

Connection Guidelines for Large-Scale PV

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1 SCOPE

These Guidelines provide information meant for KSA Consumers, Consultants and Contractors on the essential aspects which have to be taken into consideration in order to connect a Large-Scale Solar PV System to the Low Voltage or Medium Voltage Distribution Network of SEC. These Guidelines apply to the planning, execution, modification, operation and maintenance of the Large-Scale Solar PV Systems. These Guidelines comply with the WERA Regulations that set out the regulatory framework for the connection of a Large-Scale Solar PV Systems to the Distribution System of SEC.

This document contains basic principles of large-scale solar PV systems along with the illustration of the connection process as per SEC specific conditions. Thus, this guide shall serve as a basis for SEC and for the Consumer or its appointed agent in the planning and decision-making process at all applicable stages.

The technical aspects are not treated here, but separately in the Technical Standards for the Connection of Solar PV Systems > 2MW to the MV Distribution Networks of SEC (in this document referred to as "Technical Standards"), 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 COMPANION DOCUMENTS

[1] CESI_SEC-DREG Health and Safety Requirements for Large-Scale PV_Final.docx
[2] CESI_SEC-DREG Large-scale PV - Best Practice Design v1.0_Final.docx
[3] CESI_SEC-DREG Manual for the maintenance of Large-Scale PV Systems_Final.docx
[4] CESI_SEC-DREG PV components and recommendations for PV larger than 2 MW_Final.docx
[5] CESI_SEC-DREG PV Large Scale Technical Connection Standards_Final.docx
[6] CESI_SEC-DREG Inspection and Testing Checklists for Large Scale Solar_Final.docx
[7] CESI_SEC-DREG Inspection and Testing Guidelines Solar Greater than 2 MW_Final.docx

DISCLAIMER
For understanding the connection process for connection large scale PV systems, users must refer to the common connection process document for REG systems. The connection process for all DREG system is the same, and hence, all users are shall be updated with the REG connection process which is applicable for Large Scale PV systems too.

3 TERMS AND DEFINITIONS

Building-Attached Photovoltaic Modules (BAPV modules) – Photovoltaic modules are considered to be building-attached, if the PV modules are mounted on a building envelope and the integrity of the building functionality is independent of the existence of a building-attached photovoltaic module.
Building Attached Photovoltaic system (BAPV system) – Photovoltaic systems are considered to be building attached, if the PV modules they utilize do not fulfil the criteria for BIPV modules

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.
Building-Integrated Photovoltaic system (BIPV system) – Photovoltaic systems are considered to be building-integrated, if the PV modules they utilize fulfil the criteria for BIPV modules
Consultant/Contractor – An entity that is registered with the Habilitation/Qualification Committee to carry out design and electrical installations work specific to solar photovoltaic (PV) systems as a consultant or contractor.
Connection Point - Is the location at which a solar PV generating system is connected to the distribution network and where the main electricity meter is installed.
Data sheet – Basic product description and specification (Note: Typically, one or two pages, not a full product manual)
Eligible Consumer/Consumer – A person who has an Exit Point that meets the requirements of these Regulations and the Connection Conditions between the Distribution System and the Consumer's Premises as defined in the Distribution Code.
Exit Point– The joint point of delivery of electricity supply by SEC & export of surplus generation by Eligible Consumer linked to one single meter in a Premises.
Global horizontal irradiance (GHI) – Direct plus diffuse irradiance incident on a horizontal surface expressed in W/m^2
Inspection – Examination of an electrical installation using all the senses in order to ascertain correct selection and proper erection of electrical equipment
In-plane irradiance (Gi or POA) – The sum of direct, diffuse, and ground-reflected irradiance incident 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) - The electrical protection required to ensure that either the generating plant and/or any generating unit is disconnected for any event that could impair the integrity or degrade the safety and reliability of the 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 specified time interval expressed in kWh/m^2
Large-Scale Solar PV System – As per WERA Regulations, a solar PV installation of more than 2MW capacity that is installed in one's Premises and connected in parallel to the Distribution system.
Net billing: Energy exchange and financial clearance arrangements between a consumer & a distribution service provider at one exit point in facility.
PV array – Assembly of electrically interconnected PV modules, PV strings or PV sub-arrays.
PV cell – Most elementary device that exhibits the photovoltaic effect, i.e. the direct non-thermal conversion of radiant energy into electrical energy
PV module – PV modules consists of electrically connected PV cells and packaged to protect it from the environment and the users from electrical shock.
PV string – PV string consists of two or more series-connected PV modules
PV string combiner box – Junction box where PV strings are connected which may also contain overcurrent protection devices, electronics and/or switch-disconnectors
PV sub-array – A subset of a PV array formed by parallel-connected PV strings.

Standard test conditions (STC) – Reference values of in-plane irradiance (1000 W/m^2), PV cell junction temperature (25 °C), and the reference spectral irradiance defined in SASO IEC 60904-3
Switch – Mechanical device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions. In addition, it is able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions.
Testing – Implementation of measures in an electrical installation by means of which its effectiveness is proved (Note: It includes ascertaining values by means of appropriate measuring instruments, said values not being detectable by inspection)
The computer program: It is an electronic calculator to analyze the financial aspects hosted by the authority on its website, and it is prepared by the city and approved by the authority, to carry out an economic feasibility study to calculate the cost of installing solar PV systems and estimate revenue and savings based on the energy produced from the solar system and the Consumer's consumption rates And indicate the expected time period for cost recovery, and the program includes information and data necessary to educate the consumer
Verification – All measures by means of which compliance of the electrical installation to the relevant standards are checked

4 GLOSSARY

The following acronyms and symbols are used throughout the document:

AC	Alternating Current
AFCI	Arc Fault Circuit Interrupter
ASTM	American Society for Testing and Materials
BAPV	Building-Attached Photovoltaic Modules
BIPV	Building-Integrated Photovoltaic modules
DC	Direct Current
WERA	Water and Electricity Regulatory Authority
GHI	Global horizontal irradiance
IEC	International Electrotechnical Commission
IP (or I.P.)	Interface Protection
IR	Infrared
ISO	International Organization for Standardization
MPPT	Maximum Power Point Tracker
NEC	National Electrical Code
NFPA	National Fire Protection Association
P	Active power
PELV	Protected Extra Low Voltage
Pnom	Nominal active power of equipment
POA	Plane of Array
PPE	Personal protective equipment
PR	Performance Ratio
PV	(Solar) Photovoltaic

Q	Reactive Power
RCD	Residual Current Device
S/Sn	Apparent Power
SASO	Saudi Standards, Metrology and Quality Organization
SBC	Saudi Building Code
SEC	Saudi Electricity Company
SELV	Safety extra low voltage
SPD	Surge Protection Device
SR	Soiling Ratio
STC	Standard Test Condition
UL	Underwriters Laboratories
UV	Ultraviolet
V	Voltage
Vnom	Nominal Voltage
Wp	Watt peak rating

5 SOLAR PV SYSTEMS – BENEFITS, TECHNOLOGY, ENVIRONMENT

5.1 The sun as an energy source

Every day we receive from the Sun thousands of times the energy we consume but the solar energy is distributed on the Earth's surface, and thus large collection surfaces are required to exploit it.
Furthermore, if we consider a given area, the sun energy is discontinuous, mainly for the following reasons:

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

The daily variability is due to the Earth rotation, which is the spinning of the Earth around its own axis. One rotation takes 24 hours and is called a solar day. The seasonal variation is due to the orbit of the Earth around the sun, is called Earth revolution and takes 365 1/4 days to complete one cycle. The Earth's orbit around the sun is elliptical, thus the Earth's distance from the Sun varies at different times of the year. Outside the Earth atmosphere, the 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 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 atmosphere

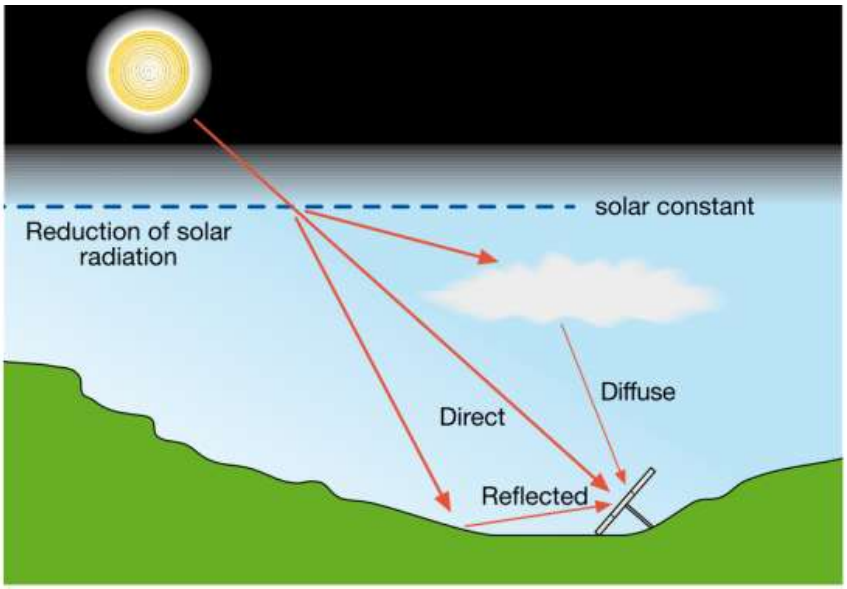


Figure 1 – Effect of the atmosphere on the sunlight

As a consequence, 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 for daily or

monthly or yearly basis. Figure 2 shows average annual solar radiation received in KSA referred from Solargis database, a third-party service meteo data service provider.

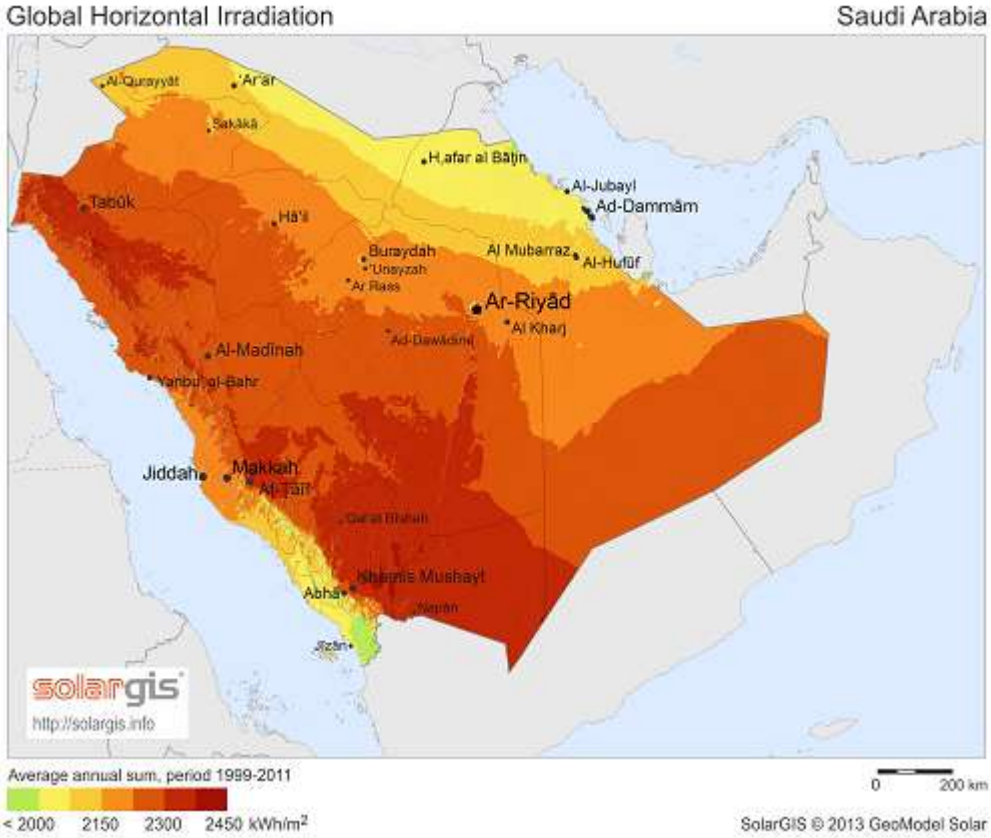


Figure 2 – Example of a yearly solar map for the Saudi Arabia

There are several databases on solar radiation and climate data that cover all the world or specific regions. In the Kingdom of Saudi Arabia, it is possible to refer to the monitoring network developed by the King Abdullah City for Atomic and Renewable Energy (K.A.CARE).

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

5.2 The PV Technology

The solar photovoltaic (PV) technology is undoubtedly the easiest way to produce electric energy from sunlight. It can be used for many purposes in households and in all sectors that need power 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 the photovoltaic conversion. PV cells are composed of semiconductors purposely designed to be exposed to the sun light and collect as much energy as possible. Not surprisingly their shape is thin and wide.

The most widely used PV cells are made up of crystalline silicon (mono or poly-crystalline), whose shape is normally square or a pseudo square with edges trimmed, as the example in Figure 3, and whose thickness usually is no more than 0.2 mm. Solar cells are therefore very fragile and must be purposely protected in a rigid structure, namely a PV module, where a number of PV cells is assembled and connected together in a single body with a transparent front glass.

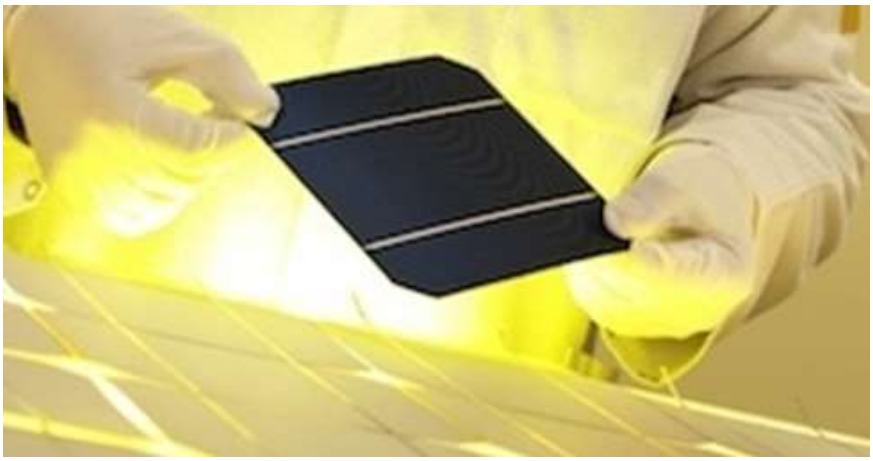


Figure 3 – Example of a crystalline PV cell

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).

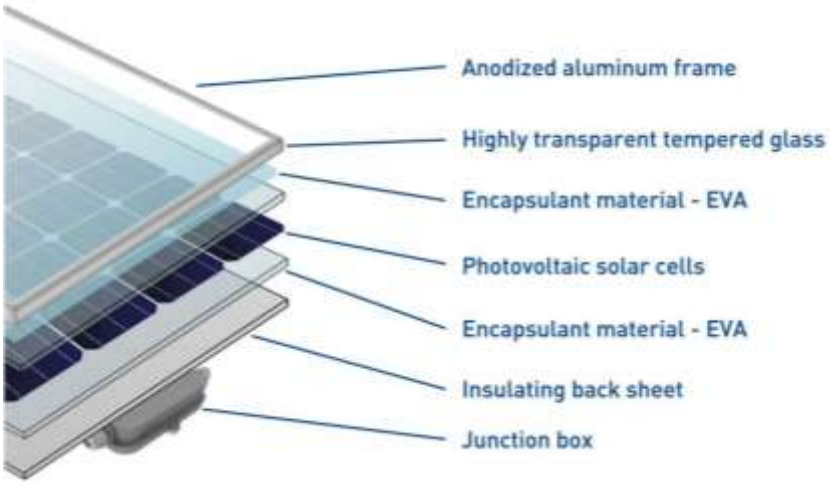


Figure 4 – Typical structure of a PV module

Presently the crystalline silicon PV modules available in the market has a nominal power typically in the range of 300Wp to 400Wp (sometimes more than 400 Wp), measured at specific irradiance and temperature called as Standard Test Conditions or STC (1000 W/m^2, 25 °C, AM 1.5).

Although the crystalline PV technology is the most widely used, there are also other technologies that are based on the deposition of a thin layer of semiconductor on a 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 counterpart (except CdTe technologies, which has 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 back side of the module into electrical power and can therefore (substantially) increase the electric yield of PV power plants depending on the specifics of the installation. The additional yield for bi-facial power plants 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 "SEC - Best practice for designing a PV system vr1.7" document)

5.3 PV systems

PV modules are mechanically assembled and electrically connected is series and parallel to form a PV array. The PV array provides all the power coming from the solar conversion, but we cannot use it directly since it generates DC electricity which is not directly compatible with the 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 by means of specific electronic equipment called Inverter. The inverter performs several functions: mainly it optimizes 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.

Figure 5 shows the general configuration of a Solar PV System. Beside the inverter there are other equipment aimed to safeguard the distribution network (Interface Protection - IP), to measure the energy produced and exchanged with the distribution network (Meters) and to sort the power (AC switchgear). Such PV systems are called *Grid-connected PV systems* or *Grid-tied PV systems*.

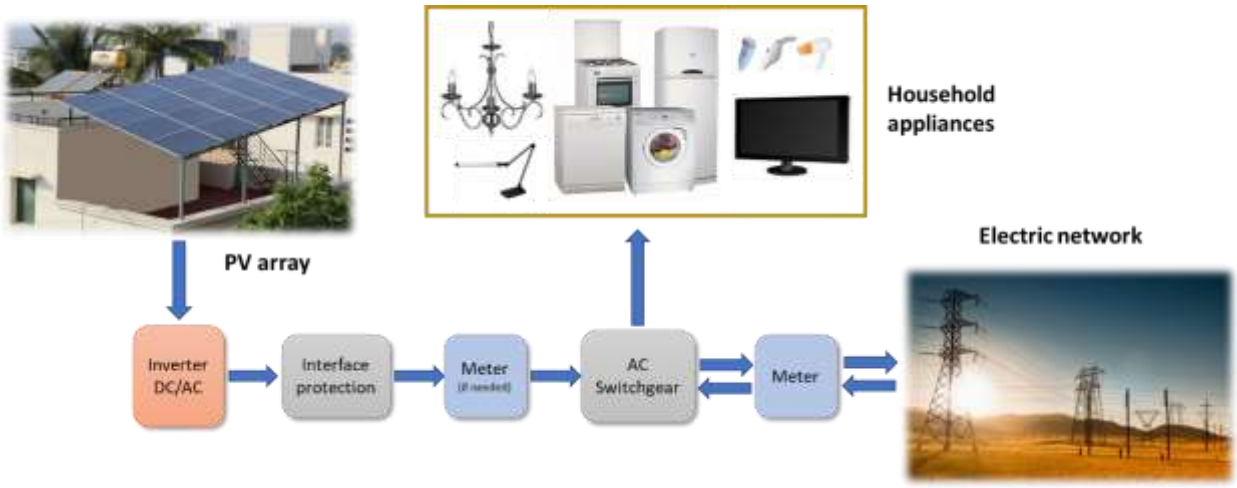


Figure 5 – General configuration of a Solar PV System

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

- The energy produced is 100% renewable and comes from the sun;
- The plant does not produce any pollutant;
- The energy produced can fully replace energy generated through fossil fuels, thus reduces emissions of pollutants and in particular greenhouse gasses in the atmosphere.

5.4 Net billing benefits

It has been illustrated that grid-connected PV systems convert solar irradiation coming 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 before sunset and after dawn. The production is also influenced by a seasonal variation.

However, from a technical point of view, shortfall between solar PV production and internal consumption may be easily managed by the presence of the public grid. When the solar PV production exceeds the internal consumption, the difference is sent to the distribution network and, conversely, when the solar PV production is less than consumption or is null (evening, night) the difference is taken from the distribution network.

Therefore, at the end of a period (month, year) the energy meter at the Connection Point registers an amount of kWh that has been taken from the distribution network and an amount of kWh that has been injected to the distribution network. The net billing mechanism in its simplest version makes the monetary difference between input and output. In case of any surplus energy produced by the solar PV system and injected to the grid, a financial evaluation will take place and the amount will be transferred and deducted from the next billing cycle.