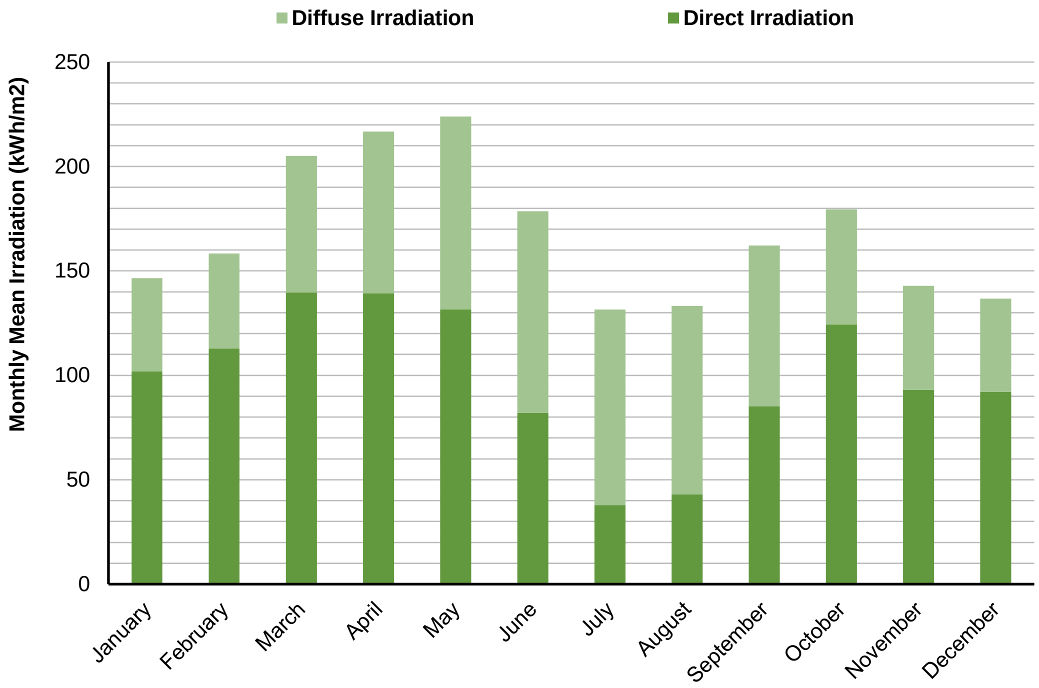

Figure 6-2: Monthly Direct and Diffuse Irradiation on a horizontal plane for the project site

6.2 Global Tilted Irradiation

Industry standard PV modelling software PVsyst (v.7.0.17), was used. An albedo of 0.2 was assumed based on the ground surface covering within and around the PV array. Table -6-3 represents the monthly GTI profile.

Table -6-3: Monthly Global Tilted Irradiation Data

Month	GTI (kWh/m²)
January	194.50
February	193.70
March	227.40
April	219.50
May	211.30
June	164.20

Month	GTI (kWh/m^2)
July	123.20
August	129.60
September	171.70
October	212.20
November	181.70
December	182.80
Annual Sum	**2,211.80**

6.3 Climate

For wind speed analysis, data sourced from Meteonorm dataset was used and has been tabulated in Table 6-4 below. The average wind speed of 2.3 m/s was measured at 10m height from ground level for the proposed project site location.

Table 6-4: Simulated Wind Speed for site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	1.7
February	1.7
March	1.9
April	2.6
May	3.7
June	3.7
July	3.4
August	2.9
September	2.2
October	1.3
November	1.2
December	1.5
Yearly Average	2.3

6.4 Temperature

Temperature data has been sourced from the SolarGIS database. A typical operating temperature range for PV modules is -40°C to +85°C. Inverter operating ranges are more bounded to temperature, typically -20°C to +45°C, with the electronic equipment in the inverter degrading quicker in high temperature environments. Thus, considering the temperature range at selected site, the modules and inverters should be able to operate normally.

The effect of temperature on module performance and the corresponding plant performance may be quite significant. Typically, a reduction in efficiency of 0.40 – 0.45%/°C is noted for crystalline modules and 0.25 -0.30%/°C for thin film modules for increase in temperatures above 25°C. Therefore, during the summer months (February-June) temperature losses may be significantly high as module temperatures typically go beyond 50°C.

Table 6-5: SolarGIS Temperature Data for Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	19.6
February	22.6
March	27.8
April	32.3
May	35.1
June	34.7
July	31.2
August	29.8
September	31.3
October	30.1
November	25.4
December	21.2
Annual Average	28.4

6.5 Precipitation

The rainfall figures have been simulated using Meteonorm 7.2 as illustrated in Figure 6-3. These figures show that the identified site is situated in a region that has marginal rainfall.

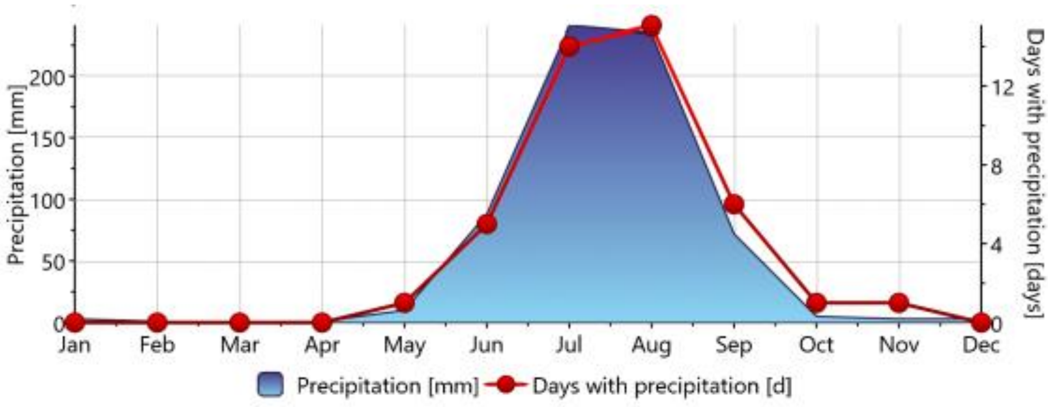

Figure 6-3 Meteonorm Predicted Precipitation for the site

PV modules are soiled by particulates of dust, dirt and bird droppings. Soiling of modules has a high impact on the energy yield thereby leading to a loss up to 3% in non-arid regions. Therefore, the modules need to be cleaned for avoiding the loss due to soiling.

Frequency of module cleaning depends on the rainfall frequency and the prevalence of dust and pollution in the local vicinity. Typical cleaning techniques include water cleaning, dry brushes or vehicle-based mechanical cleaning.

The frequency of module cleaning is primarily dependent on the amount of soiling experienced on the site. Soiling loss of 2% has been considered by considering cleaning frequency of twice a month.

7 Energy Yield Analysis

SgurrEnergy has computed the annual energy yields for the 20MW$_{AC}$ Solar PV Plant using basic designs and indicative layout. Energy yields for all the PV technology configurations under evaluation is further elaborated in the following section.

Parameter	Description
Modules	Kyocera Solar 240 Wp, (KD240GX-LPB)
Inverters	Power-One – PVI-Central-500-TL
Mounting System	Fixed Tilt
DC Capacity (MW$_p$)	20

For energy yields SgurrEnergy has:

1) Sourced average monthly horizontal irradiation, wind speed and temperature data with the other sources which included satellite image derived data. These data have been assessed for use in the energy yield simulation software.
2) Following the assessment, SgurrEnergy has selected site specific data sourced from SolarGIS to arrive at representative energy yield estimates.
3) Calculated the global incident radiation on the tilted plane, taking into account shading.
4) Applying downtime losses, AC ohmic losses, and module degradation losses to obtain energy yields that reflect twenty-five-year plant life.

Using statistical analysis of resource data for inter-annual variability to derive appropriate levels of uncertainty in the energy yield prediction, steps 2 and 3 are facilitated using industry standard photovoltaic simulation software which simulates the energy yield using hourly time steps. The software takes as input detailed specifications of:

- The solar PV modules.
- The inverter.
- Mounting system.
- Electrical configuration including number of modules in series and parallel.

7.1 Correction and Losses

Data obtained for irradiation on collector plane, PV module and inverter specifications and plant configuration are input into the PV modelling software to calculate DC energy generated from the modules in hourly time steps throughout the year. This direct current is converted to AC in the inverter.

A number of losses occur during the process of converting irradiated solar energy into AC electricity fed into the grid. The losses may be described as a yield loss factor. They are calculated within the PV modelling software and calculated from the cable dimensions. Others are nominal figures applied from knowledge of performance of similar PV plants. The losses are broadly summarised in Table 7-1 below.

Table 7-1: Description of Energy Yield Losses

Loss	Description
Shading	Three types of shading losses are considered in the PV energy yield model: horizon shading, shading between rows of modules and near shading due to trees and buildings.

Loss	Description
Incident Angle	The incidence angle loss accounts for losses in radiation penetrating the front glass of the PV modules due to angles of incidence other than perpendicular.
Low Irradiance	The conversion efficiency of a PV module reduces at low light intensities.
Module Temperature	The characteristics of a PV module are determined at standard temperature conditions of 25˚C. For every ˚C temperature rise above this, module efficiency reduces according to their temperature coefficient.
Soiling	Losses due to dust and bird droppings; soiling the module.
Module Quality	Most PV modules do not match exactly the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a given tolerance within which the actual power is guaranteed to lie.
Module Mismatch	Losses due to "mismatch" are related to the fact that the real modules in an array do not all rigorously present the same current/voltage profiles: there is a statistical variation between them.
DC Wiring Resistance	Electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).
Inverter Performance	Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.
MPP Tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the maximum power point voltage. Different inverters do this with varying efficiency.
AC Losses	This includes ohmic losses from inverter to evacuation point.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
Grid Availability and Disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Power Curtailment Losses	Curtailment loss is attributed to the utility limiting the power intake at the contracted AC capacity of the PV Plant; thus, the excess energy generated beyond the limit of 30MW$_{AC}$ at the metering level shall not be accounted
Degradation	The performance of a PV module decreases with time.

7.2 P50 Energy Yield Predictions

This section presents the SgurrEnergy's independent energy yield prediction for the 20 MW$_p$ solar PV Plant with Kyocera Solar PV modules and Power-One central inverters. Table 7-2 summarises the solar PV power plant, the available resource, the losses and the predicted P50 yields.

Table 7-2: Energy Yield for the 20MW_{AC} Solar PV Plant

Parameters	Description
PV Module Technology	polycrystalline
DC Capacity (MW_p)	20.00
AC Capacity (MVA)	20.0
Contracted Capacity (MW)	20.0
P_{NOM} Ratio	1
Tilt (°)	23
Pitch (m)	7
Annual Global Horizontal Irradiation (kWh/m^2)	2015.00
Global Irradiation Incident on Collector Plane (kWh/m^2)	2211.81
Transposition Factor	1.10
Losses	
Horizon Shading	0.00%
Incident Irradiation Below Threshold	0.00%
Near Shading	2.50%
Incident Angle	2.49%
Soiling	2.00%
Low Irradiance	2.09%
Module Temperature	12.16%
Electrical Shadings	0.08%
Module Quality	-0.80%
First year Degradation	2.00%
Module Mismatch	1.00%
DC Ohmic	0.79%
Inverter Performance	1.55%
Availability	1.00%
AC Ohmic	0.56%
Transformer (LV/MV)	1.03%
Transformer (MV/HV)	0.50%
Transmission Line	0.00%
Auxiliary Consumption	0.95%
Curtailment	
Total Annual Loss Factor	***0.736***
First Year P50 Energy Yield (MWh/annum)	**32,542.187**
Ninth Year P50 Energy Yield (MWh/annum)	**31,263.05**
Ninth Year Specific Yield (kWh/kW_p)	**1563.15**
Ninth Year CUF on AC Installed Capacity	**17.84%**
Ninth Year CUF on Contracted Capacity	**17.84%**

Parameters	**Description**
Ninth Year CUF on DC Installed Capacity	**17.84%**
Ninth Year Performance Ratio	**70.67%**

Based on the thermal loss observed in the evaluation, SgurrEnergy has validated the same from the PAN file provided. However, it is understood that the plant may not in actuality have such high operational thermal losses and the same may have been provided by the manufacturer for warranty purposes.

Graphical representation of the monthly generation, performance ratio and CUF for 20 MW$_{AC}$ evaluated is illustrated graphically in the Figure 7-1.

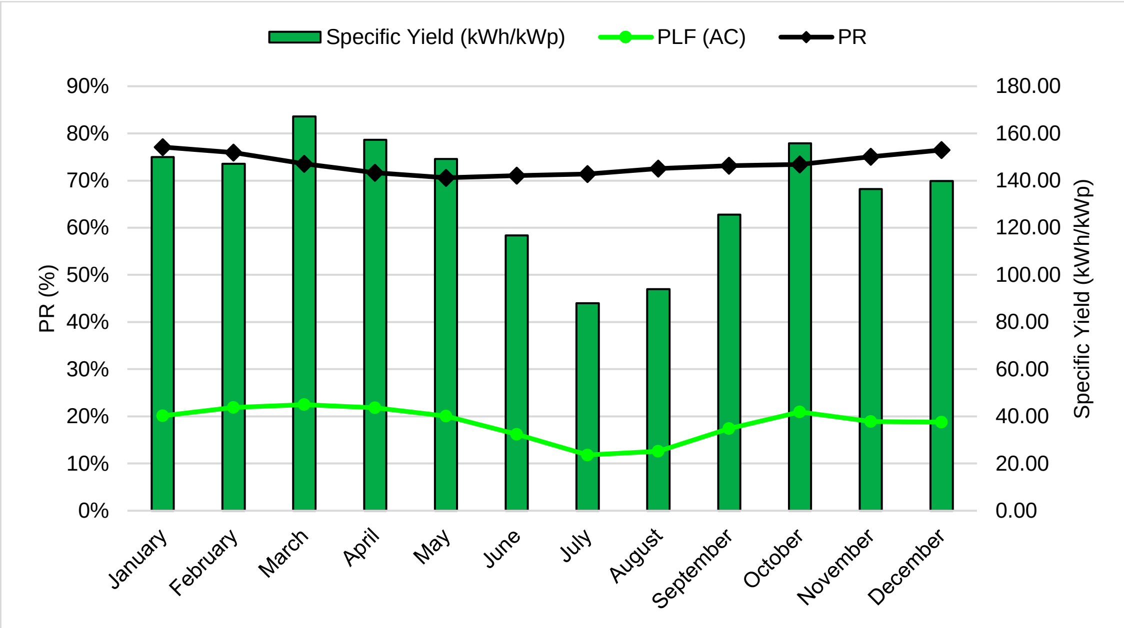

Figure 7-1: Monthly Energy Yield for 20MW$_{AC}$

7.3 Yield Uncertainty

The uncertainty in energy yield predictions is difficult to quantify as it is a function of many independent factors. The discussion below represents simplification of the estimated uncertainty which is believed to be the best approach given the uncertainty in the resource data.

7.3.1 Solar Resource Measurement Uncertainty

Energy yield prediction is based on SolarGIS database, a satellite data which is derived from Meteosat Indian Ocean Data Coverage (Meteosat IODC) and atmospheric parameters using high performance algorithms set by SolarGIS method.

The resource data for 16+ years (1999-2015) has been obtained from the SolarGIS climatological database. SolarGIS recommends an uncertainty of 3.9%.

The uncertainty in transposing the global horizontal irradiation to global tilted irradiation is dependent on the accuracy of the initial data and the characteristics of the specific location. Based on the SgurrEnergy's experience, the uncertainty associated with the transposition model is 1.5%.

7.3.2 Inter – Annual Variation in the Solar Resource

Mean global daily irradiation on a horizontal plane varies on an annual basis. This means that the plant owner does not know what energy yield to expect in any given year but can have a good idea of the expected yield in the long term.

The likely variation can be quantified based on analysis of variation in long-term irradiation data in the vicinity of site. SgurrEnergy has sourced 35 year's data from NASA database for the proposed site location which is used to estimate the standard deviation of variation in irradiation. SgurrEnergy has analysed this dataset and computed the coefficient of variation (standard deviation divided by the mean) as shown in Table 7-3.

Table 7-3: Summary of Figures for Inter-Annual Variation in Resource

Number of Years of Data	35
Coefficient of Variation	4.68

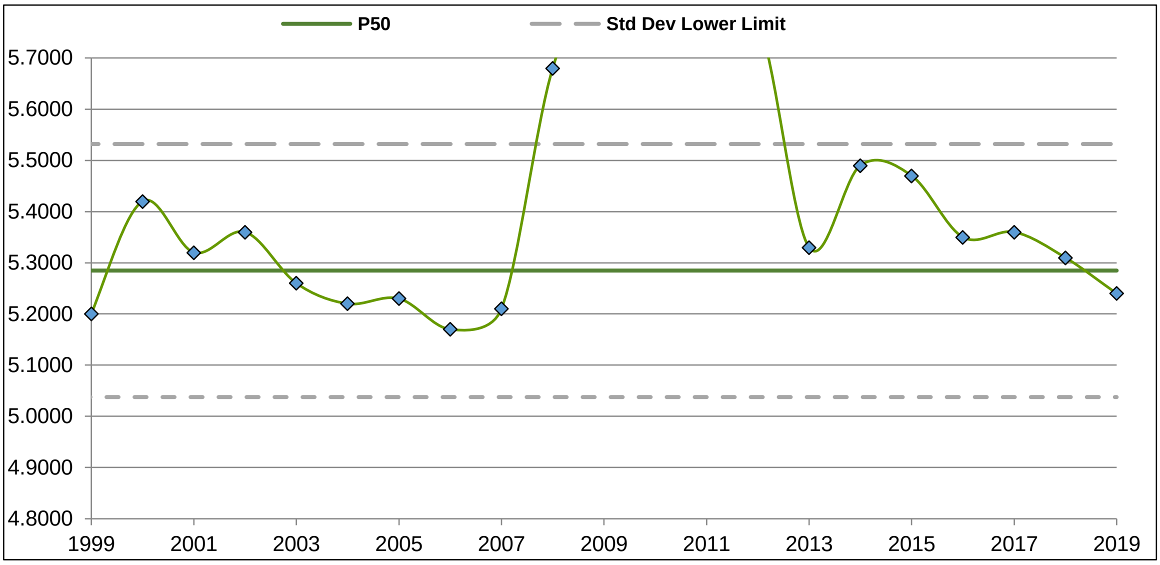

Figure 7-2: Inter-Annual Variability of GHI

Graphical illustration of inter annual variation is presented in Figure 7-2.

SgurrEnergy uses a coefficient of variation of 4.68% to quantify the inter-annual variation in the solar resource.

7.3.3 Modelling Uncertainty

The modelling uncertainty is a combination of the various uncertainties for each loss factor assessed in the modelling process. Efforts to validate the photovoltaic simulation software used data from seven grid connected systems in Europe. These indicated that the accuracy of the results of the simulation is in the order of 2 to 3%.

7.3.4 Total Uncertainty (P75 and P90 Energy Yield Predictions)

Combining the uncertainties in energy yield and inter-annual variation in the solar resource, the P50, P75 and P90 confidence interval are presented for each PV plant configuration in the table below.

Table 7-4: Life Cycle P50, P75 and P90 Generation Prediction for 20 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[11]	P90 Generation Prediction[12]
9	31,263.05	29,893.85	28,661.52
10	31,106.74	29,744.38	28,518.22
11	30,951.20	29,595.66	28,375.63
12	30,796.45	29,447.68	28,233.75
13	30,642.47	29,300.44	28,092.58
14	30,489.25	29,153.94	27,952.12
15	30,336.81	29,008.17	27,812.36
16	30,185.12	28,863.13	27,673.29
17	30,034.20	28,718.81	27,534.93
18	29,884.03	28,575.22	27,397.25
19	29,734.61	28,432.34	27,260.27
20	29,585.93	28,290.18	27,123.96
21	29,438.00	28,148.73	26,988.34
22	29,290.81	28,007.99	26,853.40
23	29,144.36	27,867.95	26,719.14
24	28,998.64	27,728.61	26,585.54
25	28,853.64	27,589.96	26,452.61

[11] The P75 values have been calculated over 10-year averages

[12] The P90 values have been calculated over 10-year averages

8 Operational Analysis and Generation Comparison

To assess the operational performance of the plant, SgurrEnergy has comparatively evaluated the monthly energy yield predicted using satellite-based weather data with the plant generation SCADA values. A factor of 0.5% degradation has been considered for values after a duration of 1 year from COD (Commercial Operational Date) and henceforth. The variation has been evaluated with respect to the difference between the two generation figures.

Based on the information provided by the Owner, SgurrEnergy understands that the PLG solar PV plant was commissioned in 23rd February 2012. SgurrEnergy was provided with plant, grid availability and irradiation records from July 2018 to April 2021[13] for the solar PV plant.

SgurrEnergy has thus carried out the generation comparison for the PV project for the period from July 2018 to April 2021, henceforth referred to as 'operational period'. SgurrEnergy compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Owner.

SgurrEnergy also observed that the monthly availability figures were provided for the operational period of the solar PV plant. These availability figures were captured within the monthly energy yield predictions assessed for the site in question and were accounted for representative comparison. The average availability based on the provided data has also been specified below.

Based on the availability records provided, SgurrEnergy has analysed the trend in the plant availability and grid availability for each month as presented in the following sections.

1.1.1 Grid Availability

The ability of a PV power plant to export power is dependent on the availability of the grid transmission network and the utility grid substation. Grid unavailability is solely due to the breakdown events associated with the grid substation and substation maintenance, which is beyond the Owners control.

The monthly records of the grid availability from July 2018 to April 2021 have been graphically illustrated in Figure 8-1 below.

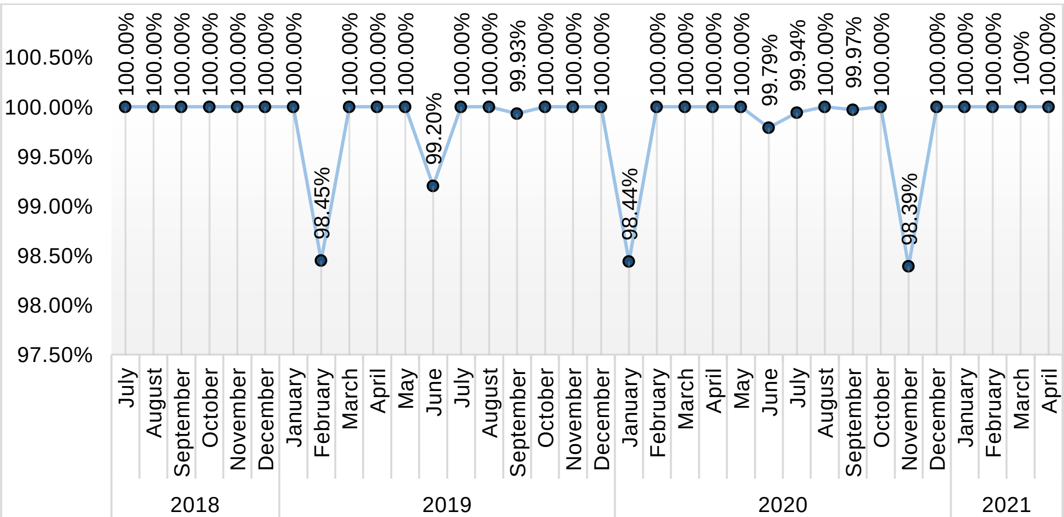

Figure 8-1: Grid Availability

[13] SgurrEnergy was provided with both the plant and grid availability records until April 2021 and hence the analysis conducted in the sections below has been done to incorporate the available data.

From the above illustration, SgurrEnergy notes that the unavailability loss experienced due grid anomalies are minimal over the operational period and are within expected range. However, for the month of February 2019, January 2020 and November 2020 the unavailability due to grid was slightly high when compared to other months. The downtime due to grid unavailability was close to 100% during the remaining months for which the grid availability was noted to be exceeding 99.20%.

Overall the average grid availability experienced on site for the operational period was calculated to be 99.96%

1.1.2 Plant Availability

Plant downtime is a period when the plant does not generate due to failure of equipment in plant until the injection point. The plant downtime period depends on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.

Plant availability of the PLG solar PV plant is graphically illustrated below in Figure 8-2.

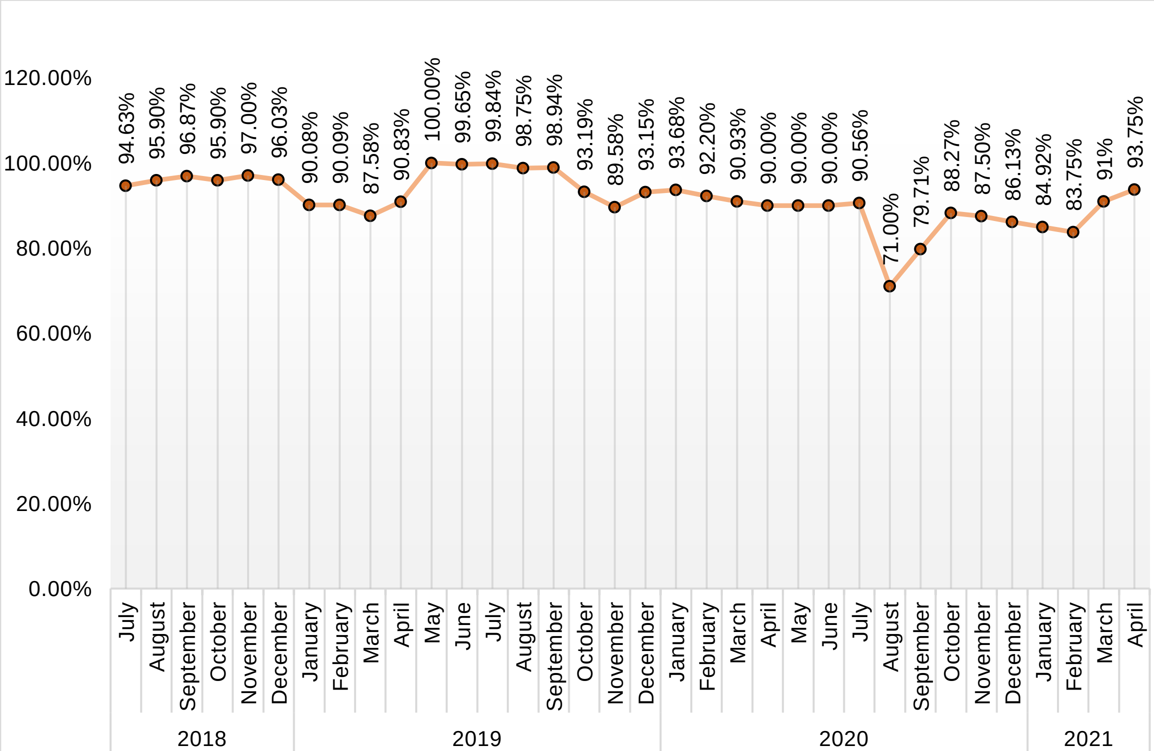

Figure 8-2: Plant Availability

Based on the above illustrations, SgurrEnergy notes the plant availability for the SEPEPL solar PV plant is notably inconsistent for all the months ranging between 71.00% to 100%. The average plant availability is noted to be 91.51% which is considered to be significantly lower than expected range.

Based on the evaluation for the availability provided, SgurrEnergy understands that the same has been carried out using time-based availability and has therefore over-estimated the losses associated with the same. SgurrEnergy has further carried out the energy yield comparison in the following section using an estimated unavailability of 1%.

1.1 Energy Yield Comparison

SgurrEnergy has compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Client. To make the operational energy yield predictions more representative, SgurrEnergy has applied the monthly losses due plant and grid unavailability provided by the Client. These predictions are in turn compared with the actual performance of that plant, which are the generation figures shared by the Client.

The yearly comparison of the generation data is illustrated below in Figure 8-3.

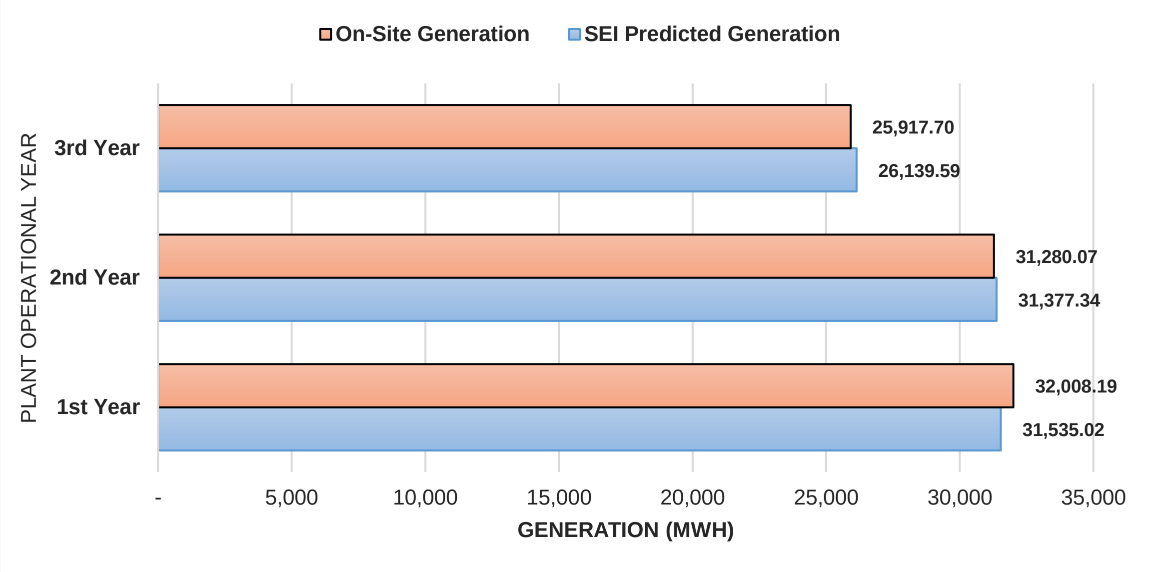

Figure 8-3: Generation Comparison

The variation of the performance of the PV plant for the period of evaluation has been tabulated below in Table 8-1

Table 8-1: PV Plant Performance – PLG 20MW

PV Plant Operation Period	Predicted Generation (MWh)	Recorded Generation (MWh)	Performance Percentage[14] (%)
July 2018 -June 2019	31,535.02	32,008.19	**1.50%**
July 2019 -June 2020	31,377.34	31,280.07	**-0.31%**
June 2020 –April 2021	26,139.59	25,917.70	**-0.85%**
Cumulative Period	**89,051.95**	**89,205.96**	**0.17%**

Based on the above comparison, SgurrEnergy notes that the PV plant is generating higher than the expected yield. However, SgurrEnergy considers that such variations in the energy yield can be attributed to higher irradiation level experienced on the Project site. The irradiation levels significantly impact the actual generation from the PV plant as the system losses may vary significantly due to slight change in the irradiation.

In order to understand the deviation in the irradiation pattern, SgurrEnergy has compared the monthly incident irradiation data provided by the Client with the monthly incident irradiation predicted using satellite-based meteorological data for the period of evaluation. The result of the comparison is presented in the table below and the same is graphically illustrated in the Figure 8-4.

[14] Positive values indicate higher generation, while negative values indicate lower generation

Table 8-2: Irradiation Comparison– PLG 20MW

PV Plant Operation Period	Predicted Irradation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[15] (%)
July 2018 -June 2019	2,211.80	2,111.16	-4.55%
July 2019 -June 2020	2,211.80	2,013.72	-8.96%
June 2020 –April 2021	1,836.30	1,838.18	0.10%
Cumulative Period	6,259.9	5,963.06	-4.74%

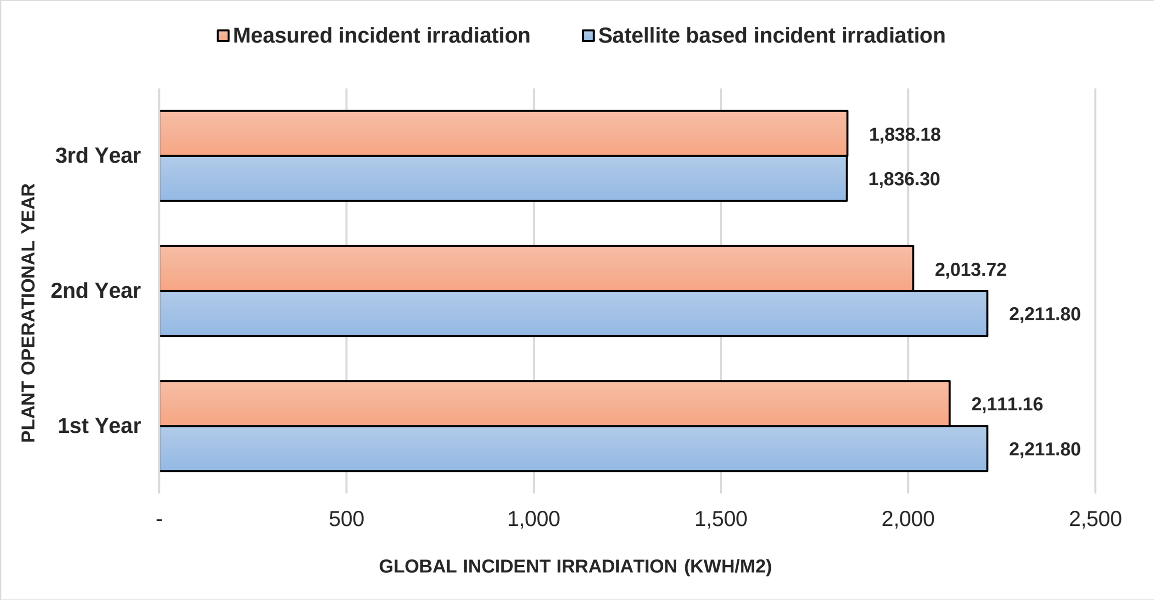

Figure 8-4: Irradiation Comparison

Based on the above illustration, it is observed that the overall recorded generation is approximately 0.17% higher than the generation predicted on site. It has also been observed that the recorded irradiation is approximately 4.74% lower than the predicted irradiation.

Based on the comparative analysis, the increase-in generation can be attributed to the conditions experienced at the site.

[15] Positive values indicate higher irradiation, while negative values indicate lower irradiation

9 Solar Plant Life beyond 25 years

The traditional life of a solar plant is 25 years, which is based primarily on solar panel warranty period. The National Renewable Energy Laboratory (NREL) in the U.S however lists solar pv plants as having a lifetime of 25-40 years[16].Most modules are expected to see a degradation rate of 0.7% for the 25 years and hence the expected power output at the end of 25 years is around 80% of the rated power. However, research from NREL[17] shows that the median degradation rates of panels are around 0.5% and power output after the 25 year term could be higher than the power output guaranteed by the module manufacturer. Hence the possibility of the module producing electricity beyond 25 years with a year on year degradation is not farfetched, however whether these degradation rates will be in a linear pattern or in an unpredictable pattern is yet discovered and hence evaluating the generation/ performance of the plant and life of the plant beyond 25 years becomes risky. The life of the plant also depends on the quality of the other components such as inverters, cables, transformers used. Over the twenty five year plant life, these component will need to be serviced and repaired, as the warranty period for all of these components are less than 10 years. The repair and service of these equipment can continue beyond 25 years and the component may be fit for use for another ten years, however the risk of equipment failure increases year on year. The life of the plant also depends on the operations and maintenance activities carried out during the plant lifecycle and hence carrying out O&M activities diligently during the lifetime of the plant can increase the life of the plant beyond 25 years.

Overall, the pv plant is expected to function beyond plant life of 25 years, however the risk associated with the plant operation increases as the panel warranties would have expired, degradation rates beyond 25 years are unknown and other components used in the plant would also need additional repair/replacement

[16] https://www.nrel.gov/analysis/tech-footprint.html

[17] https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

Virescent Infrastructure

30MW(AC) USUPL Solar PV Plant

Universal Saur Urja Private Limited

Technical Assessment Report

July 2021

Report Details

Prepared for:	Virescent Infrastructure
Client Contact:	Atul Raaizada
Report Distribution:	
SgurrEnergy:	Ahmed Dalvi
Report Classification:	Confidential

	Name	**Job-Title**	**Signature**
Prepared by	Advisory Team		
Reviewed by	Ahmed Dalvi	Sr. Project Engineer	
Authorised by	Arif Aga	Director	
Date of Issue	20 July 2021		

Amendment Records

Revision Number	Date	Purpose of Revision	Summary of Amendments
B1	23 June 2021	Draft Issue	-
B2	28 June 2021	Minor Updates	-
B3	2 July 2021	Minor Updates	-
B4	6 July 2021	Minor Updates	-
B5	15 July 2021	Minor Updates	-

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Executive Summary

Virescent Infrastructure (the Client) backed by leading global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy has been appointed by the Client to conduct a technical appraisal of 30MW$_{AC}$ USUPL plant.

The summary of the technical assessment is captured in the below table.

Table 1-1: Summary

Sr. No.	Parameter	Comment
1	Plant Overview	Review presented in section 2
2	PV Module	According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of Canadian Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard. Further, according to the warranty documents available in public domain for the module manufacturer, SgurrEnergy considers the warranty terms and conditions offered by Canadian to be in-line with the industry standard and raises no major concern regarding the warranties offered. Regarding the certifications, SgurrEnergy considers the PV modules to have adequate design, performance and safety certifications based on IEC's prescribed testing methods. In conclusion, SgurrEnergy does not raise any major concerns about the modules used in the project.
3	Inverter	SgurrEnergy has conducted review of the ABB PVS800-57-1000kVA central inverter ABB PVS800-57-1000kVA central inverter has the required certification for use in solar PV plants. In-house testing of the inverter and individual components is relatively extensive during the R&D phase with functional and temperature cycling testing of each manufactured inverter. ABB offers a product warrant of 5 years which is in line with the current industry standards. In conclusion, ABB can be considered as an established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. ABB inverters have more than 3GW of installation worldwide. These inverters are quite known to the Indian market and have installed capacity of more than 1.3GW which demonstrates a good track record in the Indian solar PV market.
4	Inverter and PowerTransformer	The inverter transformers (2000kVA) and power transformer (15/20MVA) used within the project are manufactured by Raychem and Shilchar Technologies Limited, respectively. The manufacturers have good track record of supplying transformers for solar application throughout the. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

Sr. No.	Parameter	Comment
5	String Sizing	The V_{OC} does not exceed the inverter input voltage for the site, and therefore, SgurrEnergy considers the number of modules in series to be acceptable for the PV Project.
6	Resource Assessment	For resource analysis, SgurrEnergy has compared various satellite datasets. For the satellite databases, SEI has comparedMeteonorm 7.3, NASA, SWERA and SolarGIS data to find the most suitable solar resource for long-term energy yield prediction. Owing to low uncertainty and high resolution, SEI considers SolarGIS dataset to be the most representative satellite database among all the satellite databases for long-term energy yield assessment.
7	Operational Analysis and Generation Comparison	Review presented in Section 8
8	Allied Components and Systems	Review presented in section 4
9	Energy Yield Assessment	Subsequent to the solar resource assessment, SEI considers SolarGIS database as the most representative for long-term energy yield predictions. The table below summarises the energy yield predictions for fifth year of plant operation for the 30MW$_{AC}$ PV plant.

	Fix Tilt	Tracker
Global Horizontal Irradiation (kWh/m2)	1859.80	1859.80
Global Inclined Irradiation (kWh/m^2)	2004.34	2186.49
First Year P50 Energy Yield (MWh/annum)	58,115.74	
Fifth Year P50 Energy Yield (MWh/annum)	56,962.11	
Fifth Specific Yield (kWh/kW$_p$)	1540.39	
Fifth Performance Ratio (PR)	75.91%	
Fifth PLF on Contracted Capacity (30MW$_{AC}$)	21.68%	

Glossary

A	Amp
AC	Alternating Current
a-Si	Amorphous Silicon
CdTe	Cadmium Telluride
c-Si	Crystalline Silicon
CIGS/CIS	Copper Indium (Gallium) Di-Selenide
CPV	Concentrated photovoltaic
CSP	Concentrating solar power
CUF	Capacity Utilization Factor
°C	Degrees Centigrade
°	Degrees
DC	Direct Current
E	East
GWh	Giga Watt hour
HV	High Voltage
Hz	Frequency, Hertz
IAM	Incident Angle Modifier
Isc	Short Circuit Current
IEC	International Electro technical Commission
kA	One Thousand Amps
km	One metric kilometre
kV	One thousand Volts
kVA	One thousand Volt Amps
kWp	One thousand Watts peak
kWh	One thousand Watt hours
LV	Low Voltage
m	Meters
m^2	Meters squared
mm	Millimetres
mm^2	Millimetres squared
m/s	Meters per second
mc-Si	Mono-crystalline Silicon

MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MTBF	Mean Time Between Failures
MV	Medium Voltage
MVA	One million Volt Amps
MW	One million Watts or Megawatt
MWp	Megawatt peak of Solar PV modules
N/m^2	Newton per meter Squared
N	North
NASA	National Aeronautics and Space Administration
NEC	National Electric Codes
O&M	Operations and Maintenance
ONAN	Oil Natural Air Natural
ONAF	Oil Natural Air Forced
%	Percentage
pc-Si	poly-crystalline Silicon
PV	Photovoltaic
REC	Renewable Energy Certificates
RPO	Renewable Purchase Obligation
STC	Standard Test Conditions
SWERA	Solar and Wind Energy Resource Assessment
TUV	TÜV Rheinland Group Testing and Standards Organisation.
V	Volts
Voc	Open Circuit Voltage
VT	Voltage Transformer
W/m^2	Watts per metres squared
Wp	Watt peak
XLPE insulation	Cross-Linked Polyethylene insulation

1 Introduction

Virescent Infrastructure (the Client) backed by global investment firm Kohlberg Kravis Roberts (KKR) in India, was established to acquire and invest in renewable energy assets in the Indian power sector.

SgurrEnergy India (SEI) has been appointed by the Client to conduct technical appraisal for the 68MW$_{AC}$ portfolio of Solar PV projects in India. The portfolio comprises of four projects, as presented within Table 1-1.

Table 1-1: Project Key Summary

Project Name	SSEPL – 5MW$_{AC}$	SSEGPL – 13MW$_{AC}$	PLG – 20MW$_{AC}$	USUPL – 30MW$_{AC}$
Site Location	26.52N, 72.85E, Tiwari, Jodhpur, Rajasthan, India	23.9128°N, 71.2183°E, Santalpur, Patan, Gujarat, India	23.9°N, 71.5°E, Dahisar, Patan, Gujarat, India	25°18'52.79"N, 79°25'2.49"E, Devgaon, Mahoba, Uttar Pradesh, India
Owner	Sindicatum Solar Energy Private Limited (SSEPL)	Sindicatum Solar Energy Gujarat Private Limited (SSEGPL)	PLG Photovoltaic Private Limited (PPPL)	Universal Saur Urja Private Limited (USUPL)
DC / AC Capacity	5.745MW$_P$ / 5MW$_{AC}$	15MW$_P$ / 13MW$_{AC}$	20MW$_P$ / 20MW$_{AC}$	36.98MW$_P$ / 30MW$_{AC}$

This report presents the evaluation of the 30MW$_{AC}$ solar PV plant developed by Universal Saur Urja Private Limited (USUPL). The Solar PV plant under evaluation is located in Devgaon village, Mahoba district in Uttar Pradesh state. The purpose of this report is to provide a technical appraisal of PV plant under evaluation.

The report focuses on the following key parameters:

- System Design.
- Major Components.
- Engineering Design.
- Independent Solar Resource Assessment and Energy Yield Prediction.
- Plant Operational Analysis and Generation Comparison.
- Permits and Approvals.

This report presents independent technical appraisal of the Project and is based on information made available by the Client through online data room. The main Project characteristic is summarised in Table 1-2.

Figure 1-1 illustrates the project structure indicating key project participants for the 30MW$_{AC}$ solar PV plant.

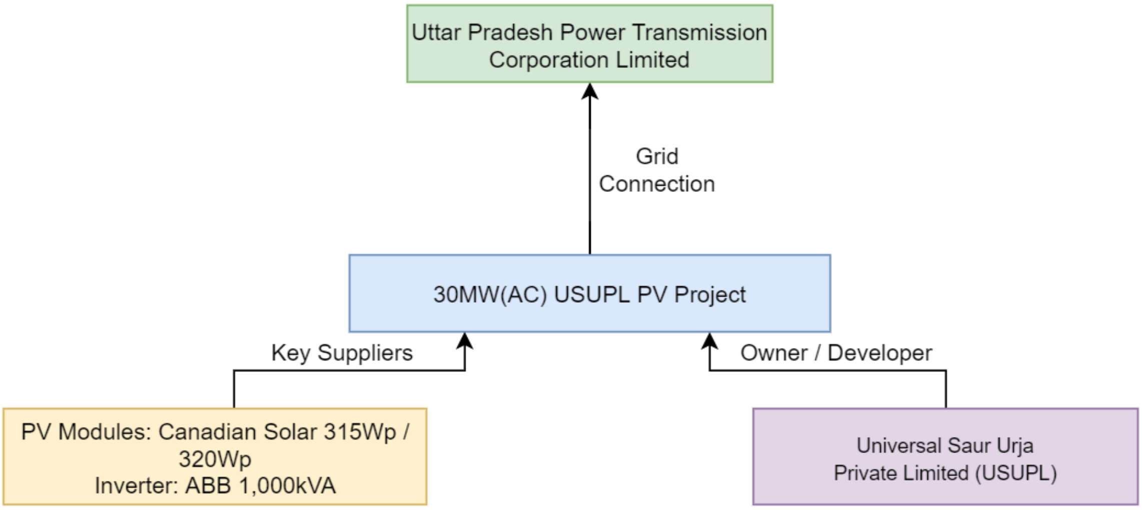

Figure 1-1: Project Structure for 30MW$_{AC}$Solar PV Plant

Table 1-2: Project Key Summary

Project Information	
Project Name	30MW$_{AC}$ USUPL solar PV plant
Location	Devgaon, Mahoba, Uttar Pradesh
Developer	Universal Saur Urja Private Limited (USUPL)
DC/ AC capacity	30MW$_{AC}$ PV Plant – 36.98MW$_{P}$ / 30MW$_{AC}$
Key Equipment Manufacturers	PV Modules: Canadian Solar Inverters: ABB
MMS Configuration	Fixed Tilt: 19°, Tracker, Azimuth: 0°
Commissioning Status	Commissioning for 10MW$_{AC}$ PV Plant was achieved on 15 September 2016.

2 30MW_{AC} Solar PV Plant Overview

The project site lies around the coordinates 25°18'52.79"N, 79°25'2.49"E. Satellite imageries of 30MW_{AC} solar PV plants are illustrated below in Figure 2-1. The Owner owns approximately 142.79 acres of land for the project. The Project site is located near the *Devgaon* village, in *Mahoba* district of Uttar Pradesh.

Project is contracted for generating 30MW_{AC} power; SEI therefore interprets 30MW_{AC} as the maximum AC installed capacity for the solar PV plant.

Figure 2-1: Satellite image of 30MW_{AC} plant

2.1 30MW_{AC} Project Summary

Solar PV plant is modular in nature; therefore, USUPL 30MW_{AC} solar PV plants is implemented by adopting modularity in designs. 4MW_{AC} and 2MW_{AC} is the typical inverter stations considered for implementing USUPL 30MW_{AC} solar PV plant.

Table 2-1 presents the summary of 30MW_{AC} PV plant

Table 2-1: Summary of 30MW_{AC} Plant Configurations

General	
PV Module Technology	Poly-crystalline
Inverter Technology	Central Inverters
Installed DC Peak Capacity (MW_p)	36.98
Installed AC Capacity (MW)	30.0
Mounting Type	Fixed Tilt / Tracker
Tilt Angle (°)	19° / ±45°
Pitch (m)	7.5 / 5.0
PV Modules	
PV Module Manufacturer	Canadian Solar
Model	CS6X - 315P, CS6X - 320P
Wattage (W_p)	315W_p / 320W_p

General	
Number of Modules per String	20
Inverter	
Inverter Manufacturer / Model	ABB / PVS800-57-1000kW
Inverter Nominal AC Output	1,000kW
Number of Inverters	30

The 30MW$_{AC}$ plant is implemented with a total of seven (7) inverter stations of capacity 4MW$_{AC}$ and 2MW$_{AC}$. The 4MW$_{AC}$ stations comprise of a five winding transformer to accommodate 4 × 1,000kVA inverters, taking the individual inverter station size to 4MW$_{AC}$. While The 2MW$_{AC}$ station comprises of a three winding transformer to accommodate 2 × 1,000kVA inverters, taking the individual inverter station size to 1MW$_{AC}$.

The output of the inverter stations are connected to two (2) two winding transformers of 15MVA for stepping up the voltage.

The power generated by the USUPL 30MW$_{AC}$ PV plant is fed to *Panwari* substation located approximately 12km from the Project site. The point of interconnection is at the *Tinwari* substation.

3 Review of Major plant components

SgurrEnergy has conducted a desktop review of the main plant components which includes a high-level review of the company, its track record, product certifications obtained, technical characteristics and warranty conditions.

3.1 PV modules – Canadian

SgurrEnergy has conducted a technical review of the supplier and module specification with regards to their suitability for their use in the Projects under evaluation.

3.1.1 Company Profile

Canadian Solar (NASDAQ: CSIQ) is a vertically integrated producer of ingot, wafer, solar cell and solar modules and was established in Ontario, Canada in 2001. Canadian Solar has subsidiaries in 20 countries on six continents. The company has 17 manufacturing facilities in Asia and America. Along with over 14,000 employees around the world, Canadian Solar had reported net revenue of $3.5 Billion at the end of the fourth quarter of 2020[1]. The company has achieved shipment of over 52GW of solar module in more than 150 countries. Canadian Solar also has a portfolio of solar power plants in operation. Canadian Solar is currently have more than 20GW pipeline projects worldwide.

As of December 2020, the company has an ingot manufacturing capacity of 1.85GW per annum, wafer-manufacturing capacity of 5GW per annum, cell manufacturing capacity of 9.6GW per annum[2].

On acquisition of Recurrent Energy, a leading utility-scale solar project developer, Canadian Solar now boats a resulting portfolio of over 4.7GW[3] of solar power plants built and connected worldwide.

The company also operates three state-of-the-art research centres in Canada and China which focus on improvement of efficiency and performance of its products. These research facilities employ over 515 scientists along with engineers and technicians in order to conduct research to improve the existing technologies. The company has more than 1,500 authorized patents worldwide until March 2020.

Canadian solar modules have been shipped globally for more than 52GW capacity since 2001 and have been used in the development of ground-mounted, commercial, and residential roof-mounted applications worldwide.

Few of the commissioned solar power plants using Canadian modules are listed in Table 3-1.

Table 3-1: Track record of Canadian Solar Modules

Sr. No.	Project	Capacity
1	Tamil Nadu	309.0
2	Ontario, Canada	300.0

[1] https://investors.canadiansolar.com/news-releases/news-release-details/canadian-solar-reports-fourth-quarter-and-full-year-2020-results#:~:text=Full%20Year%202020%20Highlights&text=9%25%20annual%20growth%20in%20net,GWh%20of%20battery%20storage%20contracts.

[2] https://www.pv-tech.org/canadian-solar-adding-significant-manufacturing-capacity-in-2021-in-attempt-to-keep-pace-with-rivals/#:~:text=In%20the%20second%20half%20of,nameplate%20capacity%20to%2010%2C000MW.&text=New%20plans%20announced%20would%20add,by%20the%20end%20of%202021.

[3] https://www.canadiansolar.com/au/wp-content/uploads/sites/2/2020/07/AU-Canadian-Solar-Company-Brochure-2020s.pdf

Sr. No.	Project	Capacity
3	Roserock, Texax, USA	212.0
4	Garland Solar Plant, USA	272.0
5	Dubai, UAE	268.0
6	Tranquility Solar Plant, USA	257.7
7	Finley, Australia	175.0
8	Shizuishan, China	150.0
9	Brandenburg, Germany	148.0
10	Mustang, CA, USA	134.0
11	NC, USA	102.4
12	Wuhu City, Inner Mongolia, China	100.0
13	Oakey, Australia	100.0
14	Yucheng, China	100.0
15	Minas Gerais State, Brazil	82.5
16	Goyalri, India	78.0
17	Rovigo, Italy	70.0
18	Aguascalientes State, Mexico	67.0
19	Barren Ridge, NC, USA	60.0
20	Yamaguchi, Japan	56.3
21	Yangquan, China	50.0
22	Dai County, China	46.8
23	CA, USA	20.0
24	Paraguay, Maule Region, Chile	10.8
25	Thunder Bay Airport, Ontario, Canada	8.5

Canadian Solar is considered a Tier 1 supplier by Bloomberg (Q1, 2021). A Tier 1 supplier is defined as a module manufacturer who has *'provided products to five different projects, which have been financed non-recourse by five different (non-development) banks, in the past two years*.

Whilst the Bloomberg tiering system does not reflect on a product's technical or quality aspects, it does provide an indication of acceptability in the marketplace. SgurrEnergy considers Canadian solar to have a strong track record in delivering PV modules to utility-scale projects worldwide).

3.1.2 Main Technical Characteristics

The Canadian Solar CS6X-P modules of 315W$_P$ and 320W$_P$ capacities have been utilized for the project. The 315W$_P$ and 320W$_P$ modules have efficiencies of 16.42% and 16.68%, respectively and a positive power tolerance of 0~+5W. The CS6X-P series have temperature coefficient (Pmax) of -0.41%/°C. These temperature coefficients are in line with SgurrEnergy's expectation for c-Si technology. Generally, the temperature coefficient of crystalline silicon modules is in the range of -0.4% rise in temperature. The technical characteristic of the shortlisted modules is presented in Table 3-2.

Table 3-2: Technical specifications of 315W$_P$ and 320W$_P$

Specifications	CS6X-315P	CS6X-320P
Technology	Polycrystalline	
Nominal power (P_{MPP})	315W	320W
Voltage at P_{MAX} (V_{MPP})	36.6V	36.8V
Current at P_{MAX} (I_{MPP})	8.6A	8.7A
Open circuit voltage (V_{OC})	45.1V	45.3V
Short circuit current (I_{SC})	9.2A	9.3A
Efficiency (%)	16.4%	16.7%
Maximum System Voltage	1,000V	
Power tolerance (W)	0~+5W	
Dimensions (length × breadth × width) (mm)	1954 × 982 × 40mm	
Module area (m^2)	1.9m^2	
Weight (kg)	22kg	
Temperature coefficient at P_{MAX}	-0.4%/°C	
Maximum reverse current	15A	
Maximum mechanical load	2400Pa	
Maximum snow load	5400Pa	
Product warranty	10years	
Power output guarantee	25years	

Modules have a power tolerance of 0~+5W. This is in line with the offering from other leading suppliers. The maximum system voltage is 1,000V for CS6X-P series and 1,000/ 1,500V for CS3U-P series which are standard and compatible with the project system design. Maximum snow and wind loading specifications are in line with industry norms.

NOCT Characteristics

The nominal operating cell temperature (NOCT)[4] characteristics of selected CS6X-P modules of 315W$_P$ and 320W$_P$ capacities are given in Table 3-3 corresponding to realistic operating conditions as compared to STC. It is affected by module materials used as well as the packing density of module materials. The NOCT for the module is 42±3°C.

Table 3-3: PV Module NOCT Characteristics of CS6X-P and CS3U-P

Model	CS6X-315P	CS6X-320P
Maximum Power (P_{MAX})	228W$_P$	232W$_P$
Max Power Voltage (V_{MPP})	33.4V	33.6V
Max Power Current (I_{MPP})	6.8A	6.9A
Open Circuit Voltage (V_{OC})	41.5V	41.6V
Short Circuit Current (I_{SC})	7.4A	7.5A

3.1.3 Certification of Modules

[4] Irradiance = 800W/m^2, Air Mass = 1.5, Ambient temperature = 45±3°C.

General review of datasheet indicates Talesun Solar PV modules manufactured in facilities with the following certifications:

- ISO 14001 certification for environmental management systems
- ISO 9001 Certification for quality management systems
- OHSAS 18001 certification for Occupational Health and Safety Management Systems

Further, SgurrEnergy has summarised the certification mentioned in the datasheet of the modules under evaluation within Table 3-4.

Table 3-4: Certification for PV Module- Canadian Solar Modules

Certification	Description
IEC 61215	Crystalline silicon PV modules – Design qualification and type approval
IEC 61730	PV module safety qualification
IEC 61701	Resistance to salt mist and corrosion
IEC 62716	Ammonia Corrosion Testing
UL 1703	Standard for safety for flat-plate photovoltaic modules
IEC 60068	Dust and Sand

3.1.4 Warranty

As is standard within the industry, the specified modules are provided with two forms of warranty; a Limited Product Warranty and a Limited Peak Power Warranty. Both warranties are described further below and start at the earlier of the date of installation or 90 days from the delivery date.

3.1.5 Product Warranty

Canadian Solar provides a limited product warranty of 10 years and 12 years for CS6X-P series. During this period the modules shall be free from defects in materials and workmanship that affects the performance of the module under normal application, installation, use, and service conditions as specified in Canadian Solar's standard product documentation.

SgurrEnergy considers product warranty provided by Canadian Solar to be in line with the current industry standard.

3.1.6 Linear Power-Output Warranty

Canadian solar warrants that the modules will not experience a power loss of greater than 2.5% in the first year of operation, and the nominal power output at that time, shall not be less than the 97.5% of the initial nominal power output; and 0.7% each year thereafter until that date which is 25 years following the warranty start date, at which the module's actual power shall not be less than 80.7% of the initial nominal power output.

For either warranties mentioned above, if defects are noted or the module's performance falls below the specified levels, Canadian solar will either repair, replace or provide additional modules to make up for the loss in power output.

3.2 Inverters – ASEA Brown Boveri (ABB)

The project has utilized ABB PVS800-57-1000kW central inverter for the project under evaluation.

3.2.1 Company background

ABB is a global leader in power and automation technologies. Based in Zurich, Switzerland, ABB is one of the largest engineering companies as well as one of the largest conglomerates in the world. ABB has operations in around 100 countries, with approximately 147,000 employees[5]. Company reported global revenue of around $34,312 million for 2017.[6]

The firm's shares are traded on the stock exchanges of Zurich, Stockholm, and New York. ABB is a multinational corporation headquartered in Zurich, Switzerland, operating mainly in robotics and power and automation technology.

On July 9, 2019 the Italian company FIMER acquired ABB's solar inverter business. The takeover of ABB's solar inverter business included 800 employees in 26 countries as well as two manufacturing plants, in Italy and in India, and a R&D facility in Finland.

FIMER was founded in 1942, headquartered in Vimercate, Italy, has been actively working in inverter technology since 1983. As of 2020, the company employs more than 1,100 employees across its three manufacturing facilities and three R&D centres across the globe. As a result of acquisition of ABB's PV inverter line, FIMER ranked the fifth-largest PV inverter globally in 2019.

3.2.2 Track Record

ABB India commenced local manufacturing of solar inverters in 2012 and partnered with several customers. ABB is the solar inverter market leader in India holding approximately 24% market share in 2018. ABB has approximately 3,590MW in operation across more than 350 sites in India. ABB India manages close to 40% of the installed bases in India. As on 30 August 2017, ABB India crossed the 5GW threshold for the supply of inverters in the country.

Table 3-5 lists the state-wise installed capacity of ABB inverters in India. However, it is to be noted that the table below doesn't not comprise of the installed capacities till date.

Table 3-5: ABB Inverter Track Record

Location	Capacity (MW)
Punjab	227
Haryana	62
Uttar Pradesh	106
Bihar	225
Rajasthan	371
Madhya Pradesh	271
Chhattisgarh	28
Odisha	20
Andhra Pradesh	647
Maharashtra	261
Tamil Nadu	747
Karnataka	305

[5] https://new.abb.com/news/detail/26838/abb-to-exit-solar-inverter-business

[6] https://new.abb.com/investorrelations/company-profile/facts-figures

Location	Capacity (MW)
Kerala	50

ABB India has strategically located it headquarter in Bangalore and offices other cities Pune, Ahmedabad, Jaipur, Faridabad, Hyderabad, Tamil Nadu, and Bhopal in order to facilitate quick spare part availability and minimal response time. ABB aims to provide first response to its customers within 4 hours on weekdays and within 24 hours on weekends and holidays. ABB also provides a Turn-Around-Time of 48 and 72 hours on weekdays and weekends respectively, hence maintaining an average uptime of over 99%.

3.2.3 Technical Characteristics

ABB PVS800-57-1000kVA inverter has been selected for technical feasibility of the Project. The technical specification of 1000kW ABB inverter is listed in Table 3-6.

The PVS800-57-1000kVA Series of central inverters designed ideal for large PV Power Plants. PVS980 inverters are designed for fast and easy installation. These inverters are designed to operate with DC inputs up to 1,500 V. They incorporate maximum power point tracking (MPPT) and grid management features to meet utility requirements.

PVS800-57-1000kVA inverter is designed for outdoor use with an IP42 ingress protection class. They have closed loop cooling system based on phase transition and thermosiphon technology with water and dustproof enclosure. They perform optimally at ambient air temperatures between -15°C to 50°C and relative humidity in the range of 15% to 95% with maximum noise level of less than 75dBA.

The PVS800-57-1000kVA inverter has peak efficiency of 98.8% and a European efficiency of 98.6%.

The main technical characteristics of these inverters are illustrated in Table 3-6.

Table 3-6: ABB inverter specifications

ABB Central Inverter Specifications	
Inverter	ABB PVS800-57-1000kVA
Type	Central Inverter
Input Data	
PV voltage range, MPP (V)	600 to 850V
Maximum DC voltage (V)	1100V
Maximum input current (A)	1710A
Output Data	
Nominal AC power (kW)	1000kW
Maximum AC current (A)	1445A
Nominal AC voltage(V)	400V
AC grid frequency (Hz)	50Hz-5%+3%
Maximum THD	< 3%
Operating Performance	
Maximum efficiency (%)	98.80%
Euro efficiency (%)	98.60%
Power consumption	

ABB Central Inverter Specifications	
Own consumption in operation(W)	650W
Standby operation consumption (W)	65W
Other	
Dimensions (W × H × D) (mm)	3630mm x 2130mm x 708mm
Weight (kg)	2320kg
Environmental Protection Rating	IP42
Operating temperature range (°C)	-15 to+50°C
Relative humidity (%)	15% to 95%

The following protection devices are included within the inverter design:

- Ground fault monitoring
- Grid Monitoring
- Anti-islanding protection
- DC reverse-polarity protection
- AC and DC short circuit and over current protection
- AC and DC over voltage and temperature protection

ABB inverters comprise of suitable protection devices in place on both the DC and AC side to protect the PV system and inverter components.

3.2.4 Certification

ABB is certified to the internationally recognised standard for management systems and according to ISO 9001 that they conform to the latest quality standards.

Inverter reliability is further enhanced via stringent quality control procedures. ABB inverter manufacturing facilities operate with the following certifications:

- ISO 9001:2015 Quality Certificate
- ISO 14001:2015 Environmental Certificate
- OHSAS 18001 Health and Safety Management System

Based on information available in public domain, SgurrEnergy has summarized the certification of the ABB inverter within Table 3-7.

Table 3-7: Description of Certification of ABB inverters

Certification	Description
IEC 60068-2-6/29	Environmental testing of inverters to assess their ability to perform and survive under conditions such as transportation, storage, operational environments, extreme cold and heat
IEC 61683:1999	Procedure for measuring efficiency
IEC 62109-2:2011	Safety of Power Converters
IEC 62116:2014	Islanding prevention measures

3.2.5 Warranties

According to the warranty documents provided, ABB has offered the inverter warranty of 60 months from commissioning of last inverter or 63 months from the date of supply of last inverter, whichever is earlier. SgurrEnergy considers the warranty offered by the manufacturer to be in line with industry standards and do not raise any concern over the use of inverter for the project.

3.3 Transformers

The solar PV plant is implemented with two level transformation. Power at low voltage from inverters is stepped up to 11kV using 2000kVA transformers of Raychem make inverter transformers, and further to 132kV using 15/20MVA power transformer manufactured by Schneider Electric.

3.3.1 Inverter Transformer- Raychem RPG Private Limited

3.3.1.1 Company Profile

Raychem RPG Private Limited incorporated in 1989 is a joint venture between TE connectivity –USA and RPG Enterprises, India. TE connectivity provides global solutions in Network, Transportation, Consumers and Industrial since last 50 years with $12.2B sales for the financial year 2016. RPG enterprise is a leading group in India with turnover of US$ 3.5 Billion. The group has diversified business sectors such as Automotive Tyres, Infrastructure, IT and Specialty including Pharmaceuticals, Power Ancillaries & Plantations. Headquartered in Mumbai, Raychem RPG has sales offices in Thane, New Delhi, Chennai, Bangalore, Hyderabad, and Kolkata. They have state of art manufacturing facilities in Maharashtra and Gujarat with capacity to manufacture transformer up to 45MVA, 132kV class. The company has the following transformer product segments:

- Dry Transformer
  - Cast resin Transformer up to 20MVA,33kV.
  - Vacuum Pressure Impregnated up to 10MVA,33kV.
- Special Transformers
  - Scott T transformers up to 5MVA,33kV
  - Dry type transformers up to 10MVA, 11kV
  - Oil Filled transformer up to 20MVA; 33kV.
  - Furnace transformer-up to 30MVA, 33kV
- Oil Filled transformer up to 20MVA; 132kV.

Transformer manufacturing unit has ISO 9001:2015, ISO 14001-2015 and OHSAS 18001-2007 and is equipped with state-of-the-art manufacturing and testing facilities to meet IEC, ANSI, IEEE, IS, BIS and other international standards.

Raychem has supplied its product to Indian customers like State Electricity Boards and Power Utilities such as Reliance Energy Ltd., Tata Power, NDPL, CESC and leading Industries such as Tata Motors, Bajaj Auto, Volkswagen, Hindustan Unilever, Tata Steel, JSPL, Force Marshall, Siemens and many more. The company has a cumulative track record of supplying transformers equating to 2,302.37MVA for solar PV plants in India.

3.3.1.2 Technical Specifications

Inverters Transformers utilized in the project are outdoor type, five-winding transformers of capacity 2000kVA.

The transformers hold Class A insulation and are oil immersed with ONAN type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

SgurrEnergy is satisfied that the transformer has been designed to adhere local and country specific grid codes and relevant IS codes (IS-2026). The technical characteristics of the inverter transformers utilized for the project are presented in Table 3-8

Table 3-8: Technical Specification of Raychem Transformer

Technical Parameters	Description
Rated Power	2,000kVA
Rated HV	11kV
Rated LV	0.38 - 0.38 - 0.8 - 0.8kV
Tapping on HV	+5% to -5% (steps of 2.5%)
Phases	3
Frequency	50Hz
Vector group	Dy11y11
Impedance	6.25% (Sub, to IS Tol.)
Cooling Strategy	ONAN
Oil temperature rise	50°C
Winding temperature rise	55°C
Winding material	Electrolytic Copper

3.3.1.3 Temperature Rise Detection and Protection

Inverter transformers have been provided with standard temperature sensing systems. These comprise of an analogue oil temperature indicating (OTI) unit and winding temperature indicating (WTI) unit. Both the units have been adequately provided with alarm/trip contacts and wired to relay units located at HT panel.

The transformers are adequately provided with the Buchholz Relay that essentially serves as a critical protective device in case of excessive gas pressure released in the event of higher transformer loadings and faults.

3.3.1.4 Warranties and Guaranties

SgurrEnergy is unable to comment on warranty/guaranty of Raychem transformer, since SgurrEnergy has not been provided with the warranty certificate. Hence, SgurrEnergy suggests seeking clarity from the Developer.

3.3.2 Power Transformer- Schneider Electric

Schneider Electric is a French multinational corporation, headquartered in Rueil-Malmaison, France, specializing in Schneider Electric equipment. The company began in 1836 as Schneider & Cie working mainly in iron, steel, and armaments. From 1981-1997, Schneider Electric focused mainly on electricity through strategic acquisitions.

With more than 180 years of experience, the company launched a brand strategy called “Life Is On” in 2015 which has a dedicated business unit for solar[7]. The Solar Business of Schneider Electric is focused on designing and developing products and solutions for commercial scale and residential & off-grid systems. Schneider Electric employs more than 137,000 employees in over 100 countries.

[7] https://solar.schneider-electric.com/

As of December,2018, Schneider Electric generated a revenue of €26 billion. The company devotes around 5% of the total revenue generated to Research & Development.[8] Schneider Electric is a Fortune Global 500 company, publicly traded on the Euronext Exchange. The company was also included in the World's 100 most ethical companies by the Ethisphere Institute in February,2019.[9]

3.3.2.1 Technical Specifications

The 15/20MVA Power transformers used in the project are outdoor type, three-winding (copper wounded), Class A insulation class, oil immersed with ONAN/ONAF type of cooling with detachable radiators. These transformers have been designed suitable for operations with a pulsed inverter.

SgurrEnergy is satisfied that the transformer has been designed to adhere local and country specific grid codes and relevant IS codes (IS-2026). The transformer technical characteristics are presented in Table 3-9.

Table 3-9: Technical Specification of Schneider Electric Transformer

Technical Parameters	Description
Rated Power	15/20MVA (ONAN / ONAF)
Rated HV	132kV
Rated LV	11kV
Tapping on HV	-5% to +15% (steps of 1.25%)
Phases	3
Frequency	50Hz
Vector group	YNyn0
Cooling Strategy	ONAN / ONAF
Oil temperature rise	50°C
Winding temperature rise	55°C
Winding material	Electrolytic grade Copper

3.3.2.2 Temperature Rise Detection and Protection

The 15/20MVA Power transformers have been provided with standard temperature sensing systems. These comprise of an analogue oil temperature indicating (OTI) unit and winding temperature indicating (WTI) unit. Both the units have been adequately provided with alarm/trip contacts and wired to relay units located at HT panel.

The transformers are adequately provided with the Buchholz Relay that essentially serves as a critical protective device in case of excessive gas pressure released in the event of higher transformer loadings and faults.

3.3.3 Warranties and Guaranties

SgurrEnergy is unable to comment on warranty/guaranty of Schneider Electric transformer, since SgurrEnergy has not been provided with the warranty certificate. Hence, SgurrEnergy suggests seeking clarity from the Developer.

[8] https://solar.schneider-electric.com/company/about-us/

[9] https://annualreport.se.com/

3.4 Conclusion on Major Plant Components

PV Modules

According to the information available in public domain and the information provided by the Client, SgurrEnergy has conducted a desktop review of Canadian Solar, assessing the companies overview, track records, module technical characteristics, industry certifications and warranty conditions. SgurrEnergy considers the modules to have technical characteristics in line with the industry standard.

Further, according to the warranty documents available in public domain for the module manufacturer, SgurrEnergy considers the warranty terms and conditions offered by Canadian to be in-line with the industry standard and raises no major concern regarding the warranties offered. Regarding the certifications, SgurrEnergy considers the PV modules to have adequate design, performance and safety certifications based on IEC's prescribed testing methods. In conclusion, SgurrEnergy does not raise any major concerns about the modules used in the project.

Inverters

SgurrEnergy has conducted review of the ABB PVS800-57-1000kVA central inverter ABB PVS800-57-1000kVA central inverter has the required certification for use in solar PV plants. In-house testing of the inverter and individual components is relatively extensive during the R&D phase with functional and temperature cycling testing of each manufactured inverter. ABB offers a product warrant of 5 years which is in line with the current industry standards.

In conclusion, ABB can be considered as an established and reputable inverter manufacturer and is known for producing good quality and high-performance inverters. ABB inverters have more than 3GW of installation worldwide. These inverters are quite known to the Indian market and have installed capacity of more than 1.3GW which demonstrates a good track record in the Indian solar PV market.

Transformers

The inverter transformers (2000kVA) and power transformer (15/20MVA) used within the project are manufactured by Raychem and Shilchar Technologies Limited, respectively. The manufacturers have good track record of supplying transformers for solar application throughout the. SgurrEnergy has reviewed the transformer based on the information available and considers the transformers utilized for the Project to have technical characteristics in line with industry standards and raises no concerns over its use in the project.

3.5 Module support structures

The Array Layout provided by the Client for the 30MW(AC) USUPL Solar PV Plant indicates the fixed tilt module mounting structure is inclined at 19° tilt angle.

SgurrEnergy observed that the structure has been designed with two rows of modules placed in portrait orientation with 20 modules in each row. In total there are 40 modules in one mounting structure.

Figure 3-1 and Figure 3-2 illustrate the module mounting structure configuration provided by the Client for the 30MW(AC) USUPL Solar PV Plant.

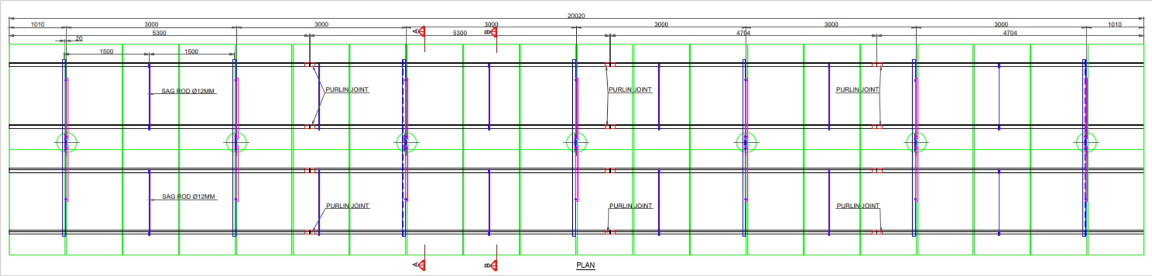

Figure 3-1: Two in portrait module mounting structure with 20 modules in each row

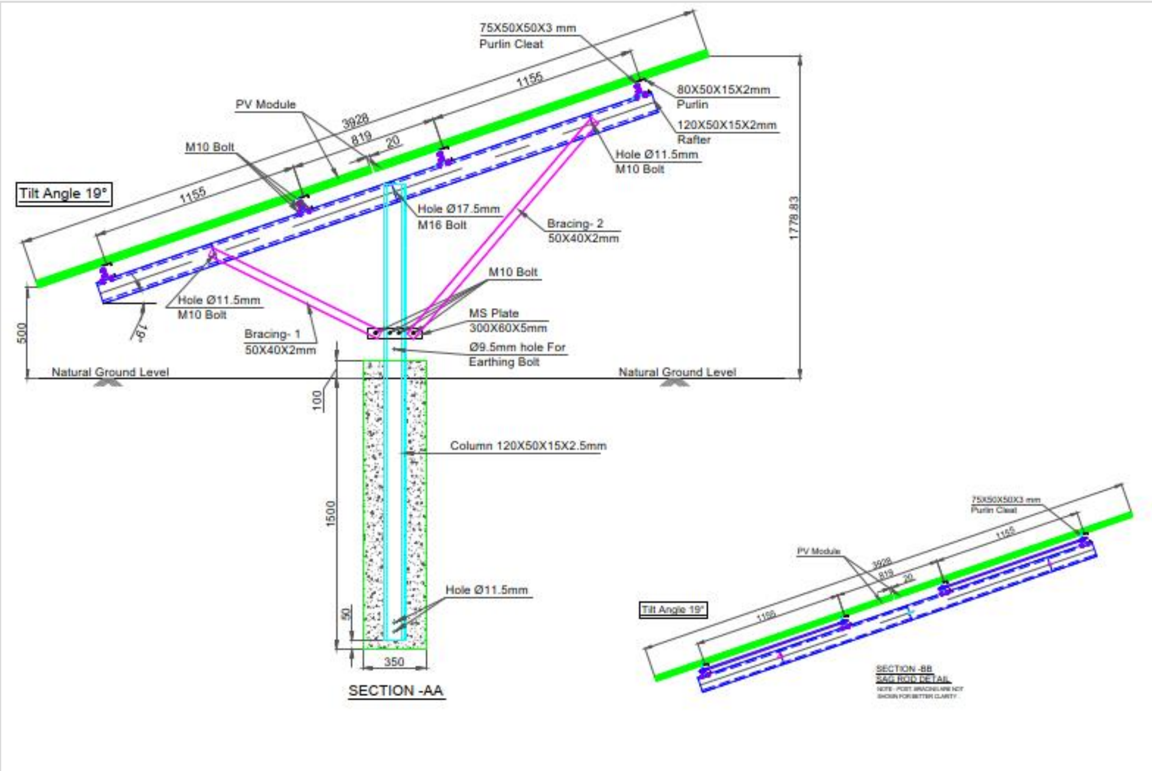

Figure 3-2: Section of the module mounting structure configuration

4 Allied Components and Systems

4.1 Civil Structures

Based on the review of Plant layout, SgurrEnergy observed that the inverter stations are placed at centre of each block module to minimise cable losses.

4.2 PV Power Transfer

SgurrEnergy has reviewed the electrical schematic provided by the Client. The electrical schematic describes the overall connection of the PV modules, inverters, transformers, switchgear, and plant substation as well as providing the ratings of all the components.

SgurrEnergy has been provided with the following electrical schematic for the Project.

- 132kV Single Line Diagram dated 23/12/2015
- MCR key SLD (DC), ICR-2 to ICR-8 key SLD (DC) – R1

The 30MW$_{AC}$ solar PV Plant is designed with 315W$_P$/320W$_P$ Canadian solar PV modules and 1000kW ABB inverters. PV modules are interconnected in series to form a string of 20 modules. Such two strings are paralleled with the help of Y-connector and the output of such 10/11/12 Y-connectors feeds as inputs to 12 input monitoring boxes. Eight string monitoring boxes are further connected to the inverter.

The 30MW$_{AC}$ solar PV plant has been configured with thirty ABB 1000kW central inverters and eight inverter stations. SgurrEnergy observed out of eight inverter station, seven inverter stations is of 4MW$_{AC}$ capacity and other one is of 2MW$_{AC}$ capacity.

Each 4MW$_{AC}$ capacity inverter station consists of four 1000kW inverters connected to 4MVA, 11/4x0.380kV five winding transformer while the inverter station of 2MW$_{AC}$ capacity consists of two inverters, which are connected to 2MVA, 11/2x0.380kV three winding transformer. The voltage is stepped up to 11kV for all inverter stations by 4MVA and 2MVA transformers.

The medium voltage output from seven inverter duty transformers is connected with 11kV ICOG (Incoming and outgoing) panel placed at inverter station. The power output from seven ICOG panels and one 2MVA transformer is radially connected to 11kV HT switchboard panel located in CMCS room. The 11kV output from switchboard panel is connected to 2x15/20MVA, 11/132kV power transformers located in switchyard.

The power from 11/132kV plant end substation is transferred to *Panwari S/S bay, UPPTCL, Switchyard* through 5km 132kV transmission line.

Figure below illustrates a power flow summary for the 30MW$_{AC}$ Solar PV plant.

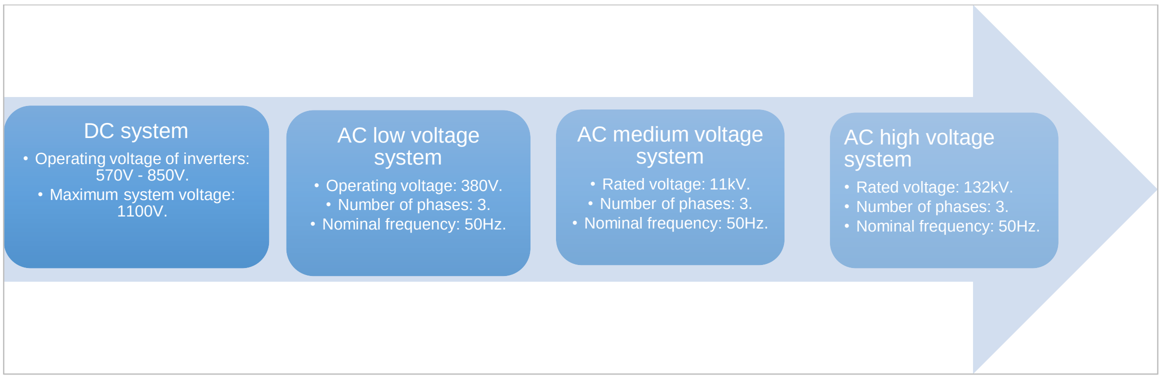

Figure 4-1: Power flow of 20MW$_{AC}$ PV plant

4.3 Cabling

4.3.1 DC Cabling

DC cabling comprises of PV module leads, string cables connecting the PV module strings to combiner box and main DC cables connecting the combiner box to the inverter fuse and then to the inverter. PV modules are interconnected in series with 6mm^2 solar grade cables.

The Y connectors shall be further connected to the 12 input String Monitoring Box using 6mm^2 solar grade cables. The string monitoring box output is connected to inverters by using single runs of single core 300mm^2 Aluminium XLPE cables. The inverter DC inputs are equipped with 315A fuses for overcurrent protection.

4.3.2 AC Cabling

Three phase AC output from inverter is connected to the LV windings of 4MVA, 2MVA inverter duty transformers respectively, using multiple run single core 300mm^2 Aluminium Armoured XLPE cable. The inverter transformers step up the voltage to 11kV.

Power is fed from the high voltage side of each transformers using 1R, 3C, 300mm^2, 11kV Al XLPE armoured cable to the 11kV ICOG panel in the inverter stations using a radial feeder arrangement.

Power from each inverter station ICOG panel is transmitted to 11kV main HT switchboard panel located within CMCS room using 1R, 3C, 185mm^{2,} 11kV Al XLPE armoured HT cables.

The power from the Main HT switchboard panel is transferred to 2x15/20MVA, 11/132kV, power transformers. Cable details are mentioned in SLD, however as the submitted SLD is not clearly visible. Further the output power of 11/132kV plant end switchyard is transmitted to UPPTCL switchyard, Panwari.

4.4 Inverter Station

The 30MW$_{AC}$ solar PV plant has been configured with 30 inverters and eight inverter stations. out of eight inverter station, seven inverter stations is of 4MW$_{AC}$ capacity and other one is of 2MW$_{AC}$ capacity.

Each 4MW$_{AC}$ inverter station consists of four inverters connected to a 4000kVA five winding transformers, while each 2MW$_{AC}$ inverter station consists of two inverters connected to a 2000kVA three winding transformer. Each transformer, along with allied switchgears, steps up the voltage to 11kV for all inverter stations. Further the power from the HV side of the transformer is fed to the 11kV ICOG panel through radial feeder arrangement.

11kV ICOG panel comprises of current transformer, fixed type line potential transformer, 11kV Vacuum Circuit Breaker and other electrical protection system. The ratings of equipment are not clearly visible in SLD submitted.

4.5 LV/MV Transformers

SgurrEnergy has reviewed the SLD and observed that 4MVA, 11kV/4x0.380kV, Dy11y11 five winding transformer and 2MVA, 11kV/2x0.380kV, Dy11y11 three winding transformer have been used in this project. These inverter duty transformers step up the voltage to 11kV.

The inverter transformers output is connected to 11kV ICOG panels located within inverter station. The energy from all the inverter stations is radially combined at main HT switchboard panel located in CMCS room.

4.6 11kV ICOG Panel

The 11kV ICOG panel comprises of inverter duty transformer incoming feeder with metering and protection current transformer, potential transformer, circuit breaker and other electrical protection system. The ratings of equipment are not clearly visible in SLD submitted.

4.7 11kV HT Switchboard Panel

The 11kV main HT switchboard panel comprises of inverter station incoming feeders, two outgoing feeders. Each feeder comprises of dedicated VCB, instrument transformer with metering and protection class. All feeders have been provided with relay and metering unit. All feeders are provided with instantaneous and IDMT (50/51) O/C relay instantaneous and IDMT (50N/51N) E/F relay protections.

Power from 11kV HT switchboard panel is transmitted to 2x15/20MVA, 11/132kV power transformers located in switchyard.

4.8 11kV/132kV Switchyard

The 11kV HT switchboard panel outgoing feeders are connected to respective 15/20MVA, ONAN/ONAF, YNyn0, 132/11kV, power transformers located in 132/11kV plant end switchyard.

The 132/11kV switchyard is equipped with SF_6 circuit breaker, isolators, surge arrestors and current transformers for both line and transformer feeders. The 0.2S class current transformers and 0.2 class potential transformers for tariff metering considered.

4.9 Auxiliary Power Supply

Auxiliary system single line diagram has not been provided to SgurrEnergy. However, based on information received, SgurrEnergy understand that one 150kVA, 380/415kV auxiliary transformer is considered with inverter room ACDB for auxiliary loads.

4.10 Circuit Breakers

Circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal and abnormal circuit conditions. The circuit breakers are three poles type with electrically and mechanically operated trip-free with anti-pumping facility suitable for remote electrical closing and tripping. The circuit breakers are normally mounted on individual structures.

The ratings of circuit breakers are not clearly visible in SLD submitted.

4.11 Isolators

Isolators are used to transfer load from one bus to another and also to isolate equipment for maintenance.

The ratings of isolators are not clearly visible in SLD submitted

4.12 Instrument Transformers

Current transformers (CT) and voltage/potential transformers (VT) are known to be as instrument transformers. Instrument transformers are devices used to transform the values of current and voltage in the primary system to values suitable for the measuring instruments, meters, protective relays, etc.

The current transformer of Class 0.2S and potential transformer of Class 0.2 is seems to be considered for tariff metering in 11/132kV switchyard.

4.13 Surge Arrestors and Lightning Arresters

The substation equipment has to be protected against travelling waves due to lightning strokes and switching surges from incoming lines. The apparatus most commonly used for this purpose is the surge arrester. Transformer is the costliest equipment in substation, and it is normal practice to install surge arrester near to the transformer. Additional surge arresters shall be provided either on bus or on various lines for protection of the equipment.

Following the review of SLD, SgurrEnergy observed that surge arrester have been considered for transformer and line feeders of 11/132kV switchyard. The ratings of surge arresters are not clearly visible in SLD submitted

4.14 Metering

In addition to the metering and monitoring arrangement in inverters, monitoring of voltage, current and energy will be provided at the medium voltage switchboards for each of the feeder sections. These meters will be digital with an RS 485 port for remote monitoring. These usually have an accuracy class of 0.5.

Similarly, HV side shall also be equipped with voltage, current, power and energy meters in order to correlate the energy generation and losses. Class of meters at the evacuation point shall be 0.2S. The current transformer of Class 0.2S and potential transformer of Class 0.2 is seems to be considered for tariff metering in 11/132kV switchyard.

5 System Design Appraisal

SgurrEnergy has performed a detailed analysis to evaluate the string sizing and compatibility of the inverters with PV modules used for the Project. The following sections discuss the results obtained from the analysis.

5.1 Plant Layout Design

SgurrEnergy was provided with as built plant layout and electrical schematics. SgurrEnergy has verified the plant configuration with electrical schematics provided by the Client. The PV plant is implemented with Canadian Solar (315W$_P$ and 320W$_P$) PV modules. The total DC installed capacity stands at 36.98 MW$_P$ out of which 30.76MWp has been implemented with fixed tilt configuration and remaining 4.28MWp has been implemented with trackers. The AC installed capacity stands at 30 MW$_{AC}$ with 30 inverters of capacity 1000 kW each. Overall 30 MW$_{AC}$ PV plant is illustrated below in the Figure 5-1.

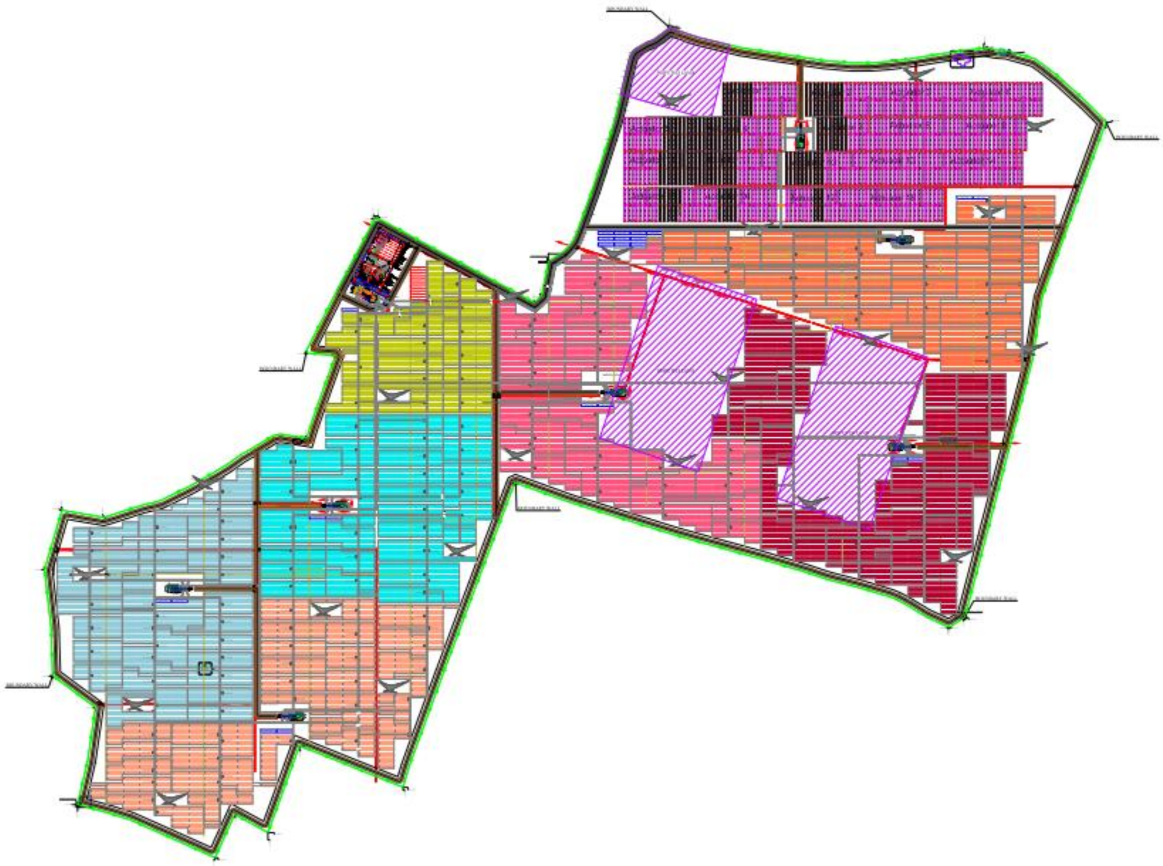

Figure 5-1: Plant layout of 30 MW$_{AC}$

The selected tilt for the 30 MW$_{AC}$ plant is 19° for Fix tilt and the tracers are deployed with North South axis. The 30 MW$_{AC}$ plant is designed with a pitch of 7.5m for Fix tilt and 5 m for Trackers

The nominal plant power ratio (DC to AC) of the Project is 1.17. Typically, PV plants are designed to have a nominal power ratio upto 1.45 in India; a higher ratio leads to greater overload losses during peak irradiance conditions. However, PV module temperature losses are substantial at the high ambient temperatures corresponding to the higher nominal power ratio. 20 modules are connected in series to form a string.

5.2 String Sizing

The plant layout provided by the Developer indicate Ten 320 W_p Canadian Solar modules to be connected in series to form a string for the plant.

As the string voltage is dependent on temperature and irradiation, open circuit voltage (V_{OC}) of the string must be corrected using the temperature co-efficient for the PV modules. Therefore, it becomes necessary to ensure that the maximum voltage input (i.e. the maximum V_{OC} of string at minimum temperature) to inverter does not exceed the inverter maximum operating D.C voltage and hence is a critical value considered by SgurrEnergy in validating string configuration. Subsequent to calculating open circuit voltage (V_{OC} max), maximum power voltage (V_{mp} min) is calculated to ensure that it is within the maximum power point (MPP) range of the implemented inverters.

SgurrEnergy considers the maximum and minimum ambient temperature of 47°C and 4°C respectively for system design validation to be fair and representative for the PV plants' site.

The results of string sizing validation are presented in Table 5-1. Results indicate that V_{OC} max at the minimum ambient temperature is within the maximum system voltage of 1,000V for the selected ABB 1000 KVA (PVS800-57-1000kW-C) inverters.

Table 5-1: String Sizing for Canadian Solar PV Modules

Parameters	Canadian Solar 320Wp
PV module power (W_p)	320
Modules per string	20
Inverters	ABB 1000 KVA (PVS800-57-1000kW-C)
Maximum Open-circuit voltage (V_{OC} max) at minimum ambient temperature of 4°C	844 V
Minimum power voltage (V_{mp} min) at maximum ambient temperature of 47°C	660V

5.3 Inverter Compatibility

SgurrEnergy performed a detailed analysis on plant sizing to assess the compatibility of inverters with the PV modules used in the projects. The electrical design compatibility summary with Canadian Solar and ABB central inverter is presented in Table 5-2. SgurrEnergy has selected the highest rated Canadian Solar module (320W_p) their compatibility with ABB inverter, as SgurrEnergy considers this to be representative for all the Canadian Solar PV modules installed on site.

Table 5-2: Inverter Compatibility with Canadian Solar 320W_p Modules

Parameters	Inverter Compatibility	
PV module	Canadian Solar (CS6X - 320P) 320 Wp	
Modules per string	20	Acceptable
Strings per inverter	187	Acceptable
Maximum power, Pmpp at STC (kWp)	1,190.00	Nominal power ratio is 1.19, this is within the inverter bus current carrying capacity.

Parameters	Inverter Compatibility	
Maximum power voltage, Vmpp at STC (V)	736	Acceptable.
Maximum power current, Impp at STC (A)	834.24	Acceptable
Open-circuit voltage, Voc at STC (V)	906	Acceptable.
Minimum MPP voltage at 47ºC ambient temperature (V)	660	Acceptable: Inverter MPPT ranges 450 - 825V.
Maximum MPP voltage at 4ºC ambient temperature (V)	734	Acceptable: Inverter MPPT ranges 450 - 825V.
Maximum open circuit voltage, Voc at 4ºC (V)	844	Acceptable: Maximum inverter voltage 1000V.

Overall, SgurrEnergy does not raise any concerns regarding the string sizing and inverter compatibility.

6 Resource assessment

The accuracy of any solar energy yield prediction is heavily dependent on the accuracy of the solar resource dataset used. Solar irradiation data is currently not being measured at the location of the proposed power plant and it is therefore necessary to use alternative data sources to obtain estimates of the irradiation figures for the site.

The solar resource of a location may be defined by values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. These parameters are described below.

Global Horizontal Irradiation (GHI) - The global horizontal irradiation is the total solar energy received on a unit area of horizontal surface. It includes energy received from the sun in a direct beam and energy that is received from radiation scattered off the atmosphere arriving from all directions of the sky (diffuse irradiation). The units of GHI are given in kWh/m2. Values are often provided for a period of a day, a month or a year.

Diffuse Horizontal Irradiation (DHI) - The diffuse horizontal irradiation is the energy received from radiation scattered off the atmosphere arriving from all directions of the sky on a unit area of horizontal surface. It is measured in kWh/m^2 and values are strongly dependent on weather conditions and the clearness of the air.

Direct Normal Irradiation (DNI) - The direct normal irradiation is the total solar energy received on a unit area of surface *directly facing the sun at all times*. The units of DNI are kWh/m^2. The direct normal irradiation is of particular interest for solar installations that track the sun and to concentrating solar technologies as only radiation coming directly from the sun may be focussed by a lens or mirror.

For modelling of solar PV plants, GHI and DHI are required for calculating the estimated energy yield. In the northern hemisphere, tilting the modules at an angle towards the south increases the total annual global irradiation that is received on the module plane compared to the horizontal plane. This is quantified by the global tilted irradiation. The optimal tilt angle varies primarily with latitude and also depends on local weather patterns, ground conditions and plant layout configurations.

Tilted modules also benefit from irradiation reflected from the ground which is dependent on the ground reflectance, or albedo. Albedo and global tilted irradiation are described below.

Global Tilted Irradiation (GTI) – The global tilted irradiation is the total solar energy received on a unit area of a tilted surface. It includes direct and diffuse irradiation along with ground reflected irradiation. The units of GTI are kWh/m^2. A transposition model is used for translating horizontal irradiation to tilted irradiation within PV modelling software.

Albedo – The ground albedo or reflectance affects the irradiation on a plane when it is tilted from horizontal and increases the GTI. The albedo is highly site and weather dependent, with typical grass coverings giving an albedo of approximately 0.2 and fresh snow giving an albedo of approximately 0.8, meaning that 20% and 80% respectively of the irradiation is reflected back into the atmosphere.

Comparison of Resource Data

There are a variety of possible solar irradiation data sources that may be accessed. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite imagery. A minimum of 10 years of data is recommended to allow for the expected variability of resource data between years. SEI has sourced monthly horizontal plane irradiation data for the Project site from:

- ***NASA****'s Surface Meteorology and Solar Energy data set;* holds satellite derived monthly data for a grid of 0.5° × 0.5° covering the globe for a thirty-four-year period (1984-2017). The data are suitable for pre-feasibility studies of solar energy projects.

- *The **METEONORM (version 7.3)** global climatological database and synthetic weather generator;* contains a database of ground station measurements of irradiation and temperature. Where a site is over 11km from the nearest measurement station it outputs climatologic averages estimated using interpolation algorithms. Where no radiation measurement station is within 300km from the site, satellite information is used. If the site is between 50 and 300km from a measurement station a mixture of ground and satellite information is used. The accuracy of irradiation figures close to measurement stations are within a few percent. Uncertainty increases with distance between the site and the measurement station, especially in hilly and mountainous terrain.
- **SolarGIS:** SolarGIS is developed and operated by GeoModel a solar company maintaining databases of climate data to support solar energy projects and systems. Database is derived from Meteosat and Geostationary Operational Environmental Satellite system (GOES) satellite data and atmospheric parameters (aerosol and water vapour) using high performance algorithms. SolarGIS regional coverage includes Europe, Africa, Asia and parts of South America and Australia. The spatial resolution of primary parameters for European region is approximately 4km × 4km with a temporal resolution of between 15 minutes to 3 hours. SolarGIS radiation models use multispectral channels and multi-dimensional statistical treatment of ground albedo, daily values of aerosol and water vapour. SolarGIS models is validated by *IEA (International Energy Agency) SHC Collaboration Agreement, and EU FP6 project MESoR* in terms of bias and RMSE.
- **Solar and Wind Energy Resource Assessment (*SWERA)* / National Renewable Energy Laboratory *(NREL)*** data was developed from NREL's Climatological Solar Radiation (CSR) Model using primary data from geostationary satellites. The satellites provide information on the reflection of the earth-atmosphere system and the surface and atmospheric temperature which is useful in determining cloud cover. Model outputs are verified with ground-based data to ensure quality of the measurements.

SEI has compared the irradiation datasets given by NASA - SSE, Meteonorm 7, SolarGIS and, NREL (SWERA) data for the site. The comparison is graphically illustrated Table6-1

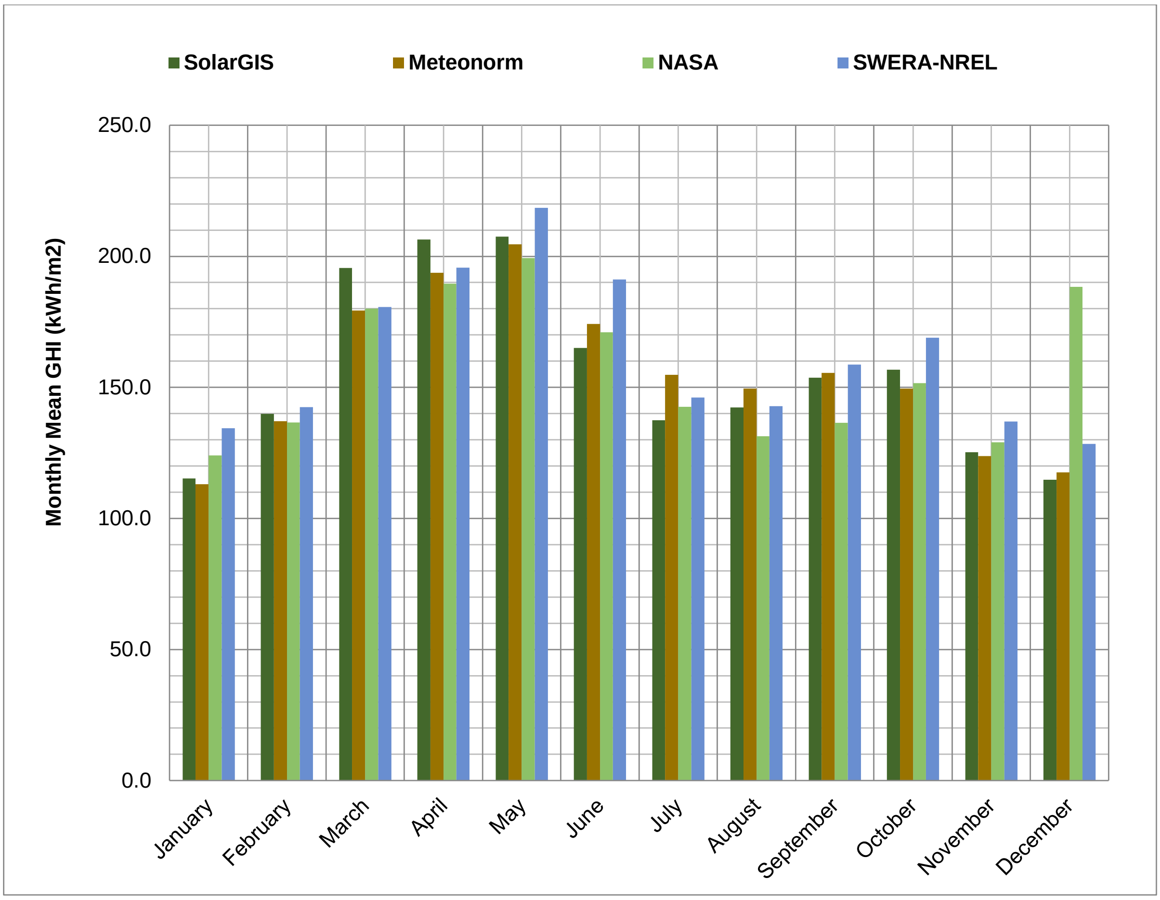

Figure 6-1: Monthly Global Horizontal Irradiation

Table6-1: Comparison of Solar Irradiation Datasets for the site

Data source	Satellite Resolution	Uncertainty	GHI (kWh/m^2/annual)
SolarGIS	4km × 4km	3.9%	1859.8
Meteonorm 7.3	14km × 14km	4.0%	1852.752
NASA	55km × 55km	Unknown	1880.1
NREL (SWERA)	40km × 40km	Unknown	1944.867

The comparison of solar data for Project site location illustrated in Table6-1 indicates NREL (SWERA) dataset to give the highest irradiation levels. The next highest irradiation is given by NASA followed by SolarGIS and Meteonorm 7.2.

The irradiation values given by Meteonorm 7.2 typically provide a combination of ground and satellite measured data. Meteonorm 7.2 has interpolated the data using satellite data for the proposed site. Uncertainty of satellite data is obtained as 5.2% for the proposed site.

The NREL (SWERA) data illustrated has been obtained for a location approximately 18.62 km away from the proposed site. SgurrEnergy performed iteration on an extensive list of NREL (SWERA) datasets to obtain appropriate coordinates that lie within the Indian boundaries. The results give only irradiation data without temperature and wind data.

The NASA-SSE data source provides purely satellite measured data for a grid covering 0.5° × 0.5° on the earth's surface and generally more suited for initial site selection.

The SolarGIS dataset has been compared with good quality ground measurements for more than 200 sites. The resulted mean bias for GHI is 0%. SolarGIS data base has also been compared with other data sources globally. The IEA (International Energy Agency) validation study conducted by University of Geneva in 2011 has resulted in SolarGIS to be the best performing database among five satellite databases. Similar IEA validation study was repeated in 2013 by University of Geneva which again resulted in SolarGIS to be the best performing database among six satellite databases. Validation study in 2013 was conducted using 18 validation sites in Europe and Mediterranean regions. Furthermore, SolarGIS has conducted its own validation for six Indian locations[10] with the following bias in GHI;

- Pantnagar (Uttarakhand)
- Kanpur (Uttar Pradesh)
- Mysore (Karnataka)
- Warangal (Telangana)
- Jaipur (Rajasthan)
- Ranchi (Jharkhand)

Comparative analysis of all the data sets available, indicate SolarGIS has been validated for India. Furthermore, SolarGIS dataset is based on the most recent long-term average that is from 1999 – 2015, while Meteonorm dataset is based on the time-period of 1991 - 2010. The uncertainty of SolarGIS is 3.9% while that of Meteonorm is 6%.

SEI is therefore of the opinion that SolarGIS dataset may be considered reasonable and a representative data source for conducting an energy yield assessment for the project location.

6.1 Global, Direct and Diffuse Irradiation on a Horizontal Plane

Horizontal plane irradiation data based on long-term monthly averages are presented in Table 6-2 and shown graphically in Figure 6-2 Diffuse irradiation accounts for 49.07%of the total irradiation. Table 6-2 illustrates direct and diffuse daily irradiation on a horizontal plane for the proposed site. SolarGIS irradiation data is presented in Table 6-2.

Table 6-2: SolarGIS Irradiation Data for the Project site

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
January	115.3	56.4	6.2%
February	139.9	54.3	7.5%
March	195.5	69.1	10.5%
April	206.4	82.5	11.1%
May	207.5	102.9	11.2%
June	165.0	97.8	8.9%
July	137.4	92.1	7.4%
August	142.4	89.0	7.7%
September	153.7	77.1	8.3%

[10] https://solargis.com/docs/accuracy-and-comparisons/overview/

Month	Monthly GHI (kWh/m^2)	Monthly Diffuse (kWh/m^2)	Proportion of GHI to Annual
October	156.8	72.5	8.4%
November	125.2	62.4	6.7%
December	114.7	56.4	6.2%
Annual Sum	**1,859.8**	**912.6**	**-**

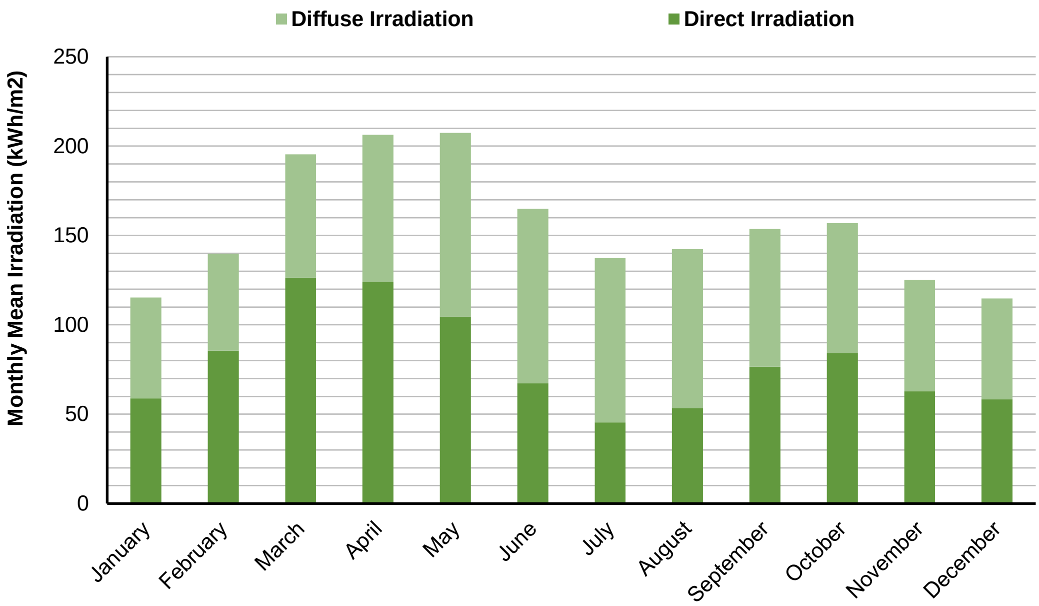

Figure 6-2: Monthly Direct and Diffuse Irradiation on a horizontal plane for the project site

6.2 Global Tilted Irradiation

Industry standard PV modelling software PVsyst (v.7.0.17), was used. An albedo of 0.2 was assumed based on the ground surface covering within and around the PV array. Table -6-3 represents the monthly GTI profile.

Table -6-3: Monthly Global Tilted Irradiation Data

Month	GTI (kWh/m^2) (Fix Tilt)	GTI (kWh/m^2) (Tracker)
January	141.8	175.70
February	166.7	207.40
March	216.7	253.60
April	211.9	217.70
May	201.3	183.40
June	156.6	137.30
July	131.2	117.60
August	141.1	135.60
September	162.6	178.00

Month	GTI (kWh/m^2) (Fix Tilt)	GTI (kWh/m^2) (Tracker)
October	178.7	210.80
November	151.8	187.50
December	144.1	181.80
Annual Sum	2004.3	2186.50

6.3 Climate

For wind speed analysis, data sourced from Meteonorm dataset was used and has been tabulated in Table 6-4 below. The average wind speed of 0.8 m/s was measured at 10m height from ground level for the proposed project site location.

Table 6-4: Simulated Wind Speed for site

Month	Average Wind Speed (m/s) – Meteonorm Data
January	0.5
February	0.7
March	0.8
April	0.9
May	1.3
June	1.3
July	1.2
August	1.1
September	0.8
October	0.4
November	0.3
December	0.4
Yearly Average	0.8

6.4 Temperature

Temperature data has been sourced from the SolarGIS database. A typical operating temperature range for PV modules is -40°C to +85°C. Inverter operating ranges are more bounded to temperature, typically -20°C to +45°C, with the electronic equipment in the inverter degrading quicker in high temperature environments. Thus, considering the temperature range at selected site, the modules and inverters should be able to operate normally.

The effect of temperature on module performance and the corresponding plant performance may be quite significant. Typically, a reduction in efficiency of 0.40 – 0.45%/°C is noted for crystalline modules and 0.25 -0.30%/°C for thin film modules for increase in temperatures above 25°C. Therefore, during the summer months (February-June) temperature losses may be significantly high as module temperatures typically go beyond 50°C.

Table 6-5: SolarGIS Temperature Data for Site (1999 – 2018)

Months	Average Monthly Temperature (°C)
January	14.8
February	18.7
March	24.7
April	30.7
May	34.9
June	35.0
July	30.8
August	28.9
September	28.2
October	25.8
November	20.4
December	15.8
Annual Average	25.8

6.5 Precipitation

The rainfall figures have been simulated using Meteonorm 7.2 as illustrated in Figure 6-3. These figures show that the identified site is situated in a region that has marginal rainfall.

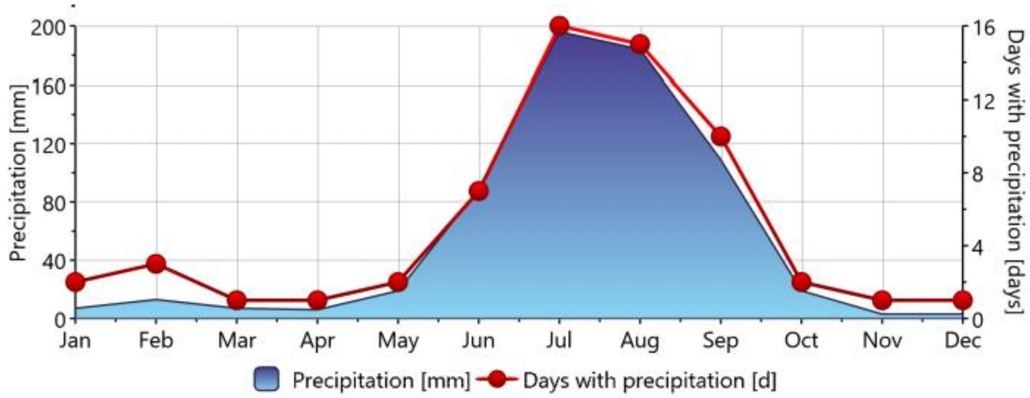

Figure 6-3 Meteonorm Predicted Precipitation for the site

PV modules are soiled by particulates of dust, dirt and bird droppings. Soiling of modules has a high impact on the energy yield thereby leading to a loss up to 3% in non-arid regions. Therefore, the modules need to be cleaned for avoiding the loss due to soiling.

Frequency of module cleaning depends on the rainfall frequency and the prevalence of dust and pollution in the local vicinity. Typical cleaning techniques include water cleaning, dry brushes or vehicle-based mechanical cleaning.

The frequency of module cleaning is primarily dependent on the amount of soiling experienced on the site. Soiling loss of 2% has been considered by considering cleaning frequency of twice a month.

7 Energy Yield Analysis

SgurrEnergy has computed the annual energy yields for the 30MW$_{AC}$ Solar PV Plant using basic designs and indicative layout. Energy yields for all the PV technology configurations under evaluation is further elaborated in the following section.

Parameter	Description
Modules	Canadian Solar 320 W_p, (CS6X - 320P) Canadian Solar 315 W_p (CS6X - 315P)
Inverters	ABB Central Inverters – 1.0MW$_{AC}$ (PVS800-57-1000kW-C)
Mounting System	Fixed Tilt, Tracker
DC Capacity (MW_p)	36.98

For energy yields SgurrEnergy has:

1) Sourced average monthly horizontal irradiation, wind speed and temperature data with the other sources which included satellite image derived data. These data have been assessed for use in the energy yield simulation software.
2) Following the assessment, SgurrEnergy has selected site specific data sourced from SolarGIS to arrive at representative energy yield estimates.
3) Calculated the global incident radiation on the tilted plane, taking into account shading.
4) Applying downtime losses, AC ohmic losses, and module degradation losses to obtain energy yields that reflect twenty-five-year plant life.

Using statistical analysis of resource data for inter-annual variability to derive appropriate levels of uncertainty in the energy yield prediction, steps 2 and 3 are facilitated using industry standard photovoltaic simulation software which simulates the energy yield using hourly time steps. The software takes as input detailed specifications of:

- The solar PV modules.
- The inverter.
- Mounting system.
- Electrical configuration including number of modules in series and parallel.

7.1 Correction and Losses

Data obtained for irradiation on collector plane, PV module and inverter specifications and plant configuration are input into the PV modelling software to calculate DC energy generated from the modules in hourly time steps throughout the year. This direct current is converted to AC in the inverter.

A number of losses occur during the process of converting irradiated solar energy into AC electricity fed into the grid. The losses may be described as a yield loss factor. They are calculated within the PV modelling software and calculated from the cable dimensions. Others are nominal figures applied from knowledge of performance of similar PV plants. The losses are broadly summarised in Table 7-1 below.

Table 7-1: Description of Energy Yield Losses

Loss	Description
Shading	Three types of shading losses are considered in the PV energy yield model: horizon shading, shading between rows of modules and near shading due to trees and buildings.
Incident Angle	The incidence angle loss accounts for losses in radiation penetrating the front glass of the PV modules due to angles of incidence other than perpendicular.

Loss	Description
Low Irradiance	The conversion efficiency of a PV module reduces at low light intensities.
Module Temperature	The characteristics of a PV module are determined at standard temperature conditions of 25˚C. For every ˚C temperature rise above this, module efficiency reduces according to their temperature coefficient.
Soiling	Losses due to dust and bird droppings; soiling the module.
Module Quality	Most PV modules do not match exactly the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a given tolerance within which the actual power is guaranteed to lie.
Module Mismatch	Losses due to "mismatch" are related to the fact that the real modules in an array do not all rigorously present the same current/voltage profiles: there is a statistical variation between them.
DC Wiring Resistance	Electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).
Inverter Performance	Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.
MPP Tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the maximum power point voltage. Different inverters do this with varying efficiency.
AC Losses	This includes ohmic losses from inverter to evacuation point.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
Grid Availability and Disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Power Curtailment Losses	Curtailment loss is attributed to the utility limiting the power intake at the contracted AC capacity of the PV Plant; thus, the excess energy generated beyond the limit of 30MW$_{AC}$ at the metering level shall not be accounted
Degradation	The performance of a PV module decreases with time.

7.2 P50 Energy Yield Predictions

This section presents the SgurrEnergy's independent energy yield prediction for the 30MW$_p$ solar PV Plant with Canadian solar PV modules and ABB central inverters. Table 7-2 summarises the solar PV power plant, the available resource, the losses and the predicted P50 yields.

Table 7-2: Energy Yield for the 30MW$_{AC}$ Solar PV Plant

Parameters	Description	
	Fix Tilt	Tracker
PV Module Technology	Polycrystalline	

Parameters	Description	
	Fix Tilt	Tracker
DC Capacity (MW_p)	31.95	5.02
AC Capacity (MVA)	26	4
P_{NOM} Ratio	1.22	1.25
Cumulative DC Capacity (MW_p)	36.97	
Cumulative AC Capacity (MVA)	30.0	
Contracted Capacity (MW)	30.0	
Cumulative P_{NOM} Ratio	1.23	
Tilt (°)	19	-
Pitch (m)	7.5	5
Annual Global Horizontal Irradiation (kWh/m^2)	1859.80	
Global Irradiation Incident on Collector Plane (kWh/m^2)	2004.34	2186.49
Transposition Factor	1.08	1.18
Losses		
Horizon Shading	0.00%	0.00%
Incident Irradiation Below Threshold	0.00%	0.00%
Near Shading	1.7%	1.5%
Incident Angle	2.8%	2.1%
Soiling	2.0%	2.0%
Low Irradiance	0.2%	0.2%
Module Temperature	9.2%	9.8%
Electrical Shadings	0.0%	0.0%
Module Quality	0.00%	0.00%
First year Degradation	2.00%	2.00%
Module Mismatch	1.00%	1.00%
DC Ohmic	0.7%	0.8%
Inverter Performance	1.6%	1.7%
Availability	1.00%	1.00%
AC Ohmic	0.5%	0.6%
Transformer (LV/MV)	1.00%	1.00%
Transformer (MV/HV)	0.5%	0.5%
Transmission Line	0.0%	0.0%
Auxiliary Consumption	0.75%	0.75%
Curtailment		
Total Annual Loss Factor	***0.775***	***0.774***

Parameters	Description	
	Fix Tilt	Tracker
First Year P50 Energy Yield (MWh/annum)	49,611.98	8,503.76
Fifth Year P50 Energy Yield (MWh/annum)	48,627.15	8,334.96
Fifth Year Specific Yield (kWh/kW$_p$)	1,521.93	1,657.74
Fifth Year CUF on AC Installed Capacity	21.35%	23.79%
Fifth Year CUF on Contracted Capacity	21.35%	23.79%
Fifth Year CUF on DC Installed Capacity	17.37%	18.92%
Fifth Year Performance Ratio	75.93%	75.82%
Cumulative		
First Year P50 Energy Yield (MWh/annum)	58,115.74	
Fifth Year P50 Energy Yield (MWh/annum)	56,962.11	
Fifth Year Specific Yield (kWh/kW$_p$)	1540.39	
Fifth Year CUF on AC Installed Capacity	21.68%	
Fifth Year CUF on Contracted Capacity	21.68%	
Fifth Year CUF on DC Installed Capacity	17.58%	
Fifth Year Performance Ratio	75.916%	

Graphical representation of the monthly generation, performance ratio and CUF for 30 MW$_{AC}$ evaluated is illustrated graphically in the Figure 7-1.1 (Fix Tilt , 26 MW$_{AC}$) &Figure 7-1.2 (Tracker , 26 MW$_{AC}$) .

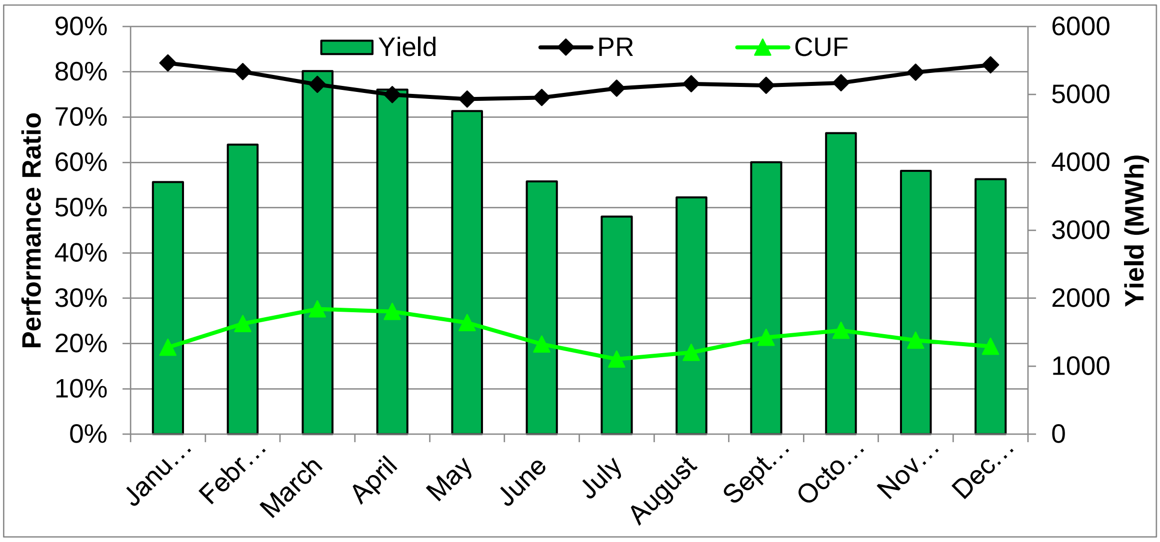

Figure 7-1.1: Monthly Energy Yield for Fix Tilt 26 MW$_{AC}$

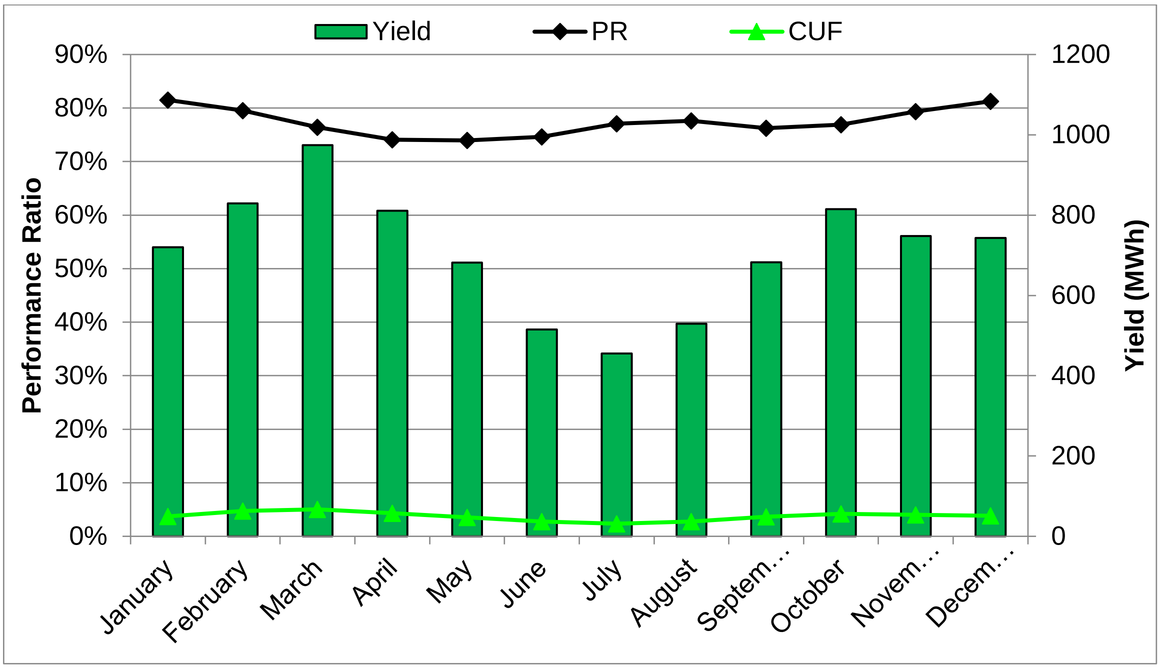

Figure 7-2.2 : Monthly Energy Yield for Tracker 4 MW$_{AC}$

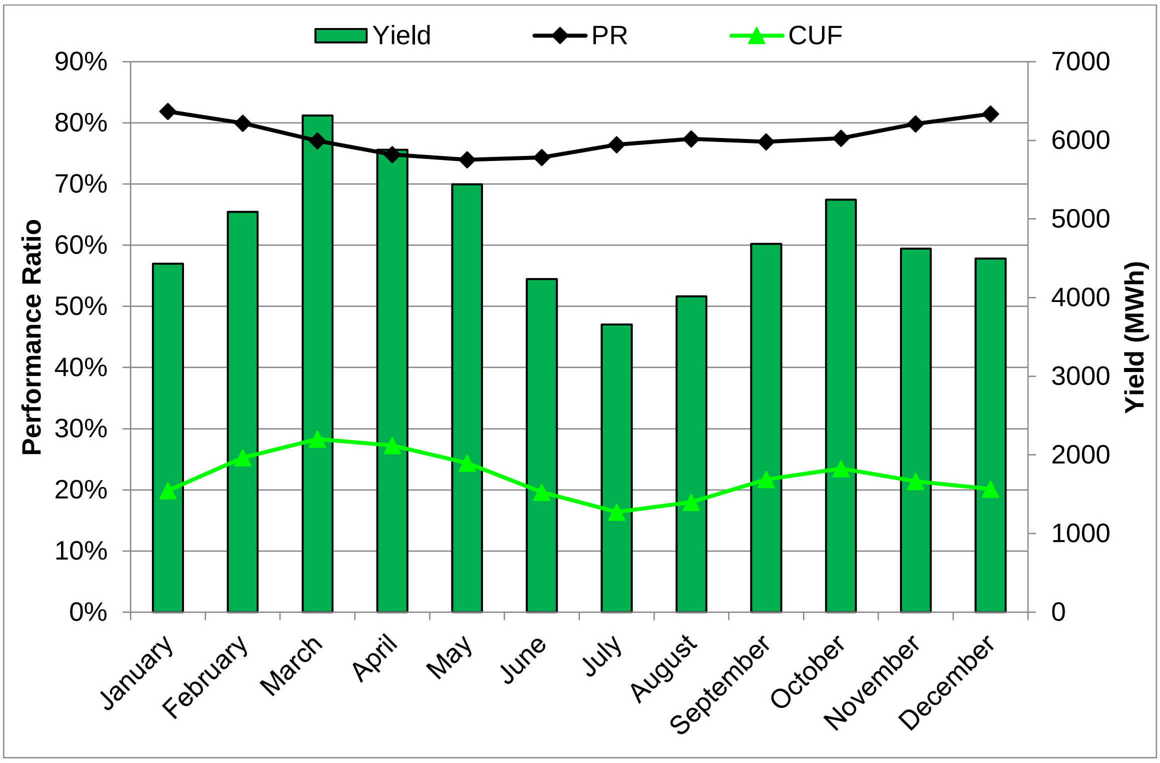

Figure 7-3.3 : Monthly Energy Yield for Tracker 30 MW$_{AC}$

7.3 Yield Uncertainty

The uncertainty in energy yield predictions is difficult to quantify as it is a function of many independent factors. The discussion below represents simplification of the estimated uncertainty which is believed to be the best approach given the uncertainty in the resource data.

7.3.1 Solar Resource Measurement Uncertainty

Energy yield prediction is based on SolarGIS database, a satellite data which is derived from Meteosat Indian Ocean Data Coverage (Meteosat IODC) and atmospheric parameters using high performance algorithms set by SolarGIS method.

The resource data for 16+ years (1999-2015) has been obtained from the SolarGIS climatological database. SolarGIS recommends an uncertainty of 3.9%.

The uncertainty in transposing the global horizontal irradiation to global tilted irradiation is dependent on the accuracy of the initial data and the characteristics of the specific location. Based on the SgurrEnergy's experience, the uncertainty associated with the transposition model is 1.5%.

7.3.2 Inter – Annual Variation in the Solar Resource

Mean global daily irradiation on a horizontal plane varies on an annual basis. This means that the plant owner does not know what energy yield to expect in any given year but can have a good idea of the expected yield in the long term.

The likely variation can be quantified based on analysis of variation in long-term irradiation data in the vicinity of site. SgurrEnergy has sourced 35 year's data from NASA database for the proposed site location which is used to estimate the standard deviation of variation in irradiation. SgurrEnergy has analysed this dataset and computed the coefficient of variation (standard deviation divided by the mean) as shown in Table 7-3.

Table 7-3: Summary of Figures for Inter-Annual Variation in Resource

Number of Years of Data	35
Coefficient of Variation	4.83

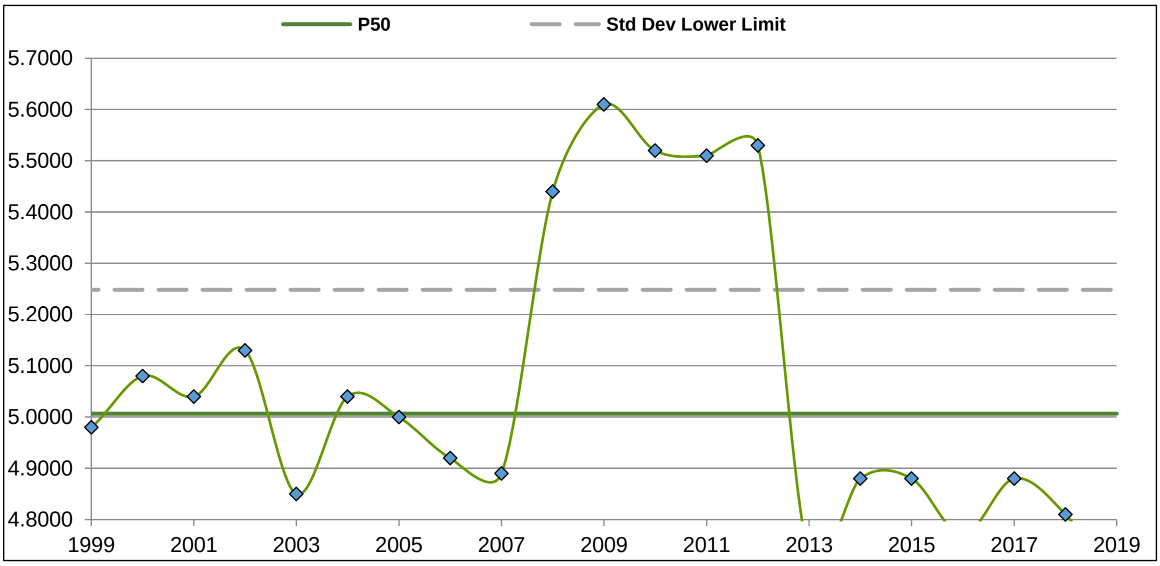

Figure 7-4: Inter-Annual Variability of GHI

Graphical illustration of inter annual variation is presented in Figure 7-4.

SgurrEnergy uses a coefficient of variation of 4.83% to quantify the inter-annual variation in the solar resource.

7.3.3 Modelling Uncertainty

The modelling uncertainty is a combination of the various uncertainties for each loss factor assessed in the modelling process. Efforts to validate the photovoltaic simulation software used data from seven grid connected systems in Europe. These indicated that the accuracy of the results of the simulation is in the order of 2 to 3%.

7.3.4 Total Uncertainty (P75 and, P90 Energy Yield Predictions)

Combining the uncertainties in energy yield and inter-annual variation in the solar resource, the P50, P75 and P90 confidence interval are presented for each PV plant configuration in the table below.

Table 7-4: Life Cycle P50, P75 and P90 Generation Prediction for 30 MW$_{AC}$

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[11]	P90 Generation Prediction[12]
5	56,962.11	54,729.27	52,719.65
6	56,677.30	54,455.63	52,456.05
7	56,393.92	54,183.35	52,193.77
8	56,111.95	53,912.43	51,932.80
9	55,831.39	53,642.87	51,673.14
10	**55,552.23**	**53,374.66**	**51,414.77**
11	55,274.47	53,107.78	51,157.70
12	54,998.10	52,842.24	50,901.91
13	54,723.11	52,578.03	50,647.40
14	54,449.49	52,315.14	50,394.16
15	54,177.24	52,053.57	50,142.19
16	53,906.36	51,793.30	49,891.48
17	53,636.83	51,534.33	49,642.02
18	53,368.64	51,276.66	49,393.81
19	53,101.80	51,020.28	49,146.84
20	**52,836.29**	**50,765.18**	**48,901.11**
21	52,572.11	50,511.35	48,656.61

[11] The P75 values have been calculated over 10-year averages

[12] The P90 values have been calculated over 10-year averages

Year	Annual P50 Generation (MWh/annum)	P75 Generation Prediction[11]	P90 Generation Prediction[12]
22	52,309.25	50,258.79	48,413.32
23	52,047.70	50,007.50	48,171.26
24	51,787.46	49,757.46	47,930.40
25	**51,528.53**	**49,508.68**	**47,690.75**

8 Operational Analysis and Generation Comparison

To assess the operational performance of the plant, SgurrEnergy has comparatively evaluated the monthly energy yield predicted using satellite-based weather data with the plant generation SCADA values. A factor of 0.5% degradation has been considered for values after a duration of 1 year from COD (Commercial Operational Date) and henceforth. The variation has been evaluated with respect to the difference between the two generation figures.

Based on the information provided by the Owner, SgurrEnergy understands that the USUPL solar PV plant was commissioned in 15th September 2016. SgurrEnergy was provided with plant and grid availability records from April 2017 to April 2021[13] for the solar PV plant. The irradiation records were provided from January 2017 to April 2021.

SgurrEnergy has thus carried out the generation comparison for the PV project for the period from April 2017 to April 2021, henceforth referred to as 'operational period'. SgurrEnergy compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Owner.

SgurrEnergy also observed that the monthly availability figures were provided for the operational period of the solar PV plant. These availability figures were captured within the monthly energy yield predictions assessed for the site in question and were accounted for representative comparison. The average availability based on the provided data has also been specified below.

Based on the availability records provided, SgurrEnergy has analysed the trend in the plant availability and grid availability for each month as presented in the following sections.

1.1.1 Grid Availability

The ability of a PV power plant to export power is dependent on the availability of the grid transmission network and the utility grid substation. Grid unavailability is solely due to the breakdown events associated with the grid substation and substation maintenance, which is beyond the Owners control.

The monthly records of the grid availability from April 2017 to April 2021 have been graphically illustrated in Figure 8-1 below.

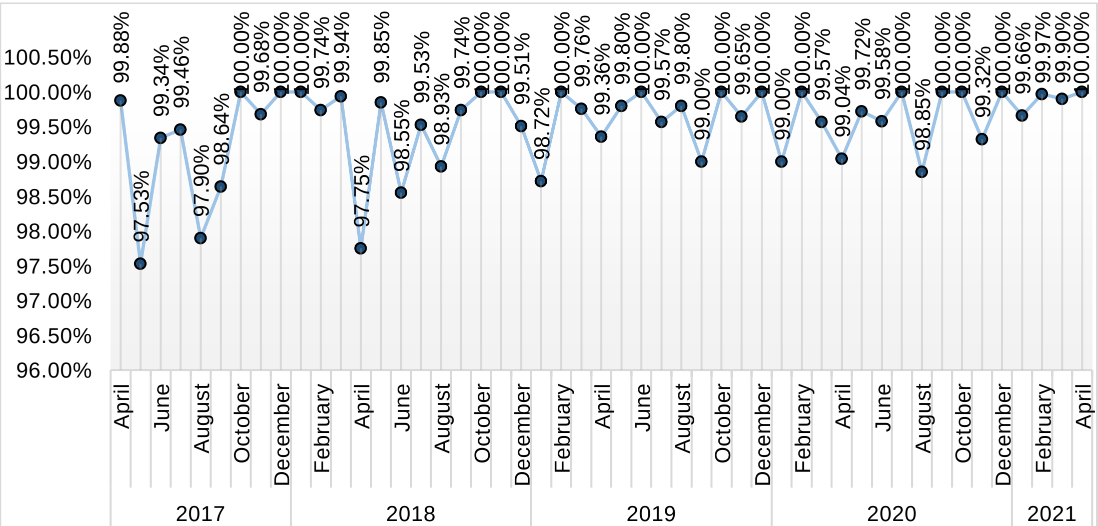

Figure 8-1: Grid Availability

[13] SgurrEnergy was provided with both the plant and grid availability records until April 2021 and hence the analysis conducted in the sections below has been done to incorporate the available data.

From the above illustration, SgurrEnergy notes that the unavailability loss experienced due grid anomalies are high over the operational period. For the months of May 2017, August 2017 and April 2018 unavailability due to grid was high when compared to other months. The downtime due to grid unavailability was above 98.55% during the remaining months.

Overall, the average grid availability experienced on site for the operational period was calculated to be 99.52%

1.1.2 Plant Availability

Plant downtime is a period when the plant does not generate due to failure of equipment in plant until the injection point. The plant downtime period depends on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.

Plant availability of the USUPL solar PV plant is graphically illustrated below in Figure 8-2.

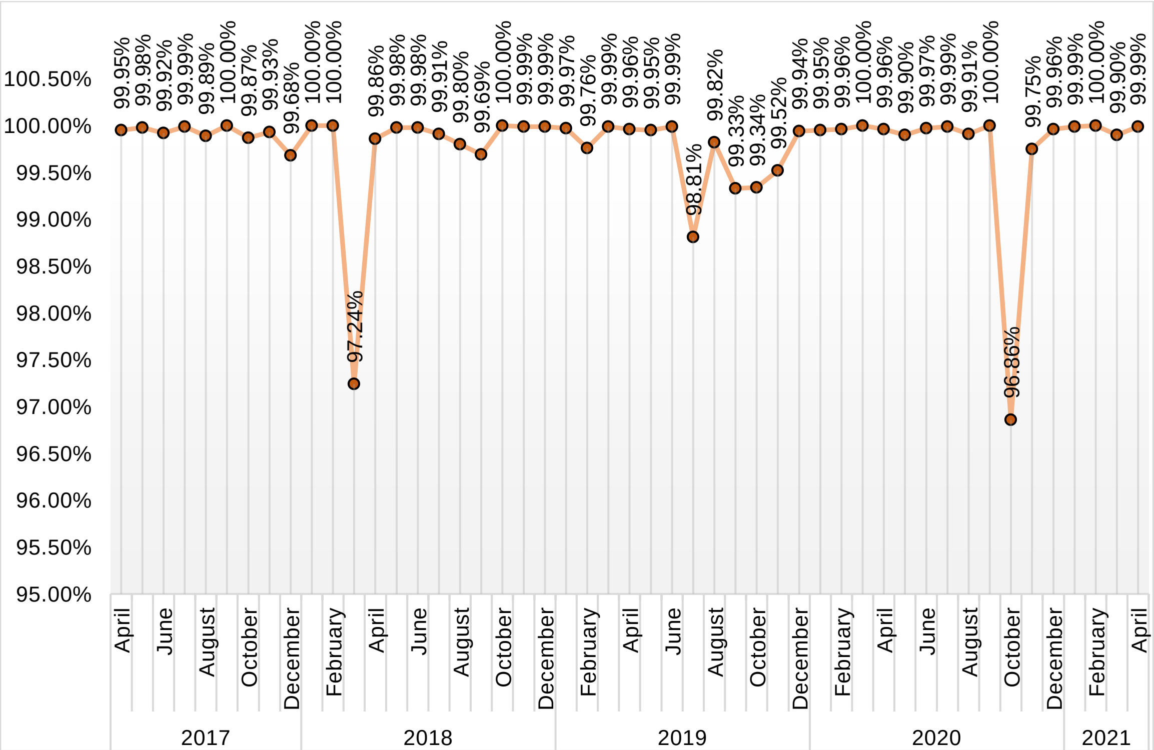

Figure 8-2: Plant Availability

Based on the above illustrations, SgurrEnergy notes the plant availability for the USUPL solar PV plant is consistently above 98.81% for all the months ranging between 98.81% to 100% except for the months of March 2018 and October 2020 where the plant availability was 97.24% and 96.86% respectively. The average plant availability is noted to be 99.76% which is considered to be well above the expected range.

1.2 Energy Yield Comparison

SgurrEnergy has compared its operational energy yield predictions with the onsite generation figures recorded at the energy meter on a monthly level data provided by the Client. To make the operational energy yield predictions more representative, SgurrEnergy has applied the monthly losses due plant and grid unavailability provided by the Client. These predictions are in turn compared with the actual performance of that plant, which are the generation figures shared by the Client.

The yearly comparison of the generation data is illustrated below in Figure 8-3.

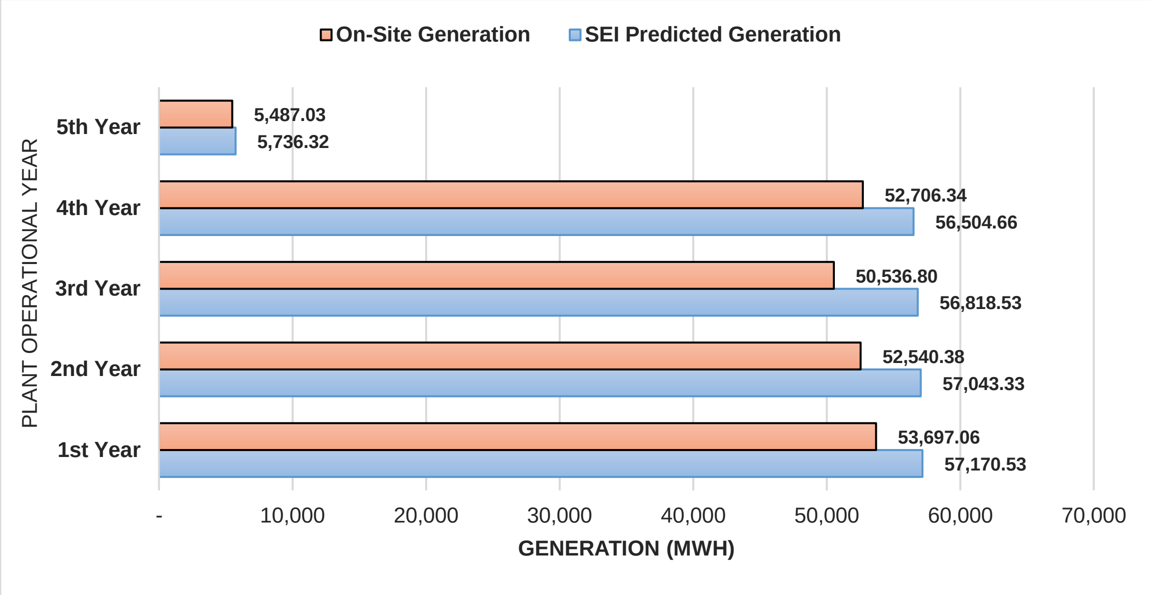

Figure 8-3: Generation Comparison

The variation of the performance of the PV plant for the period of evaluation has been tabulated below in Table 8-1

Table 8-1: PV Plant Performance – USUPL

PV Plant Operation Period	Predicted Generation (MWh)	Recorded Generation (MWh)	Performance Percentage[14] (%)
April 2017 -March 2018	57,170.53	53,697.06	-6.08%
April 2018 - March 2019	57,043.33	52,540.38	-7.89%
April 2019 - March 2020	56,818.53	50,536.80	-11.06%
April 2020 - March 2021	56,504.66	52,706.34	-6.72%
April 2021	5,736.32	5,487.03	-4.35%
Cumulative Period	**233,273.38**	**214,967.61**	**-7.85%**

Based on the above comparison, SgurrEnergy notes that the PV plant is generating lower than the expected yield. However, SgurrEnergy considers that such variations in the energy yield can be attributed to higher irradiation level experienced on the Project site. The irradiation levels significantly impact the actual generation from the PV plant as the system losses may vary significantly due to slight change in the irradiation.

In order to understand the deviation in the irradiation pattern, SgurrEnergy has compared the monthly incident irradiation data provided by the Client with the monthly incident irradiation predicted using satellite-based meteorological data for the period of evaluation. The result of the comparison is presented in the table below and the same is graphically illustrated in the Figure 8-4.

[14] Positive values indicate higher generation, while negative values indicate lower generation

Table 8-2: Irradiation Comparison– USUPL

PV Plant Operation Period	Predicted Irradiation (MWh)	Recorded Irradiation (MWh)	Performance Percentage[15] (%)
April 2017 -March 2018	2,004.50	1,934.21	-3.51%
April 2018 - March 2019	2,004.50	1,920.61	-4.19%
April 2019 - March 2020	2,004.50	1,799.01	-10.25%
April 2020 - March 2021	2,004.50	1,802.21	-10.09%
April 2021	211.90	179.73	-15.18%
Cumulative Period	**8,229.90**	**7,635.77**	**-7.22%**

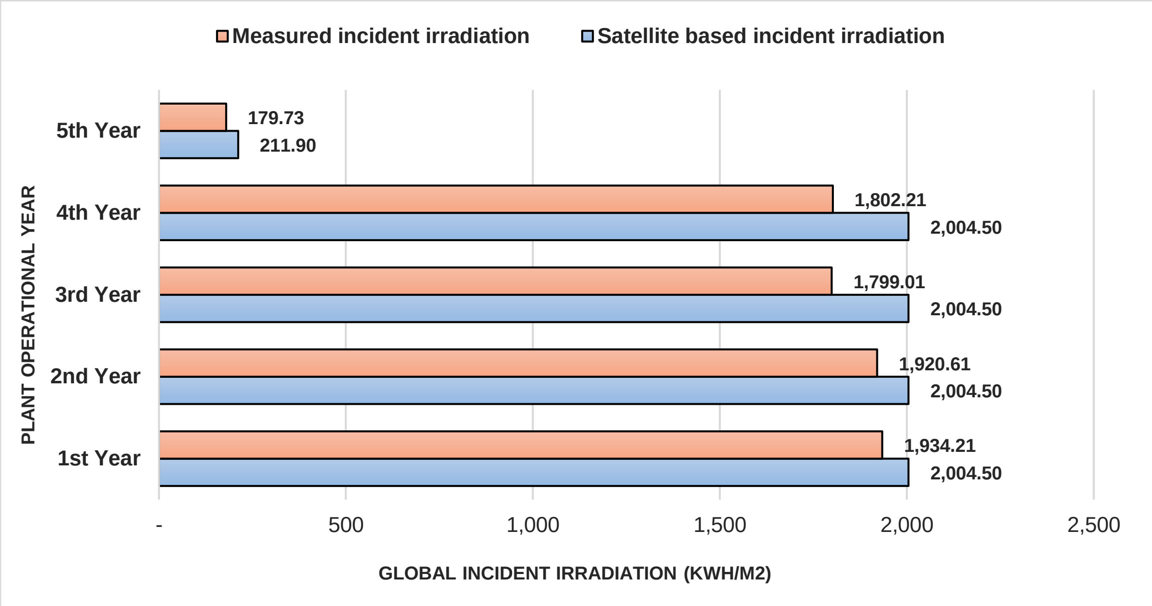

Figure 8-4: Irradiation Comparison

Based on the above illustration, it is observed that the overall recorded generation is approximately 7.85% lower than the generation predicted on site. It has also been observed that the recorded irradiation is 7.22% lower than the predicted irradiation.

Based on the comparative analysis, the drop-in generation can be attributed to the drop in irradiation.

[15] Positive values indicate higher irradiation, while negative values indicate lower irradiation

9 Solar Plant Life beyond 25 years

The traditional life of a solar plant is 25 years, which is based primarily on solar panel warranty period. The National Renewable Energy Laboratory (NREL) in the U.S however lists solar pv plants as having a lifetime of 25-40 years[16].Most modules are expected to see a degradation rate of 0.7% for the 25 years and hence the expected power output at the end of 25 years is around 80% of the rated power. However, research from NREL[17] shows that the median degradation rates of panels are around 0.5% and power output after the 25 year term could be higher than the power output guaranteed by the module manufacturer. Hence the possibility of the module producing electricity beyond 25 years with a year on year degradation is not farfetched, however whether these degradation rates will be in a linear pattern or in an unpredictable pattern is yet discovered and hence evaluating the generation/ performance of the plant and life of the plant beyond 25 years becomes risky. The life of the plant also depends on the quality of the other components such as inverters, cables, transformers used. Over the twenty five year plant life, these component will need to be serviced and repaired, as the warranty period for all of these components are less than 10 years. The repair and service of these equipment can continue beyond 25 years and the component may be fit for use for another ten years, however the risk of equipment failure increases year on year. The life of the plant also depends on the operations and maintenance activities carried out during the plant lifecycle and hence carrying out O&M activities diligently during the lifetime of the plant can increase the life of the plant beyond 25 years.

Overall, the pv plant is expected to function beyond plant life of 25 years, however the risk associated with the plant operation increases as the panel warranties would have expired, degradation rates beyond 25 years are unknown and other components used in the plant would also need additional repair/replacement.

[16] https://www.nrel.gov/analysis/tech-footprint.html

[17] https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html