Qatar General Electricity & Water Corporation

PW-PWR/G1
Solar PV Connection Guidelines for Customers

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1 Purpose

These Connection Guidelines provide information for Kahramaa Customers, Consultants and Contractors on the essential aspects which should be taken into consideration to connect a Solar PV System to the Low Voltage or Medium Voltage Distribution Network of Kahramaa.

2 Scope

These Guidelines apply to the planning, design, implementation, modification, operation and maintenance of Solar PV Systems.

This document contains the basic principles of solar PV Systems and illustrates the connection process as per Kahramaa's specific conditions. Thus, this guide shall serve as a basis for Customers and their selected Consultant/Contractor in the design and decision-making process at all applicable stages.

The technical aspects are not treated here but separately in the document "*EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network*", which represents the main reference document for the definition of the requirements that these generating facilities have to comply with in order to be connected to the Distribution Network.

2.1 Notice to Users of this Guideline.

This document is for the use of employees of Customers, Consultants, and Contractors. Users of this guideline should consult all applicable laws and regulations. The users are responsible for observing or referring to the applicable regulatory requirements. Kahramaa does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Users should be aware that this document may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. The document "*EP-EPP-P7/S1Technical Specifications for the Connection of PV Systems to the Network*" at any point in time consist of the current edition together with any amendments, corrigenda, or errata then in effect. All users should ensure that they have this document's latest edition uploaded on Kahramaa website.

Finally, the user shall refer to Qatar's local rules and regulations, as well as to applicable International Standards mentioned in these Kahramaa's documents, unless differently indicated in other Kahramaa documents related to Solar PV Systems Regulations.

3 Abbreviations, Definitions of Terms & Key References

Abbreviations

AC	:	Alternating Current	BIPV	:	Building-Integrated Photovoltaic modules
CBM	:	Condition base Maintenance	CIS	:	Copper Indium Selenide
CISG	:	Copper Indium Gallium Selenide	CPV	:	Concentrating PV array
CSP	:	Concentrated Solar Power	DC	:	Direct Current
GHI	:	Global horizontal irradiance	HV	:	High Voltage
IEC	:	International Electrotechnical Commission	IP	:	Interface Protection
kVA	:	Kilo Volt-Ampere	LV	:	Low Voltage (namely 220/127 V or 380/220 V or 400/230 V)
MV	:	Medium Voltage (namely 13.8kV or 33 kV)	MVA	:	Mega Volt-Ampere
MW	:	Megawatt	O&M	:	Operation and Maintenance
PV	:	(Solar) Photovoltaic	PW	:	Planning & Development Production Water Resource Dept
QEERI	:	Qatar Environment and Energy Research Institute			

Term	Description
Building-Integrated Photovoltaic modules (BIPV Modules)	Photovoltaic modules are considered to be building-integrated if the PV Modules form a construction product providing a function. Thus, the BIPV Module is a prerequisite for the integrity of the building's functionality. If the integrated PV Module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV Module would have to be replaced by an appropriate construction product. The building's functions in the context of BIPV are one or more of the following: • mechanical rigidity or structural integrity • primary weather impact protection: rain, snow, wind, hail • energy economy, such as shading, daylighting, thermal insulation • fire protection • noise protection • separation between indoor and outdoor environments • security, shelter or safety Inherent electro-technical properties of PV, such as antenna function, power generation and electromagnetic shielding etc., alone do not qualify PV Modules to be building-integrated.
Building-Integrated Photovoltaic system (BIPV System)	Photovoltaic systems are considered to be building-integrated if the used PV Modules fulfil the criteria for BIPV Modules.
Connection Point	Also referred to as *Point of Connection*, is the interface point at which a PV System of the Customer is connected.
Consultant	A qualified consultant for the design of grid-connected solar PV Systems.

Term	Description
Customer	The owner or tenant contracting with the competent department to supply the place, building or facility with electricity or water or both, whether a natural or legal person . In this context, this term will also be used to refer to a User owning a solar PV System.
Contractor	A certified contractor for the installation of grid-connected solar PV Systems.
Distribution System / Distribution Network	Qatar electrical infrastructure (lines, cables, substations, etc.) at 33 kV and below, operated by Kahramaa. The Distribution network can be either a Medium or Low Voltage system for the scope of the present document and in accordance with international standards: • A Low Voltage (LV) Distribution System is a network with a nominal voltage lower than 1 kV AC or 1.5 kV DC. The LV network in the State of Qatar is 240/415 V ± 6%, 3 Phase, 4 Wire. • A Medium Voltage (MV) Distribution System is a network with nominal voltage included in the range from 1 kV AC up to 33 kV. The MV Distribution System nominal voltages in Qatar are 11, 22 and 33 kV. • Electrical network voltages equal to or higher than 33 kV are not considered in this document. According to the Transmission Grid Code, the 33 kV is considered a sub-transmission network. To avoid doubt, the term Distribution Network will be preferred in this document in place of Distribution System.
Global horizontal irradiance (GHI)	Direct and diffuse irradiance incident on a horizontal surface expressed in W/m^2.
In-plane irradiance (Gi or POA)	The sum of direct, diffuse, and ground-reflected irradiance incidents upon an inclined surface parallel to the plane of the modules in the PV array, also known as plane-of-array (POA) irradiance. It is expressed in W/m^2
Interface protection (IP)	Electrical protection part of the solar PV System that ensures the PV System is disconnected from the network in case of an event that compromises the integrity of Kahramaa's distribution network.
Inverter	Electric energy converter that changes direct electric current to single-phase or polyphase alternating current.
Irradiance (G)	Incident flux of radiant power per unit area expressed in W/m^2.
Irradiation (H)	Irradiance integrated over a given time interval and measured in energy units (e.g., $kWh/m^2/day$).
Main Electricity Meter for Billing	It is the meter installed by KAHRAMAA for customers, which will utilize the feature of measuring the electric current in both directions to measure the amount of electrical energy exchanged (imported and exported) between the eligible customer and KAHRAMAA distribution network
Maximum Available Active Power Output	This is the Active Power Output based on the primary resource (for example, sun irradiance) and the maximum steady-state efficiency of the Solar PV System for this operating point.
Peak Power (Wp)	The output power achieved by a Photovoltaic Module under Standard Test Conditions (STC). It is measured in W_p (W peak). The sum of the peak power of the photovoltaic modules of either a string or an array determines the peak power of the string and the array, respectively (usually measured in kW_p). The peak power of a photovoltaic array at STC is conventionally assumed as the rated power of the array.
Photovoltaic (PV) cell	The most elementary device that exhibits the photovoltaic effect, i.e., the direct non-thermal conversion of radiant energy into electrical energy.

Term	Description
PV Array	Assembly of electrically interconnected PV Modules, PV strings or PV sub-arrays. For the purposes of this document, a PV Array comprises all components up to the DC input terminals of the Inverter.
PV Module	PV Modules are electrically connected PV cells packaged to protect them from the environment and protect the users from electrical shock.
PV String	A set of series-connected PV Modules.
Prosumer	A Kahramaa Customer with Solar PV system installed to Produce electricity and connected to Network
Solar PV System or PV System	This term also has the same meaning as Power Plant or User's System or Grid User, defined in the Transmission Grid Code. It is a solar PV installation of not more than 25 MW and not less than 1 kW capacity installed in one Premise and connected in parallel to Kahramaa's Distribution Network. This document aims to be considered a power plant with one or more Solar PV Units. Besides, circuits and auxiliary services are also part of a solar PV System. To avoid doubt, in this document, the generic term Solar PV System is considered equivalent to solar PV System. This PV System includes the PV array, controllers, inverters, batteries (if used), wiring, junction boxes, circuit breakers, and electrical safety equipment.
Solar PV System Meter	It is the smart metering installed at the output point of the solar PV System and measures the total energy produced from the Solar PV Units.
Standard Test Conditions (STC)	Reference values of in-plane irradiance (1000 W/m2), PV cell junction temperature (25 °C), and the reference spectral irradiance defined in IEC 60904-3.

Key References

[1] ES-M4 Qatar Transmission Grid Code

[2] EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network

[3] PW-PWR/G2 Safety related to the installation of Solar PV Systems, latest revision

[4] QEERI Solar Atlas, https://www.hbku.edu.qa/sites/default/files/qeeri_solar_atlas.pdf

[5] PQ-PQQ-P1/G1- Guideline on the Documentation of the KM Management System

4 What are the Benefits of Solar PV Systems, Technology and Environment?

4.1 How much Sun is there in Qatar?

Every day we receive thousands of times the energy we consume from the Sun, but solar energy is distributed on the Earth's surface, and thus large collection surfaces are required to exploit it.

The sun's energy is variable and discontinuous in a certain area mainly for the following reasons:

- Variability during the day from sunrise to sunset
- Absence in the night periods
- Seasonal variations
- Meteorological conditions (clouds, fog, sandstorms, etc.)

Outside the Earth's atmosphere, solar irradiation has an average value of 1367 W/m^2 ±3%, called Solar constant. The variation of ±3% is due to the seasonal variation of the Earth's distance from the Sun.

From Figure 1, we can understand the effect of the Earth's atmosphere on incoming solar radiation:

- A portion of the solar energy arrives directly to the ground (Beam or Direct radiation)
- A portion is diffused due to cloud and water molecules present in the atmosphere (Diffused radiation)
- The remaining portion is lost by reflection and absorption by various constituents of the atmosphere.

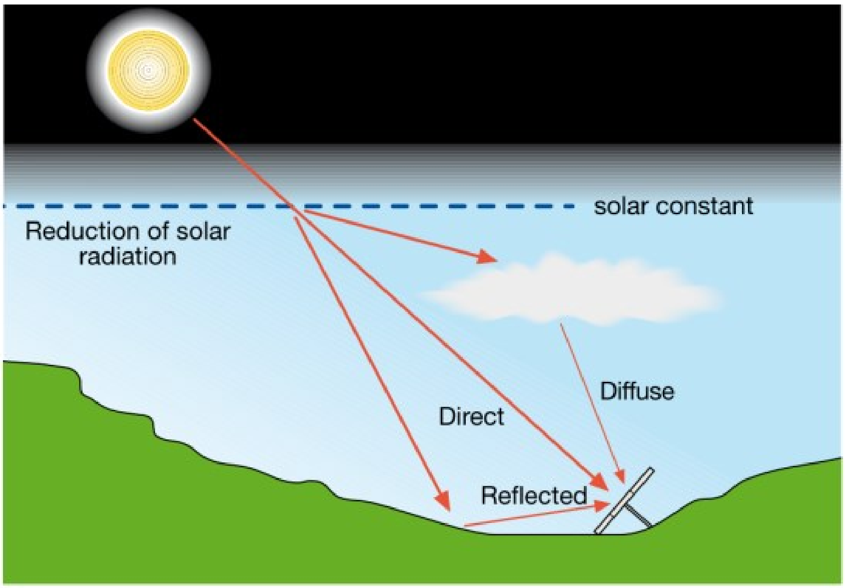

Figure 1 – Effect of the atmosphere on the sunlight

Consequently, the trend of the solar radiation received at the ground level is partially unpredictable because it depends on the local weather conditions. However, if we consider historical data collected by meteorological stations, it is possible to have time-averaged data on an hourly interval, daily, monthly or yearly basis.

The radiation in Qatar is high: the global horizontal irradiation exceeds 2117 kWh/m^2 on average. The global horizontal irradiation recommended for a PV installation should exceed 1460 kWh/m^2 on average. Figure 2 shows the average annual solar radiation received in Qatar referred from QEERI Solar Atlas.

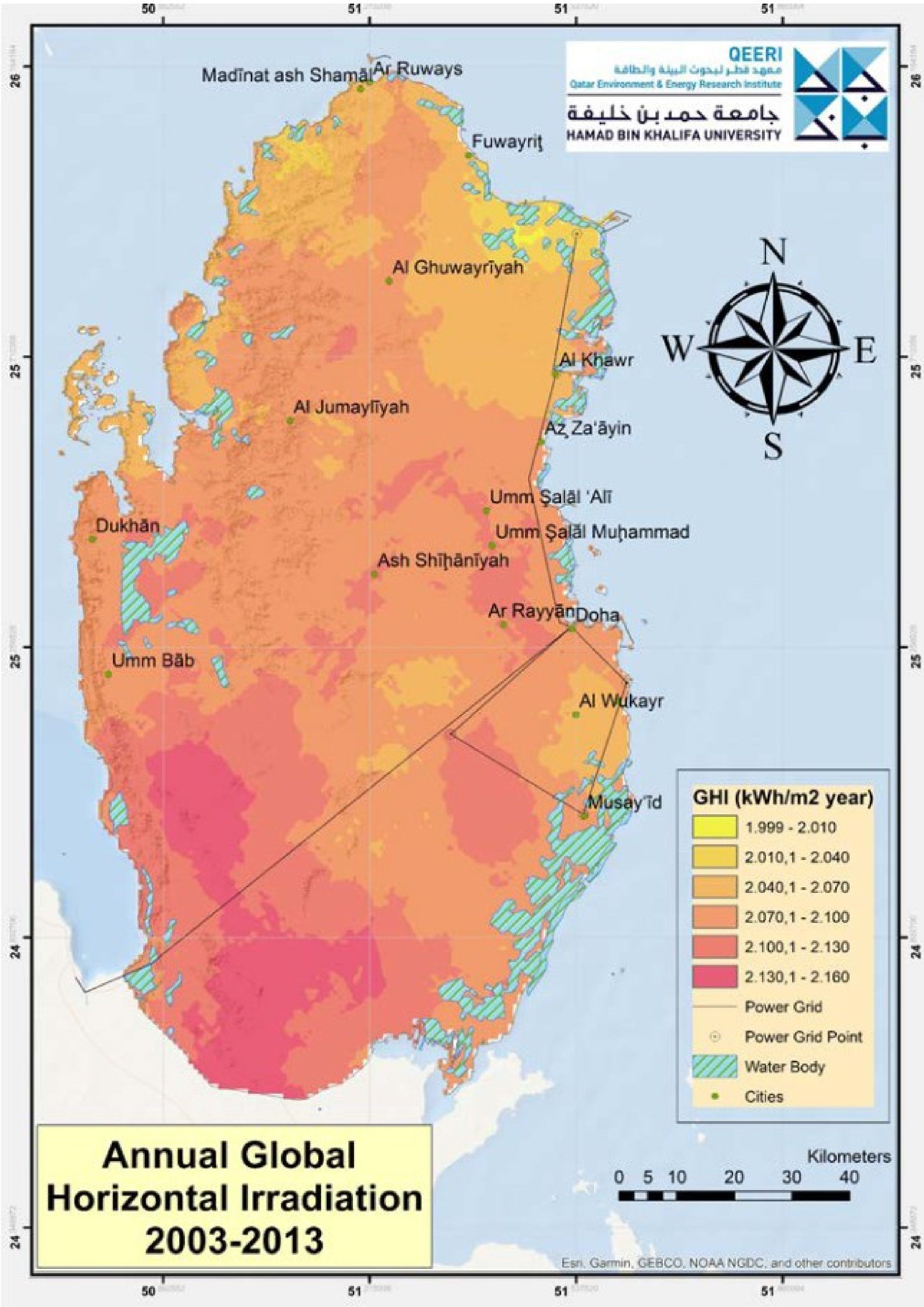

Figure 2 – GHI in Qatar from QEERI Solar Atlas

Several databases on solar radiation and climate data cover the world or specific regions. In Qatar, it is possible to refer to the Qatar Environment and Energy Research Institute (QEERI), part of Hamad Bin Khalifa University and the Qatar Foundation.

The solar databases contain the Global horizontal, Direct solar radiation and Diffuse solar radiation on a horizontal surface expressed in kWh/m^{2}-day. These data are normally available on hourly intervals, daily, monthly, and yearly basis or as a long-term average.

4.2 What are the principles of solar PV Technology?

Solar photovoltaic (PV) technology is undoubtedly the easiest way to produce electricity from sunlight. It can be used for many purposes in households and all sectors that need power, such as commercial activities, factories, office buildings, and many others.

Solar systems are based on devices that transform sunlight into electricity, the PV cells, which perform photovoltaic conversion. PV cells are composed of semiconductors designed to be exposed to sunlight and collect as much energy as possible. Not surprisingly, their shape is thin and wide.

The most widely used PV cells are crystalline silicon (mono or poly-crystalline), whose shape is normally square or a pseudo square with edges trimmed, as shown in Figure 3, and whose thickness is usually more than 0.2 mm. Therefore, solar cells are very fragile and must be purposely protected in a rigid structure, namely a PV module. Several PV cells are assembled and connected in a single body with transparent front glass.

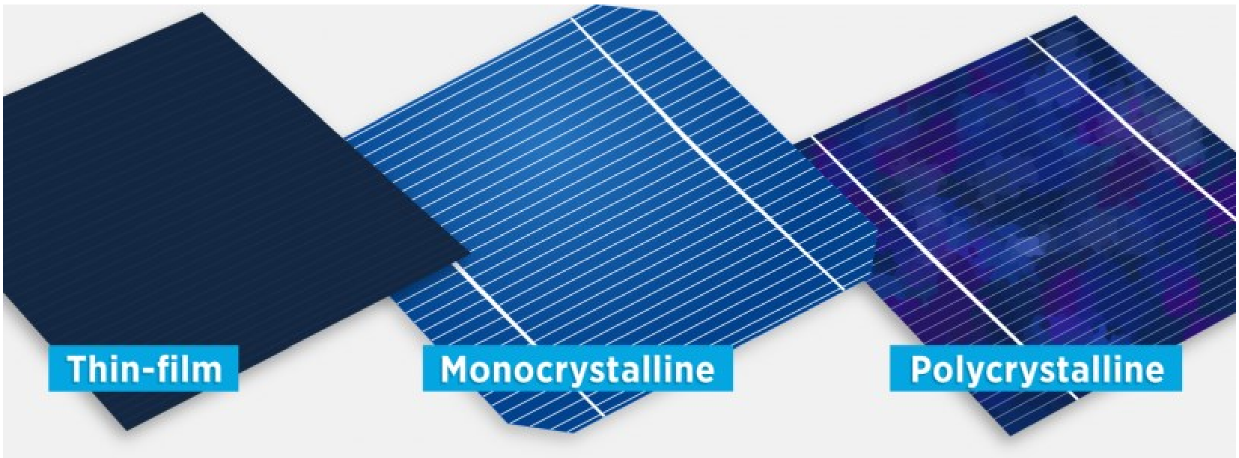

Figure 3 – Examples of a crystalline PV cell

The structure of a PV module resembles a sandwich because many layers tightly packed are necessary to protect the PV cells and give the necessary mechanical and electrical characteristics (see Figure 4).

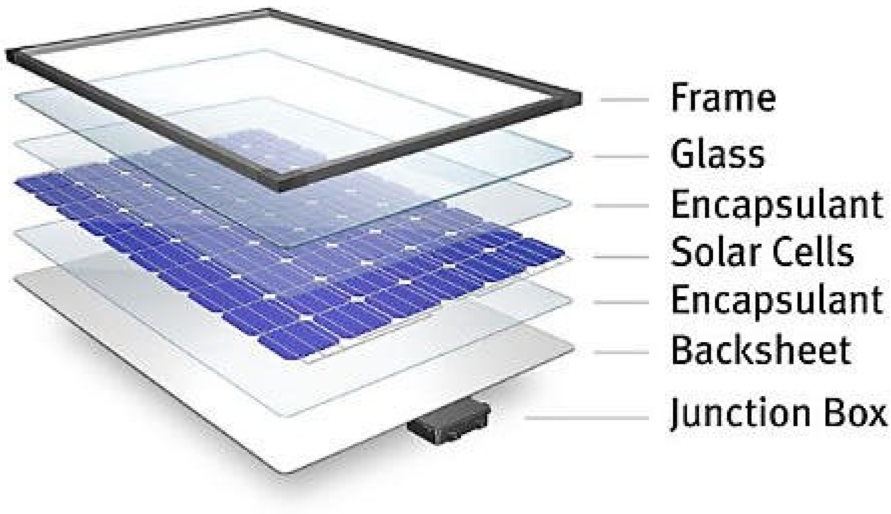

Figure 4 – Typical structure of a PV module

Presently, the crystalline silicon PV modules available in the market have a nominal power typically in the range of 300Wp to 400Wp or more, measured at specific irradiance and temperature called Standard Test Conditions or STC.

Although crystalline PV technology is the most widely used, other technologies are based on depositing a thin layer of semiconductor on the front glass. The resulting thickness of this deposit is a few µm, and for this reason, the resulting products are called thin-film PV modules. Commercially available thin-film PV modules technologies use CdTe (Cadmium Telluride), CIS (Copper Indium Selenide) or CIGS modules (Copper Indium Gallium Selenide), or Amorphous silicon can be used. The higher costs of these expensive materials are largely compensated by the much lower quantities needed to obtain the photovoltaic conversion. Conversely, the efficiency of thin-film technology modules is normally lower than their silicon wafer-based crystalline counterparts (except for CdTe technologies, which have a similar efficiency level as that of Crystalline Silicon).

Recent technology developments have led to bi-facial PV modules. These convert light captured on both the front and backside of the module into electrical power. It can, therefore (substantially) increase the electric yield of PV Systems depending on the specifics of the installation. The additional yield for bi-facial PV Systems depends on the tilt, height, and spacing of the modules, as well as the reflectivity of the ground: e.g. white foil, different soils or vegetation (further details available in “Best practice for designing a PV System” document).

4.3 How is the Design of a PV System?

How are the PV modules grouped?

The PV modules have to be grouped and interconnected efficiently to deliver the energy required and permitted by Qatari regulations.

They can be grouped in strings and then in arrays, as depicted in Figure 5.

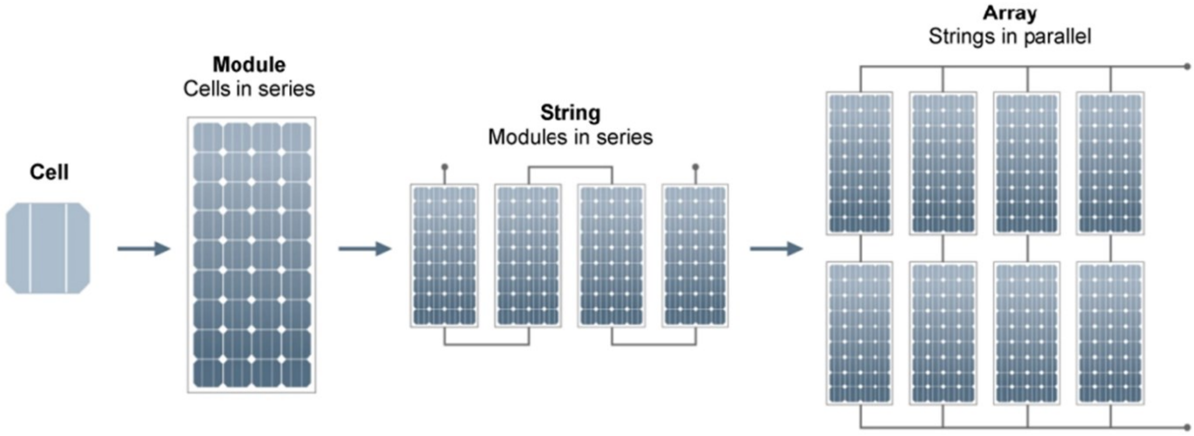

Figure 5 – Solar PV Modules Grouping

The grouping depends on the power and energy required and the voltage levels that can handle your inverter.

How is the PV Design performed?

Initially, it is important to know your roof space available and your ground space (if decided) to install a solar PV System. The capacity of your PV System is limited to the values of the Qatari regulation and your space available.

The tilt of your PV modules is important to capture as much irradiation as possible. In general, the fixed tilt arrays use the structures to orient the PV modules at a tilt angle that is fixed year-round. The PV modules are typically fixed at the site latitude angle +/- up to 20° to optimise annual generation but may be tilted at other angles to achieve specific performance and cost objectives. For example, lower tilt angles in the 5° to 20° range are sometimes used to reduce wind loading and mounting structure cost, to allow a higher power density of the plant, or to increase summer energy production if there are tariff incentives to do so.

The design should consider the impact of module shading using suitable engineering analysis, and the shading must be avoided. On flat ground, the distance between PV modules having a given inclination can be calculated.

The PV modules can be connected in series and parallel to form a PV array. The PV array provides energy that cannot be directly used since it generates DC electricity which is not compatible with electric appliances and the electric grid as these are based on AC electricity.

The DC power coming from the PV array is thus converted to AC power to be fully compatible with the public distribution networks. This function is operated using specific electronic equipment called an inverter. The inverter performs several functions: mainly, it optimises the electrical operation of the PV array and transforms the DC power into AC power that can be used by the electric appliances or injected into the distribution network when necessary.

According to many experts, in the category of distributed systems, PV Systems may be broadly classified into two types:

- Small-scale
- Utility-scale

Figure 6 shows the general configuration of a Small-Scale or Medium-Scale Solar PV System. Besides the inverter, there is other equipment aimed to safeguard the distribution network (Interface Protection - IP), measure the energy produced and exchanged with the distribution network (Meters) and sort the power (AC switchgear). Such PV Systems are called *Grid-connected PV Systems* or *Grid-tied PV Systems*.

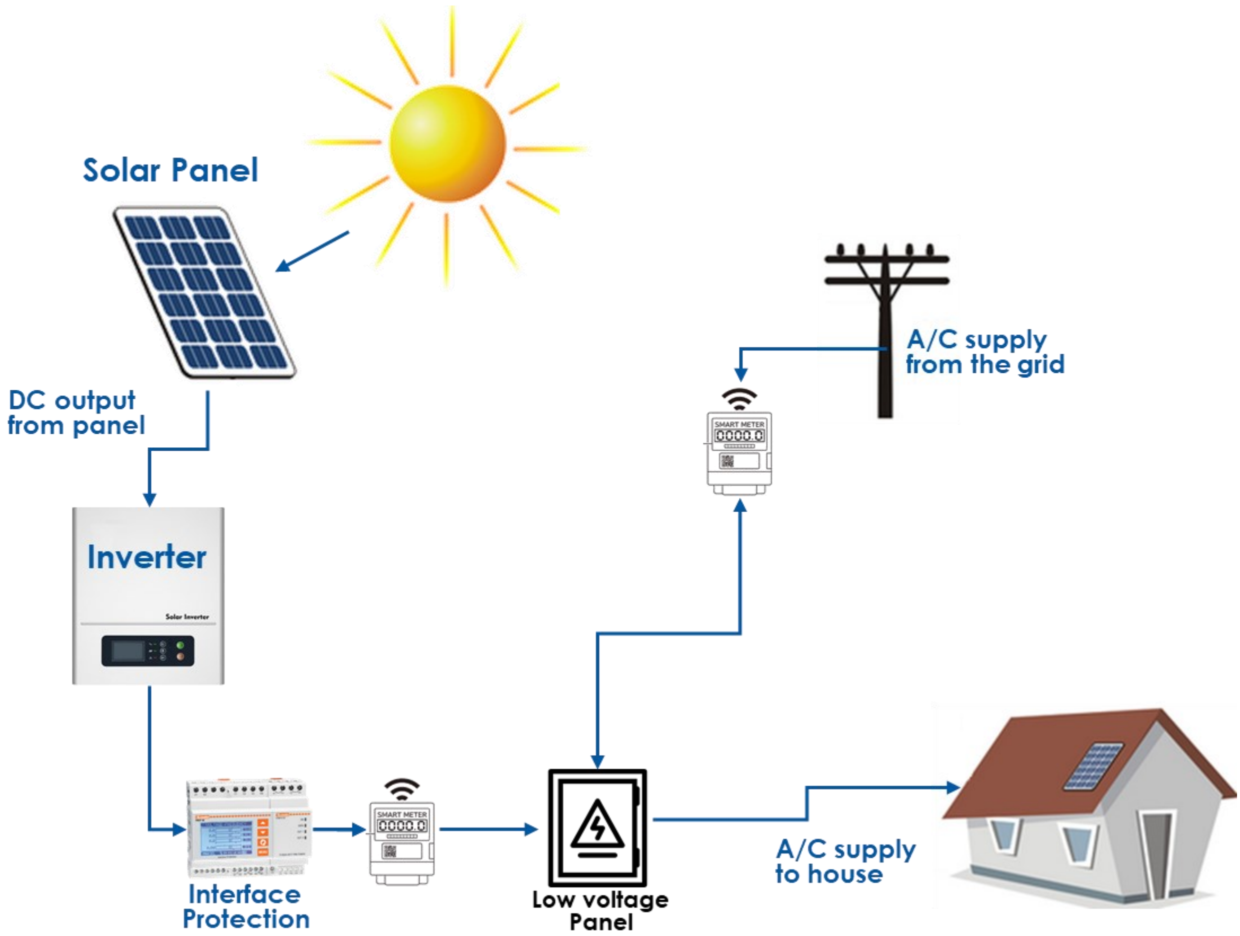

Figure 6 – General configuration of a Small-Scale Solar PV System

The environmental benefits of a grid-connected PV System are evident:

- The energy produced is 100% renewable and comes from the Sun.
- The PV System does not produce any pollutants.
- The energy produced can fully replace energy generated through fossil fuels, thus reducing emissions of pollutants and, in particular, greenhouse gasses in the atmosphere.

Recent technology developments have led to bi-facial PV modules. These convert light captured on both the front and backside of the module into electrical power. It can, therefore (substantially) increase the electric yield of PV Systems depending on the specifics of the installation. The additional yield for bi-facial PV Systems depends on the tilt, height, and spacing of the modules, as well as the reflectivity of the ground: e.g., white foil, different soils or vegetation.

Figure 7 shows a few examples of Small-Scale PV Systems on buildings.

Figure 7 – Examples of PV installations

What is a Utility-Scale PV System?

Large-Scale PV Systems are also called Utility-scale PV Systems because their power contribution is comparable to that of the traditional power stations operated by electric utilities.

The typical layout of a Utility-Scale PV-based System requires several transformers, inverters and PV arrays (Figure 8). The connection among these elements depends on the topology (configuration) used by the PV inverter. Generally, two topologies are used to connect the PV Systems to the internal grid of the PV System: central Inverter and multi-string Inverter. In the first structure, only one inverter is used to connect a PV array with the transformer. Commonly, this has a single stage of conversion (DC-AC). Meanwhile, the multi-string inverter has two conversion stages (DC-DC and DC-AC). The last configuration interconnects one string of PV modules to the internal grid AC grid of the PV System.

The central inverter is the most used topology in large-scale PV Systems. The main advantages of this topology over the second one are:

- competitive costs
- robustness
- low maintenance
- reduced number of inverters in the field

However, the multi-string inverter is used to enhance the control of the maximum power point. This could be necessary when the PV System is located on irregular surfaces. Moreover, this topology is used for each PV string, so the number of inverters increases compared to a PV System that uses only a central Inverter.

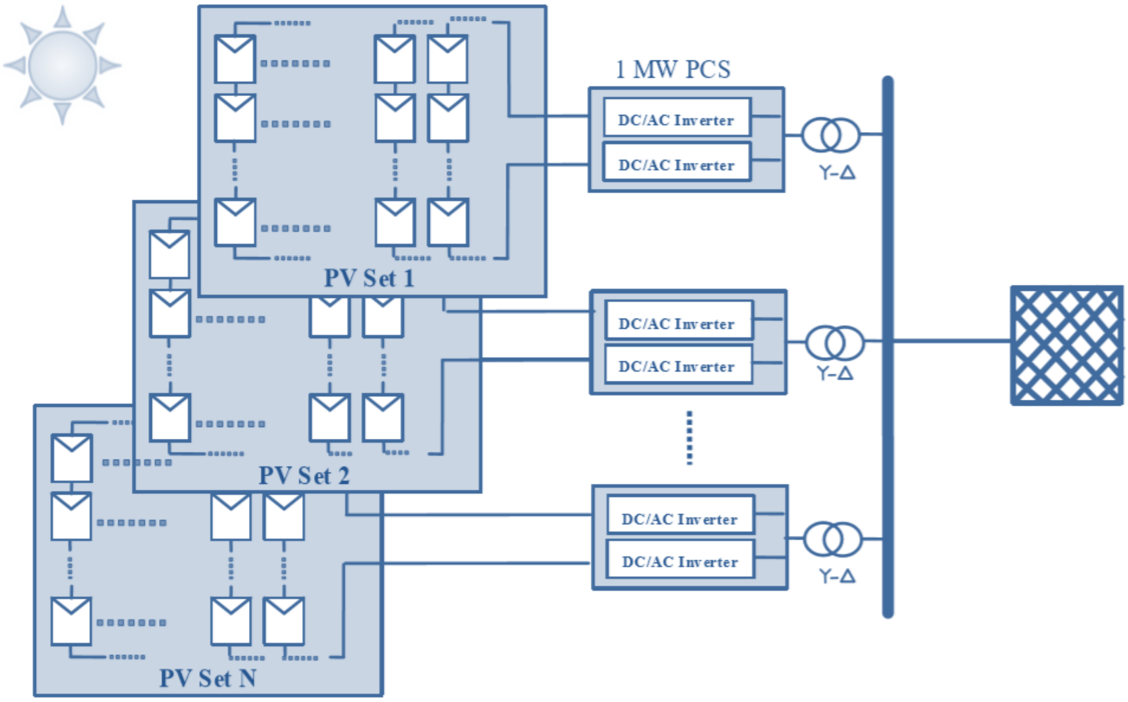

Figure 8 – General architecture of a Utility-scale PV System

Figure 9 – Examples of Utility-scale PV Systems (Panda Power Plant in Datong, and Kubuqi Desert, China)

4.3.1.1 What is a Central Inverter Configuration?

PV Systems designed with large centralised or inverters are common, particularly with multi-megawatt-sized systems. A typical centralised inverter design approach includes one or more inverters totalling, e.g., 500 kW to 4 MW installed together at an inverter station (in a housing container or on an equipment pad) with a medium voltage transformer. Most inverters have an output AC voltage in the range of 200 V to 1 000 V. The transformer steps the low AC voltage up to a standard medium voltage or high voltage level, such as 20 kV.

Figure 10 shows an example of 1 MW centralised inverter layout using an N-S single-axis tracker. The inverters are centralised within the array (see the centre of the figure) to minimise the total lengths of DC cable. The figure shows the cables from the inverter station to PV string (or harness) combiner boxes distributed throughout the PV arrays. The MV or HV output cables exiting the transformer are routed underground to a substation shown north of the array.

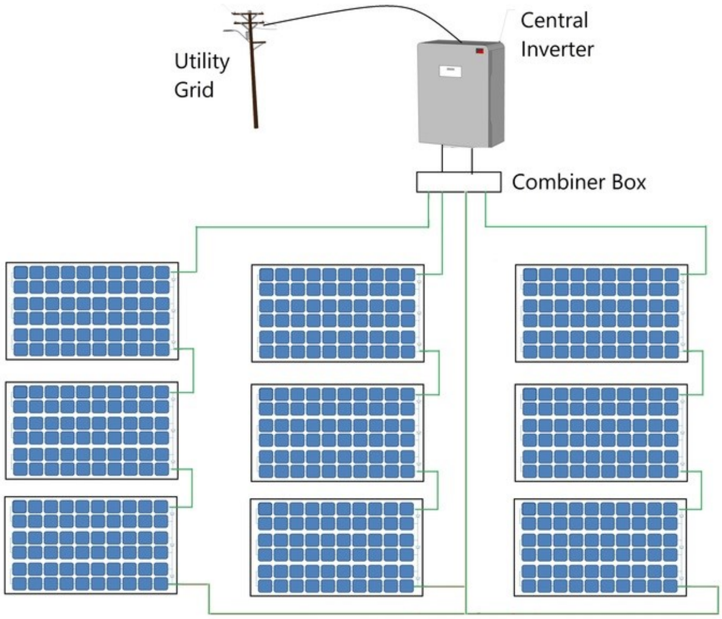

Figure 10 – Example layout of PV System central inverter-based array

4.3.1.2 What is a String or module inverter configuration?

PV Systems may also utilise string or module-level inverters. Figure 11 illustrates one approach with a similar N-S axis tracking array system. String inverters are mounted in every third row of modules. Typical configurations range from 300 V to 1 500 V maximum DC voltage and single-phase or three-phase outputs in the 240 V to 480 V AC range. The output circuits are combined in protected harnesses, modules, or fused disconnectors and then connected to the LV side of an MV/HV transformer, as indicated in the figure.

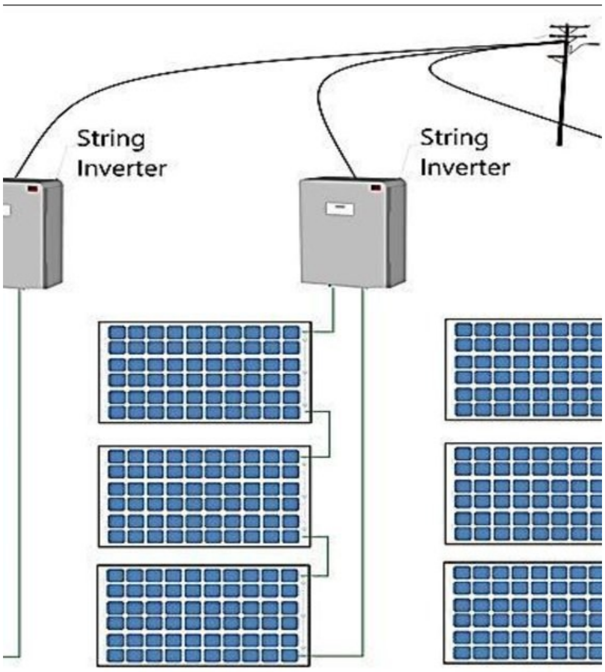

Figure 11 – Example layout of PV System with string inverters

This configuration generally warrants using a higher quantity of MV transformers with lower kVA ratings than in the centralised inverter approach because the array power is distributed at lower AC voltages.

Do I need a Civil and Mechanical Design?

Unfortunately, you need to consider civil and mechanical design in your PV System, especially if they are Large-scale. Some of the main aspects to consider are described below:

Mechanical Loads on PV Structures

The solar PV array support structures may be designed according to measured and documented site-specific conditions instead of loading requirements for PV modules. Other deviations may be permitted under engineering supervision and approved by the applicable manufacturers and local authorities.

Wind

Local code governing buildings' wind-load calculations may be unsuitable or inadequate for PV arrays. PV array structures may be designed and rated to measure site-specific conditions and application-specific structural engineering calculations in lieu of local codes, where documented and approved by local authorities.

Thermal Expansion

To account for thermal expansion and contraction, particular attention should be given to mounting rack length, module frame separation, cable management, and rigid mechanical connections of long linear spans. This may include the provision of expansion gaps for structures or expansion fittings for conduits and cable trays.

Flooding

Where project sites are at risk of flooding, the height above the ground of modules, combiner boxes, tracker motors, and other electrical components should be considered. The mounting structures' type and construction should also consider the impacts of flooding, submersion, and site drainage.

Seismic Activity

Where project sites are at risk of seismic activity, seismic loads on structures should meet the requirements of the International Building Codes or locally adopted codes. Where applicable, equipment standards with seismic qualification testing should be applied.

Typical seismic considerations for PV Systems include pier loading variations based on soil classification, lateral loads on fixed or tracking array structures, strengthened concrete equipment pads, greater requirements for bolting of enclosures to pads, use of flexible conduit (particularly for transformers), and retainer screws for tracking support structures.

Corrosion

Components in PV Systems are susceptible to corrosion from salt content in water, corrosive chemicals in the local atmosphere such as ammonia in agricultural areas, and numerous chemicals such as sulphates found in soils. Local corrosive sources must be considered, and appropriately protected components. This applies to PV modules, structures (both sub-surface and above-ground), cabling, enclosures, field-deployed inverters, and their housings. Protecting sensitive internal components from extreme humidity may be better protected with air-tight enclosures or space heaters.

The corrosion design of steel piles may be based on an analysis of local site conditions, including a geotechnical evaluation of resistivity, pH, and levels of chemicals such as sulphates and chlorates. When cathodic protection systems are utilised, particular attention should be paid to the location of the cathodic protection system vents, as the emanating gasses can cause corrosion of nearby components.

Polymeric materials used in plastic wire ties are also subject to corrosion and shall be chosen appropriately per the site and application conditions.

Access

Rows of modules, particularly in very large and with fixed-tilt systems, can be long (e.g., greater than 500 m) with little spacing in between. With low-mounted structures, safe access from row to row may only be possible by travelling to the end of a row and around the adjacent corridor. Narrow row-to-row spacing may prevent safe access with a motorised vehicle, thereby limiting internal array access to personnel who must hand-carry the required tools and materials. These factors can be overlooked when there is a design objective to create a high-density array due to site limitations, but they should not be ignored. Where pads or housings contain large equipment such as central inverters and medium voltage transformers, roads must be maintained for appropriate vehicle access (trucks or cranes) and turn-around capability. This also applies to emergency vehicles and local fire codes, which may dictate the maximum length of contiguous arrays and the minimum width of vehicle corridors in each direction.

Can my PV System follow the sun's path?

If you would like to improve the energy yield and that your solar PV System follows the sun, there are some possibilities. More sophisticated and more costly.

The options begin with a fixed tilt, normally for rooftops, followed by adjustable tilts (which can be done manually every season) and automatic single-axis and double-axis tracking systems for following the sun. These options are briefly described below.

Fixed Tilt Arrays

Fixed tilt arrays use structures that orient PV modules at an azimuth and tilt angle fixed year-round. Arrays are typically fixed at the site latitude angle +/- up to 20° to optimise annual generation but may be tilted at other angles to achieve specific performance and cost objectives. For example, lower tilt angles in the 5° to 20° range are sometimes used to reduce wind loading and mounting structure cost, allow a higher power density of the PV System or increase summer energy production if there are tariff incentives. Lower tilt angles may result in higher soiling losses depending on site conditions and, therefore, should be considered. Time of Use tariff incentives may also warrant orienting the arrays at an azimuth angle other than south (or north in the southern hemisphere).

Designs should consider the impact of module shading using suitable engineering analysis.

Adjustable tilt Arrays

Adjustable tilt arrays are fixed-tilt arrays that can be manually adjusted once or more per year. The most typical adjustable tilt array uses a higher angle tilt setting for winter and a lower angle tilt setting for summer months. The use of adjustable tilt arrays has historically been uncommon in PV Systems, but more recently, there has been an increase in their use in markets and regions with low labour costs.

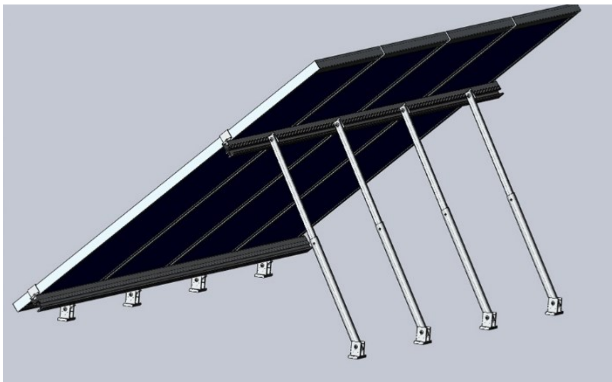


Figure 12 – Example of an Adjustable Tilt Module and Array

Single-axis Tracking Arrays

Single-axis tracking arrays employ structures that rotate PV modules along a single axis to follow the Sun's path. Figure 13 shows the rotation option on a single axis. Frequently, in large PV Systems, the structures rotate along the horizontal N-S axis, with horizontal E-W tracking.

The distance between two different rows of PV modules is particularly important because, especially in the early morning and before sunset, reciprocal shadings may occur. A backtracking technology is used to avoid this, and it can avoid shading between arrays from sunrise to sunset and make the shading loss zero.

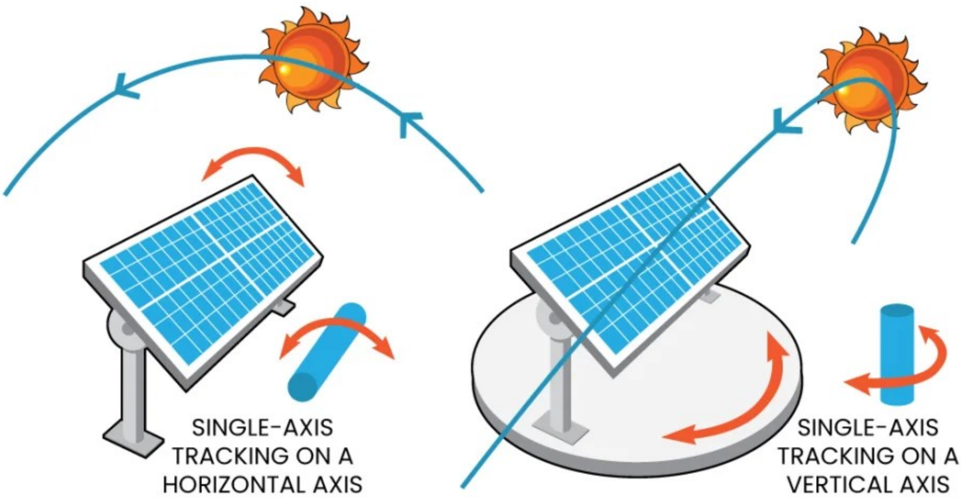

Figure 13 – Example of a Single-axis Tracking System

Backtracking refers to intentionally positioning trackers somewhat off-sun, typically to reduce shading from adjacent trackers during the early morning and late afternoon when the trackers are out of the period of facing the Sun.

To avoid shading from sunrise to the time when the array faces to the Sun, the array tilted angle is adjusted reversely from horizontal to east step by step to allow the PV array a clear line of sight to the Sun without shading until the array faces the Sun. Then the array runs normally from east to west to follow the Sun. In the afternoon, when the array reaches the designed no-shading time, the array begins backtracking until sunset, when the array is supposed to be put in horizontally and waiting for the next morning.

Backtracking technology allows the design for no-shading distance to be more flexible. This is useful mainly in designs that do not have access to enough land area to be spaced far enough apart to avoid shading in the early morning and late afternoon.

Two-axis Tracking Arrays

Two-axis tracking arrays employ structures that rotate PV modules along both the N-S and E-W axis, thereby aligning the array to the direct beam angle of the Sun throughout the day. An example is shown in Figure 14. Great care must be taken to avoid reciprocal shading, especially when the sun height is low, and thus proper spacing between heliostats is to be considered.

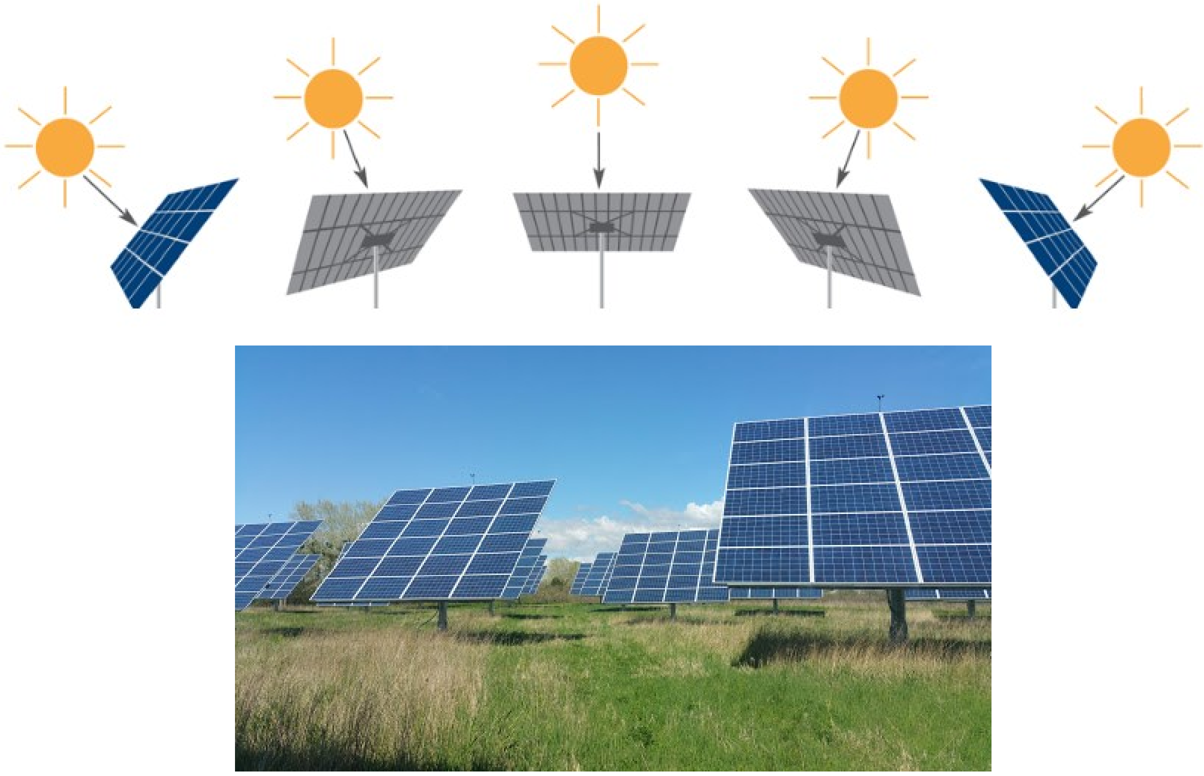

Figure 14 – Example of a 2-axis Tracking System

What are the Concentrating PV arrays?

Concentrating PV arrays (CPV) incorporate PV modules or cells that utilise lenses or other focal apparatus to concentrate greater sunlight on the cells. Concentrating arrays almost universally use either a 1-axis or 2-axis tracking mechanism. For this technical specification, all requirements about non-concentrating flat-plate arrays shall apply to concentrating PV arrays. Manufacturer instructions shall be followed to address any differences in calculating system voltages, currents, and installation methods.

However, Fresnel-lenses CPV requires higher precision than normal tracking systems, and the pointing error should not be higher than 0.5-1 degree. Therefore high-performant 2-axis trackers are required, as shown in Figure 15.

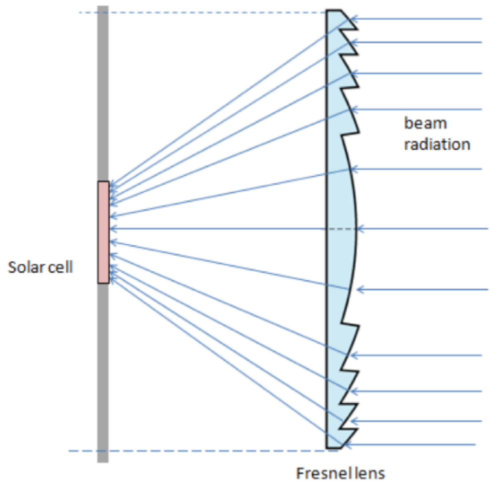

Figure 15 – Example of a CPV array with 2-axis Tracking System

Is there a PV System for Desert Environment?

According to IEA-PV Power Systems Program, PV Systems in desert areas will endure severe environmental conditions. One of the most serious issues is dust settlement (soiling). Accumulated dust on the PV modules' surface can reduce the power output considerably.

The degree of soiling and its impact depends upon surrounding environments and meteorological conditions of the site, as shown in Figure 16. A solution to soiling is 'cleaning'. The cleaning option for PV Systems can be justified if the cost of cleaning is lower than the income generated by the solutions. In general, the cleaning cost depends heavily on the local cost of labour and water.

In the case of cleaning with water, the amount of water consumption will also influence the cleaning cost.

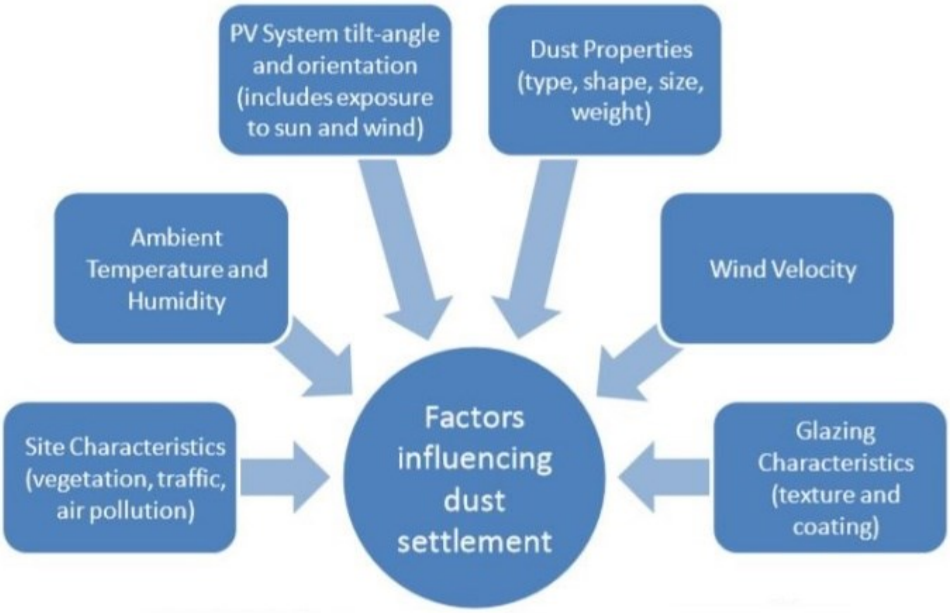

Figure 16 – Factors influencing dust settlement

The occurrence of soiling will depend upon the characteristics of sand particles, meteorological conditions, etc. There are several academic research on mechanisms of soiling in solar energy, e.g., not only PV and CPV but also CSP, and research and development on countermeasures against soiling. Recent research trends shift from 'wet' to 'dry', from 'restoration' to 'prevention'.

In addition, a simulation tool for evaluating the influences of soiling on PV Systems has also been developed. The tool requires several parameters concerning the surrounding environment. It estimates the degree of soiling and influence on the electricity output and allows the PV System owner to develop a cleaning plan before starting operation. After starting the operation, by updating environmental parameters and putting the actual result of electricity generation, the estimation is modified to improve accuracy and reliability.

5 Who can Install a PV System?

5.1 Eligible Customers

The Customers that can install a Solar PV System on their premises are called *Eligible Customers*. The eligibility is defined in KM-PW-PL01 KAHRAMAA Policy for Renewable Energy Systems Connected to the Distribution Network

This Policyestablishes that any Customer can install a Solar PV System up to the capacity of their load, i.e., if the loads amount to 4000 watts, the Customer can install a PV System with a maximum capacity of 4000 watts. This is approximately 13 solar modules on his premises of 300 watts each.

5.2 Incentive Tariff Scheme Adopted in Qatar

The countries adopted several tariff schemes for compensating and/or remunerating those who inject energy into the distribution network. Among these schemes are mainly Feed-in Tariffs, Net Metering schemes and their variations, and Net Billing schemes and their variations.

The mechanism considered for incentive schemes in Qatar Net Billing, which is defined in KM-PW-PL01 KAHRAMAA Policy for Renewable Energy Systems Connected to the Distribution Network

It has been illustrated that grid-connected PV Systems convert solar irradiation from the Sun to make it available for consumption using the grid. This power changes during the day; normally, it reaches a maximum at noon and is zero from sunset to dawn. A seasonal variation also influences production.

However, from a technical point of view, a shortfall between solar PV production at your place and your internal consumption may be easily managed if you are connected to Kahramaa's grid. If the solar PV System production exceeds your internal consumption, this difference is sent to the distribution network of Kahramaa and, conversely, when the solar PV production is less than your internal consumption (or is null in the evening and night) this difference is taken from Kahramaa network.

Therefore, at the end of a month (billing cycle), the main smart meter connected registers the quantity of kWh taken from the distribution network and the quantity of kWh injected into the distribution network.

In its simplest version, the net billing mechanism makes the monetary difference between input and output. In case of any surplus energy is produced by the solar PV System and injected into the grid, a financial valuation will take place, and the amount will be transferred and deducted from the next billing cycle.

5.3 Solar PV Systems fit Everyone

The possibilities offered by Solar PV Systems are countless. A few examples of PV on buildings are shown in Figure 7. Depending on the rooftop and the area available, PV Systems may have simple flat rooftop structures or canopies where PV modules are also used to create shading from sunshine. Sloped roofs, sheds or facades represent other possibilities.

Furthermore, Building Integrated PV (BIPV) represents an excellent use of this technology, especially in new buildings and allows for achieving great aesthetic impact results.

6 How can I Connect a Solar PV System to Kahramaa Network?

6.1 Overview

If you decide to install a Solar PV System and connect it to the Kahramaa network, first, you should know the capacity of your system according to your load, the number of solar modules they fit in your roof or ground space and some basic connection scheme.

To perform this basic estimation and provide you with a basic design, you can select and appoint a qualified consultant/contractor. can do the basic calculations and estimations regarding the space needed, the modules used, and the implementation cost. After, you need to know if there is availability in Kahramaa to connect your system to the network in your location. This is because, in your area, there could be problems with voltage, or the grid's capacity is saturated, and the connection of your solar PV System may bring a problem to other customers in the neighbourhood.

Once these main things are known, your selected Consultant (and you, of course) can follow the Connection Procedure via the integrated system of the Municipality (Baladiya).

The key steps for the Connection Process of a PV System to the Kahramaa electric grid are shown in the simplified diagram in Figure 18. The flow involves mainly the Customer, his Consultant/Contractor and Kahramaa.

6.2 Connection Process Stages

The Connection process will follow three main stages, as depicted in Figure 17.

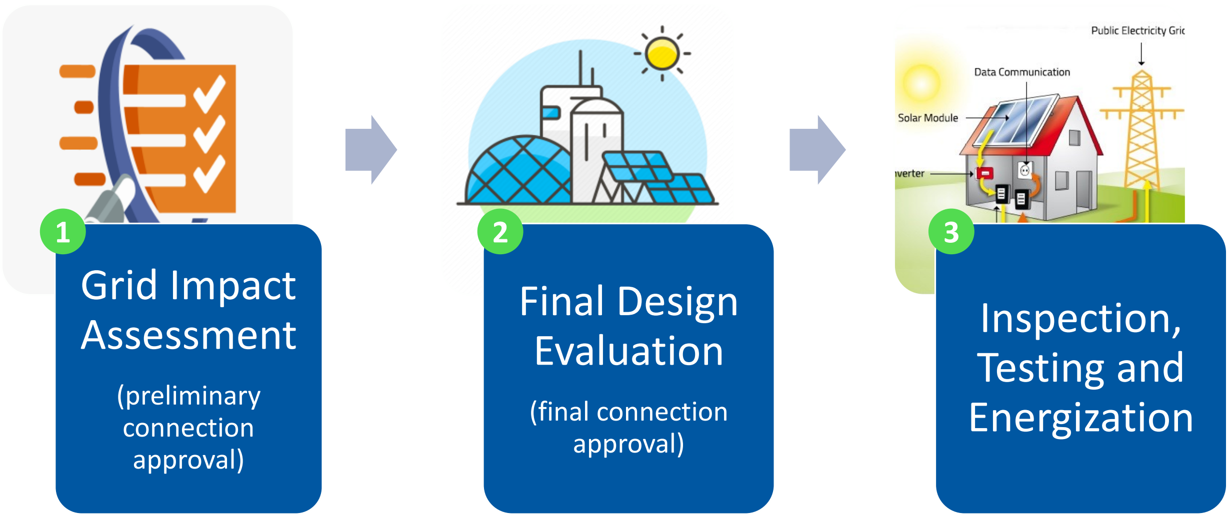

Figure 17 – Main Stages in the Connection Process

These three high-level stages also consider some activities inside each stage. For example, the preliminary connection approval (*Grid Impact Assessment*) stage has three tasks: *Application Fee* and *Building Permit*.

Stage 1: Preliminary Connection Approval (Grid Impact Assessment)

In this stage, there are two key activities to be performed: your consultant's basic design and the verification of Kahramaa if you can connect your solar PV System to his network without jeopardising the network and other Customers.

You have to enter your request via the Municipality integrated system (Baladiya) and pay the required payments and fees for this stage. Kahramaa may decide not to charge in this stage according to the type of Customer, location and PV System size.

The basic design should contain the capacity of your system, how many solar modules are required, the size of the roof and if you will require a modification of the roof's structure or premises for installing your PV System. For example, check if your roof can support the weight of the solar modules or if the modules may affect the urban landscape or may not be permitted because of the historical architecture. For these reasons, your consultant should enter the request via the Municipality and obtain, at the same time, the Build Permit.

When Kahramaa receives the Application, it can evaluate the basic design. First, verify if there is complete documentation, if it is correct, and if it is technically feasible to install a PV System on the distribution network feeder and at the specific Point of Connection indicated. This is called *Grid Impact* Assessment. During this high-level assessment, Kahramaa may require some clarifications from your side.

After a predefined deadline (respecting the quality of service to Customers), Kahramaa should issue his **preliminary connection approval** or rejection based on his high-level assessment. In case of rejection, Kahramaa should explain the reasons to your consultant or Contractor.

Stage 2: Final Connection Approval

If you obtain the approval in the previous stage, you can go ahead and require your consultant or Contractor to develop a full design of your PV System Design, fully compliant with the "*EP-EPP-P7/S1 Technical Specifications for the Connection of PV*

Systems to the Network” document issued by Kahramaa and the National Codes and regulations.

A document named EP-EPP-P7-G2 Guidelines for Information in Basic and Final Design will guide your Consultant in the PV System Design with the sufficient level of detail required by Kahramaa. The document has checklists that summarise the main points that Kahramaa requires from your PV System's final design.

Kahramaa will evaluate, based on the documentation and the mentioned checklist, if your PV System Final Design contains all required documents and data. Kahramaa will also evaluate if all the main data are consistent with those delivered in the previous stage and consistent with the specific PV technology.

After reviewing the check-listed topics of your final design, Kahramaa should approve (or observe) your design. After Kahramaa verifies that the designed conditions and characteristics of your PV System do not affect the distribution network and other Customers, it will issue a final connection approval. Therefore, you should perform payment for connecting your system (Connection Fee).

Then, you can select a Kahramaa-approved contractor for constructing your PV System. The first step of the Contractor should submit to Kahramaa a list of materials and equipment to effectively implement. Kahramaa will review and approve the list of materials and equipment, and then your Contractor can start the PV System construction.

When all civil and electrical works of the PV System have been completed, you move to the next stage.

Stage 3: Connect your PV to the Grid and Generate Electricity

In this final stage, after the construction of your PV System is finalised and compliant with the “*EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network*” and Kahramaa regulations, comes the time to require the Inspection, Testing and Energization of your PV System.

If your system is quite big, the Contractor can test your PV System in the Direct Current part, i.e., modules, strings, etc., before they are connected to the Kahramaa grid.

In order to perform the Commissioning of your PV System, your Contractor should request and notify Kahramaa that the installation is ready and require the installation of the smart meters.

When the system is energised, the Contractor can perform the tests to the installed components and equipment and make the final adjustments and protection settings according to Kahramaa’s indication.

The Commissioning of your PV System is the sole responsibility of your Contractor. In case of your PV System is greater than 50 kW (nearly 166 modules of 300 watts), Kahramaa must witness the Commissioning performed by your Contractor. Otherwise, may decide to attend or not.

If Kahramaa is present in the Commissioning Test, your Contractor shall provide the final documents and information about your PV System. He also must notify Kahramaa of the date (at least 5 days in advance) when the PV System will be subject to the Commissioning Test.

The Contractor must send the Commissioning Test results to Kahramaa for verification and approval. In the case of observations, some tests have to be repeated, or additional tests can be included. After clearing all the observations, Kahramaa provides the eligible customer with the Connection Agreement, which sets out the terms and conditions for the Self-Consumption and net-billing arrangement and any other conditions for the future operation of your PV System.

The Customer must sign the Connection Agreement and start generating!

Key Steps in the Connection Process

Summarising the three Stages, there are key steps in the process that have been summarised below:

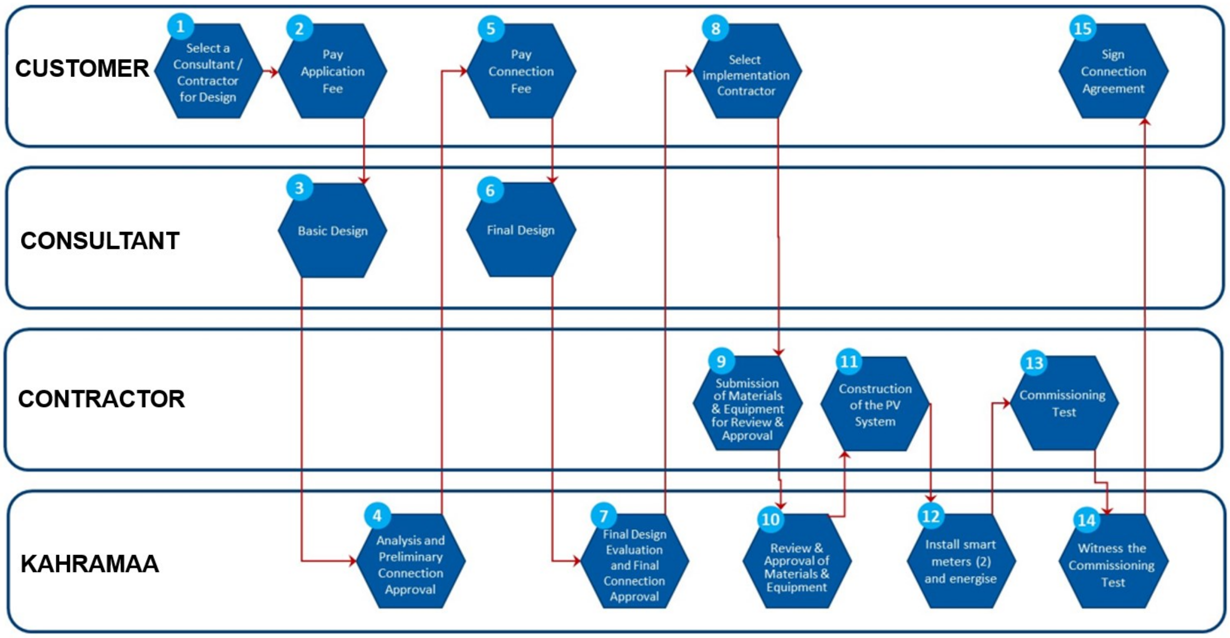

Figure 18 – Key Steps of the Connection Process

7 Can I buy any Equipment in the market for my PV System?

If you want to buy the equipment for your PV System, you must be sure that the key equipment's brand and model are listed in the *List of Approved Equipment* published by Kahramaa on his website.

This is because the key equipment for your PV System must comply with certain conditions and standards adapted for the climate of Qatar and high temperatures, wind, sand and dust conditions. The inverters must also be capable of working at 50 Hz, the frequency of the Qatar power system.

You should verify if the key equipment required (solar PV modules, inverters and Interface Protection) is listed in Kahramaa's *List of Approved Equipment*. The Interface Protection is a device to protect your PV System and Kahramaa network from disturbances and failures.

8 Should I pay to connect my Solar PV System?

Connecting your Solar PV System involves several internal processes in Kahramaa and an analysis of the distribution network in order to assure that your PV System will operate within the permitted range and will not jeopardise the distribution network and other Customers.

For these reasons, there are two payments to be performed:

1) The *Application Fee*; and
2) The *Connection Fee*.

The *Application Fee* is due to the feasibility analysis for connecting your PV System to the network. Kahramaa may decide not to change this *Application Fee* for some small PV Systems not impacting the network. Meanwhile, the *Connection Fee* is for the work to be performed for connecting your PV System, including inspections and witnessing the Commissioning Test.

In case the connection of your PV System involves some modification or upgrading of the Distribution System, Kahramaa may decide to change you (or not) those modifications based on his current incentive policy for the initiative.

9 Which are the Responsibilities?

9.1 Which are my Responsibilities as an eligible customer?

When you have a PV System connected to the grid, you are Kahramaa Customer and also a Producer of electricity.

Although the focus of this guide is to inform you about connecting your Solar PV to Kahramaa's distribution network, you should be aware (also established in the Connection Agreement) that you have some responsibilities once it is connected. This includes:

a) Keeping your generation equipment maintained by someone competent to do so.
b) Sending periodic information, if required, by Kahramaa.
c) Keep the meter of your Solar PV connected.
d) Implement some changes in the setting of your inverter when Kahramaa requires.
e) Informing Kahramaa if there are changes to the installation that affect the generating characteristics.
f) Complying with Safety requirements; and
g) Notify Kahramaa when you are decommissioning your PV System.

9.2 Which are the Responsibilities of the Consultants?

The qualified consultants are required to design your PV System in two stages:

1) Basic Design
2) Final Design

The *Basic Design* has the minimum information required of your PV System and Kahramaa to evaluate its basic characteristics and the impact on the network. The basic design is the basis for the *Preliminary Connection Approval*.

Meanwhile, the *Final Design* is a full design with the equipment specifications, drawings and all information required to construct and implement your PV System.

Therefore, the Consultants (designers) must comply with the following responsibilities:

a) Provide full technical specifications of the PV System, including quantities, make and model number of the solar modules and inverter.
b) Provide a site-specific full system design including all shading issues, orientation and tilt, along with the system's site-specific energy yield, including the average daily performance estimate in kWh for each month of solar generation.
c) Ensure the array design will fit on the available roof and/or ground space.

d) Ensure the design complies with Kahramaa's "*EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network*".
e) Ensure the array configuration is compatible with the inverter specification.
f) Ensure all equipment is fit for purpose and correctly rated.
g) Perform the Connection Process representing the Customer during Stages 1 and 2.

9.3 Which are the Responsibilities of the Contractors?

The Approved Contractors (by Kahramaa) can perform all the activities (if they have qualified consultants in the company), starting with the basic and final design (to be performed by consultants), preparing the list of materials and equipment and finalising the construction, implementation and testing of your PV System.

A Contractor can participate in all the Stages of the Connection Process:

1) Basic Design
2) Final Design
3) Construction and Testing

Therefore, the Contractors, besides complying with all the responsibilities of the Consultants (previous section), must comply with the following responsibilities:

a) Safety conditions for work on-site following the Kahramaa document *Safety for PV Systems* and the national regulation on the matter.
b) Verify that the equipment to be implemented on field and acquired by the Customer follows the standards established in the Kahramaa document "*EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network*" and is listed in the approved list of equipment published by Kahramaa.
c) Ensure all equipment is fit for purpose and correctly rated.
d) Submit to Kahramaa the list of materials and equipment for their review and approval.
e) Construct the PV System.
f) Ensure the construction complies with Kahramaa's "*EP-EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network*".
g) Propose settings for the inverter and the Interface Protection.
h) Obtain warranty information on all equipment.
i) Perform the Connection Process representing the Customer during Stage 3 if it is only the constructor of the PV System.
j) Perform the Connection Process representing the Customer during all 3 Stages of the Connection Process if the Contractor will perform the designs and construction.

10 Do I have to Maintain my PV System?

Yes, it is required appropriate maintenance of your PV System. In order to prevent, protect, and preserve your PV System, it is possible to find third-party companies (Consultants / Contractors) that generally offer a regular service to maintain solar PV Systems.

According to the PV Operation & Maintenance (O&M) best practices, there are the following major approaches for handling the O&M of solar PV Systems. Each approach achieves the three key aims of an effective O&M strategy:

- to reduce costs.
- improve availability; and
- increase productivity.

Preventative Maintenance entails routine inspection and servicing of equipment to prevent breakdowns and unnecessary production losses. Preventative Maintenance regimes are becoming increasingly popular because of their perceived ability to lower the probability of unplanned PV System downtime.

Corrective or Reactive Maintenance addresses equipment breakdowns after their occurrence and, as such, is instituted to mitigate unplanned downtime. The current industry standard, this “break-fix” method, allows for lower upfront costs but also brings with it a higher risk of component failure and accompanying higher costs on the backend (putting a premium on negotiating beneficial warranty terms).

Condition-based maintenance (CBM) uses real-time data to prioritise and optimise maintenance and resources. This is mainly for large PV Systems.

The following table summarises the typical maintenance activities as a guideline for your decision according to the size of your PV System and your budget capabilities:

Table 1 – Maintenance Approaches

TASK	FREQUENCY (Typical)
Corrective/Reactive Maintenance	
Module Cleaning	1-2x Times/Year
Vegetation Management	1-3 Times/Year
Wildlife Prevention	Variable
Water Drainage	Variable
Retro-Commissioning†	1 Time/Year
Upkeep of Data Acquisition and Monitoring Systems (e.g., Electronics, Sensors)	Undetermined
Upkeep of Power Generation System (e.g., Inverter Servicing, Inspection, Tracker Maintenance	1-2x Times/Year
Corrective/Reactive Maintenance	
On-Site Monitoring/Mitigation	Variable
Critical Reactive Repair*	As Needed (High Priority)
Non-Critical Reactive Repair**	As Needed
Warranty Enforcement	As Needed
Condition-Based Maintenance (CBM)	
Active Monitoring—Remote and On-Site Options	Continuous
Warranty Enforcement (Planned and Unplanned)	As Needed
Equipment Replacement (Planned and Unplanned)	As Needed

† Retro-commissioning identifies and solves problems that have developed during the PV System’s life.
* Critical reactive repairs address production losses issues;
** Non-critical reactive repairs address production degradation issues