KAHRAMAA
كهرماء
المؤسسة العامة القطرية للكهرباء والماء
Qatar General Electricity & Water Corporation

# EP-EPP-P7-S1

# Technical Specifications for the Connection of PV Systems to the Network

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# 1 Purpose

This document provides a common set of requirements specific for grid-connected Solar PV (Photovoltaic) Systems that operates in parallel with the LV & MV distribution networks of Kahramaa, Qatar. The maximum capacity of a Solar PV System considered in this document is 25 MW for connection to up to 33 kV voltage level and the capacity of Solar PV system should not exceed Contracted demand as defined and approved in the building permit. These requirements shall be fulfilled regardless of the presence of loads in the Customer's installation.

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| In case of standalone PV systems not connected to Kahramaa's grid, the document "*Standalone Solar PV Systems*" shall be used. |

# 2 Scope

The current Technical Standards for grid-connected PV Systems define:

a) Requirements for the equipment used to interconnect a solar PV System with the distribution network.
b) Requirements to support the frequency and voltage stability of the power system when it is subject to disturbances.
c) Requirements for the start-up, operation and disconnection of the solar PV Systems.
d) Requirements to prevent the solar PV Systems from causing disturbances and damages, either to the distribution network or to other Customers connected to the same distribution network.
e) Requirements to prevent the solar PV Systems from operating in parallel with an island or portion of the distribution network which has been disconnected on purpose from the main power system.

The present document is not contradicting additional requirements set out by other national & international standards, network codes or specific technical requirements of Kahramaa, and which may apply to the connection of a solar PV System, including, but not limited to the following:

- The Qatar Transmission Grid Code – Issue ES-M4 – Revision 0.0 – March 2020 and amendments in force (hereinafter "Transmission Code")
- CS-CSI-P1/C1 – Kahramaa's Low Voltage Electricity Wiring Code 2016
- CS-CSI-P1 E_W – Building Permit Issuance
- CS-CSI-P1-C1 – Design - Water Management Code 2016
- Qatar Construction Specifications latest edition

All the Contractors and Consultants should follow the Qatari regulations in their latest edition. Specifically, the Consultants and Contractors shall follow the *Qatar Construction Specifications* document in its last edition for all the non-solar components of the PV Systems required in the electrical design, installation and connection of a PV System.

The Transmission Code here above indicated is also applicable to all users of the distribution system. The present Technical Standards shall apply in case the new installation (or the modified one) includes a solar PV System and shall be intended as an extension of the Transmission Code for what is not directly ruled by the code itself. For all the aspects not covered by the present document, reference shall be made to the Transmission Code.

This information can be found in other companion documents, as listed in part. 0.

Finally, it is not under the purpose of these standards to define technical rules for the off-grid operation of networks in isolated (e.g., rural) areas where no part of Kahramaa distribution network is involved.

Unless otherwise explicitly specified, the requirements set forth by the present standards apply to new solar PV Systems, i.e., to those solar PV Systems which do have not already been approved by Kahramaa at the date of publication of the standards.

## 2.1 Notice to Users

This document is for the use of employees of Kahramaa, Customers, Consultants, Contractors and Manufacturers. Users of this guideline should be aware of the applicable laws and regulations. Users are responsible for observing or referring to the applicable regulatory requirements. Kahramaa, by the publication of its standards, does not 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. At any point in time, these Technical Standards consist of the current edition of the document together with any amendments, corrigenda, or errata in effect. All users should ensure that they have the latest edition of this document uploaded on Kahramaa website.

Finally, unless otherwise specified, the User shall refer to all applicable Kahramaa Standards, Qatar Standards, or International Standards mentioned in this document.

***DISCLAIMER***

***These Technical Standards are provided without a consolidated Framework Regulation by Kahramaa; therefore, the content of the present document may be subject to change in the next revisions of the Technical Standards.***

## 2.2 Kahramaa Limitation of Liability and Customer's undertaking

Kahramaa disclaims liability for any personal injury, property or other damage of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the connection point. Customers are responsible for observing or referring to the applicable laws and regulatory requirements.

It is the Customer's responsibility through their Consultant/Contractor to determine the interconnection equipment's specifications and confirmed performance to satisfy the technical needs of the Kahramaa network and be compatible with the present and any other applicable Kahramaa standards. Kahramaa standards are indispensable for solar PV applications. All equipment in an installation connected to Kahramaa network shall be designed, manufactured, tested and installed following all applicable statutory obligations and shall conform to the relevant Kahramaa standards current at the time of the connection of the installation to Kahramaa network.

The Customer shall undertake to comply with the following:

a) Arrange all necessary requirements and systems to connect his solar PV System to Kahramaa network, including compliance with security and safety requirements by providing necessary equipment.
b) Comply with the terms and conditions for the PV System connection, such as the ***Connection Agreement***, connection conditions, and any other relevant requirement adopted by Kahramaa.

c) Do not exceed the authorised Maximum Connected Capacity for exporting to the Kahramaa network.
d) Cooperate with Kahramaa staff in all matters related to exporting electricity to Kahramaa network.
e) To bear all the costs associated with the connection of his solar PV System to Kahramaa network.
f) To export to Kahramaa network any excess electricity generated by his solar PV System to Kahramaa network in accordance with the provisions of the ***Connection Agreement***.
g) To let Kahramaa disconnect or perform an immediate disconnection of his solar PV System under Kahramaa request if it was identified risk for the safety or the security of the system and the Kahramaa public electricity network.
h) Ensure the development of a Maintenance manual which guarantees the correct operation and performance of the PV system during its entire lifetime.

# 3 Abbreviations, Definitions of Terms & Key References

## Abbreviations

| | | | | | |
|---|---|---|---|---|---|
| $cos\ \varphi$ | : | Power factor | IP | : | Interface Protection |
| LOM | : | Loss of Mains | LV | : | Low Voltage |
| LVRT | : | Low Voltage Ride Through | MV | : | Medium Voltage (namely 11 kV or 22 kV) |
| NCC | : | National Control Centre | P | : | Active power |
| $P_{nom}$ | : | Nominal active power of equipment | pu | : | per unit |
| PV | : | (Solar) Photovoltaic | Q | : | Reactive Power |
| ROCOF | : | Rate of Change of Frequency expressed in Hz/s | S | : | Apparent Power |
| $S_n$ | : | Nominal Apparent Power | V | : | Voltage |
| $V_{nom}$ | | Nominal Voltage | EP | : | Electricity Planning Dept |

| Term | Description |
|---|---|
| Active Power | Active Power is the real component of the apparent power, expressed in watts or multiples thereof, e.g. kilowatts (kW) or megawatts (MW). In the text, this will be generically referred as *P* or $P_{nom}$ in case of the nominal active power of equipment |
| Apparent Power | The product of voltage and current at the fundamental frequency, and the square root of three in the case of three-phase systems, usually expressed in kilovolt-amperes (kVA) or megavolt-amperes (MVA). It consists of a real component (Active Power) and the reactive component (Reactive Power). This will be generically referred to *S* or $S_n$ in case of the rated apparent power of equipment |
| Apparent power of an Inverter | The rated apparent power of an Inverter is the product of the rms voltage and current and is expressed in kVA or MVA. |
| Auxiliary Supply Power | Electricity supply for supporting auxiliary systems and services such as Interface Protection or circuit breaker and contactor opening coils. |
| Circuit Breaker (CB) | As per the Kahramaa Electricity and Wiring Code definition |

| Term | Description |
|---|---|
| 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. |
| Customer | Any Person supplied with electricity services for his own consumption. 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. |
| Delay time (of a protection relay) | Indicates the minimum duration of a fault detected by the protection relay before the output of the protection relay is triggered. |
| Delivery Point | The interface point at which electrical energy is delivered by Kahramaa to a Demand Facility or Generating Unit or by a Demand Facility or Generating Unit to Kahramaa. |
| 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:<br>• 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.<br>• 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.<br>• 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.<br>To avoid doubt, the term Distribution Network will be preferred in this document in place of Distribution System. |
| Electricity Transmission Network (ETN) | Qatar electrical infrastructure (lines, cables, substations, etc.) from above 33 kV up to 400 kV operated by Kahramaa. |
| 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. |
| Irradiation | Irradiance integrated over a given time interval and measured in energy units (e.g. kWh/m$^2$/day). |
| Islanding | Situation where a portion of the distribution network containing generating plants becomes physically disconnected from the rest of the distribution network. One or more generating plants maintain electricity supply to such isolated parts of the distribution network. |
| Load Flow | It is a numerical analysis of the electric power flow in a transmission and/or distribution systems. A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system, and focuses on various parameters, such as voltages, voltage angles, real power and reactive power. It analyses the power systems in normal steady-state operation. |
| Loss Of Mains (LOM) | Represents an operating condition in which a distribution network, or part of it, is separated from the main power system (on purpose or in case of a fault) with the final aim of de-energisation. The protection that detects this condition is known as anti-islanding protection. |

| Term | Description |
|---|---|
| Main Meter | It is the bidirectional smart meter installed at the Connection Point which measures the amount of electric energy actually exchanged (import or export) by the Customer with the 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. |
| Maximum Capacity ($P_{max}$) | It is the maximum continuous active power which a Generating Unit can produce, less any auxiliary consumption associated used to facilitate the operation of that Generating Unit. The Maximum Capacity shall not be fed into the distribution network as specified in the *Connection Agreement*. In this document, this term is also referred to as Maximum Connected Capacity. |
| Peak Power (Wp) | The output power achieved by a Photovoltaic Module under Standard Test Conditions (STC). It is measured in Wp (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 kWp). The peak power of a photovoltaic array at STC is conventionally assumed as the rated power of the array. |
| Solar 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. |
| Solar PV Unit | A group of devices that collects the sun's irradiance in a Solar PV System, together with all plant and apparatus and any step-up transformer which relates exclusively to the operation of that part of the same Solar PV System. Only units that are Inverter based (i.e. Asynchronously connected to the Distribution Network through power electronics devices) are considered in this document. For these Technical Standards, this definition will be equivalent to that of the Power Park Module as given in the Transmission Code. For the avoidance of doubt, in this document, the generic term Solar PV Unit will be considered equivalent to a solar PV Unit. |
| National Control Centre (NCC) | Main Kahramaa's facility used to operate and control/maintain the Electric Power System. |
| 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 |
| Power Factor | Is the ratio of Active Power to Apparent Power. |
| Power Park Module (PPM) | A unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single Connection Point to the ETN. |
| PV Array | Assembly of electrically interconnected PV modules, PV strings or PV sub-arrays. For the purposes of these Technical Standards, a PV Array comprises all components up to the DC input terminals of the Inverter. |
| PV String | A set of series-connected PV modules. |

| Term | Description |
|---|---|
| PV String Combiner Box | A box where PV strings are connected, which may also include circuit breaker, monitoring equipment, and electrical protection devices. |
| Rated Active Power | Represents the sum of the nominal active power of all the Solar PV Units which compose the Solar PV System; it is generally referred to as *Pnom* of the Solar PV System. |
| Reactive Power | Represents a component of the apparent power at the fundamental frequency, usually expressed in kilovar (kVAr) or Megavar (MVAr). |
| Reactive Power Capability | Defines the reserves of inductive/capacitive reactive power which can be provided by a generating system/unit. The reactive power capability usually varies with the active power and the voltage of the generating system/unit. |
| Residual Current Device (RCD) | A sensitive switch that disconnects a circuit when the residual current exceeds the operating value of the circuit, referred as RCD in this document. |
| Switch | As per the Kahramaa Electricity and Wiring Code definition. |
| Time Current Curve (TCC) | The time current curve plots the interrupting time of an overcurrent device based on a given current level. These curves are used for the protection coordination, and are provided by the manufacturers of electrical overcurrent interrupting devices such as fuses and circuit breakers. |
| THD (Total Harmonic Distortion) | Concerning an alternating quantity, it represents the ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component. |

## Key References


[1] The Qatar Transmission Grid Code – Issue ES-M4 – Revision 0.0 – March 2020 and amendments in force until 02/2022 (in this document referred to as "Transmission Code")
[2] CS-CSI-P1/C1 Kahramaa's Low Voltage Electricity Wiring Code 2016
[3] Safety Rules for the Control, Operation and Maintenance of Electricity Transmission & Distribution System of Qatar General Electricity & Water Corporation.
[4] System Operation Memorandum (SOM).
[5] Kahramaa interlocking document, (Qatar Power Transmission System Expansion – Latest phase – Substations).
[6] Qatar Construction Specifications, Latest edition
[7] ET-P26-G1 Guidelines for Protection Requirements.
[8] ES–EST-P1-G1 Guidelines for System Control Requirements for Power Supply to Bulk Customers.
[9] ET-P20-S1 Transmission Protection Standards for TA and ET Projects.
[10] ES-M2 Qatar Power System Restoration Plan; and
[11] ES-M3 System Emergency, Categorization, Communication & Restoration Responsibility.
[12] QCDD (Qatar Civil Defence Department) regulations
[13] CS-CSI-P2 E_W – Infrastructure Preparation for Service Connection Purpose v3
[14] CS-CSI-P3 E_W – Services Inspection v5
[15] CS-CSI-P4 – Low Voltage Electrical Contractor Licensing v3
[16] CS-CSI-P5 – Handling of Contractors Violations Procedure v2
[17] CS-JCU-P1 – Illegal Connections Reconnections v3
[18] CS-CSM-P2 E_W – Supply Connection and Disconnection
[19] CS-AMI-P1 – AMI operations
[20] CS-MAS-P2 E_W – Meter Installation v4

[21] CS-MAS-P3 – Maintenance of Electricity and Water Meter v2
[22] CS-MAS-P5 – Materials Submittal Review _ Approval Procedure v2
[23] Energy and Water Conservation Code 2016
[24] EP-EPD-P1 – Electricity Supply Approval v3
[25] EP-EPD-P4 – Processing Service Notes v2
[26] EP-EPD-P6 11kV – Load Flow Study v2
[27] EP-EPP-C1 – Electricity Planning Regulations for Supply
[28] EP-EPP-P3 – Early Arrangement for Supply Connection
[29] EP-EPP-P5 – Electricity Supply Application
[30] EP-EPT-P2 – Basic Concept Report-Direct Connection Notification
[31] EP-EPT-P3 – Peak Demand Forecast
[32] EP-EPT-P4 – Power System Studies and Five Years Development Plan
[33] ES-ESN-P3 – Dispatching Procedure
[34] ES-ESN-P4 – Bulk Industrial Consumers Energy Meter Readings Collection v2
[35] ES-ESP-P1 – Creating Operational Load Forecast
[36] ES-ESP-P2 – Long Term Operation Planning
[37] ES-ESP-P3 – Develop Monitor Energy Purchase Schedules and Allocation Plans
[38] ES-ESP-P4 – Operation Studies
[39] ES-ESP-P7 – Develop Surplus Available Capacity Plan for Marketing
[40] ES-M4 – Qatar Transmission Grid Code 2020
[41] ET-P26 ETD – Responsibilities for Bulk Consumer's Request for Supply of Electricity
[42] CS-CSB-P1– Bulk Supply of Electricity and Water
[43] PW-PWP-P1 E_W – Demand Forecasting
[44] PW-PWP-P2 – Additional Capacity Planning
[45] PW-PWP-PL1 – Planning _ Procurement Policy
[46] PW-PWR-P2 – Renewable Energy Standards Development

***DISCLAIMER***

***The latest editions of the Distribution/Transmission Grid Code, the Electricity Wiring Code, Qatar Construction Specifications, as well as all the documents indicated in the above list in force at the time of the contract, shall prevail and be complied with. The Customer shall also comply with the requirements of any standards issued by Qatar Authorities at the time of the Connection Purchase Agreement.***

## Companion Documents

The documents listed hereinafter have to be considered a compendium of the current document. Therefore, they should be carefully read in addition to this.

a) EP-EPP-P7 Electricity Supply Approval for REG connection
b) EP-EPP-P7-G2 Guidelines for Information in Basic and Final Design
c) CS-CSI-P3-G2 Inspection and Testing Guidelines for Solar PV Systems Connected to LV and MV Network, last revision
d) PW-PWR-G2 Safety related to the installation of Solar PV Systems, last revision
e) KM-PW-PL01-Kahramaa policy for Renewable Energy systems connected to the distribution network

# 4 Applicable Standards for Solar PV Systems Components

Along with the Technical Standards for the Connection described in the current document, all the components of solar PV Systems shall comply with the applicable International and Qatar standards listed here below, according to the component they apply to.

This ensures that the components and equipment used in solar PV Systems in Qatar fit with a minimum set of technical characteristics that give the necessary quality avoiding using unfit or unreliable materials and equipment in Solar PV projects.

However, standards may be subject to future revisions, amendments or extensions, and it will be the User's care to find the latest published versions and utilise them.

**PV MODULES**

1) IEC 61215-1 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements.
2) IEC 61215-1-1 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules.
3) IEC 61215-1-2 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules.
4) IEC 61215-1-3 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon-based photovoltaic (PV) modules.
5) IEC 61215-1-4 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu (In, GA) $(S,Se)_2$ based photovoltaic (PV) modules.
6) IEC 61215-2 – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures.
7) IEC 61345- UV test for photovoltaic (PV) modules- PV modules subject to a greater UV exposure
8) IEC 61730-1 – Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction.
9) IEC 61730-2 – Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing.
10) IEC 61701 – Salt mist corrosion testing of photovoltaic (PV) modules.
11) IEC TS 62804-1 – Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon.
12) IEC 62716 – Photovoltaic (PV) modules - Ammonia corrosion testing.
13) IEC 62759-1 – Photovoltaic (PV) modules - Transportation testing - Part 1: Transportation and shipping of module package units.
14) IEC 62790 – Junction boxes for photovoltaic modules - Safety requirements and tests.
15) IEC 62852 – Connectors for DC-application in photovoltaic systems - Safety requirements and tests.
16) IEC 62979 – Photovoltaic modules - Bypass diode - Thermal runaway test.
17) IEC TS 62941 – Terrestrial photovoltaic (PV) modules - Guideline for increased confidence in PV module design qualification and type approval.
18) IEC TS 62782 – Photovoltaic (PV) modules - Cyclic (dynamic) mechanical load testing.

19) IEC 60068-2-68 – Environmental testing - Part 2-68: Tests - Test L: Dust and sand.
20) IEC TS 63126 – Guidelines for qualifying PV modules, components and materials for operation at high temperatures.
21) IEC 61853 (series) – Photovoltaic (PV) module performance testing and energy rating.
22) IEC TS 61836 - Solar Photovoltaic Energy System Terms, definitions and Symbols.
23) IEC 61853-2 - PV Module performance Testing and Energy rating-Part 2: Special responsivity, incidence angle and module operating temperature measurements.

**INVERTERS**

1) IEC 62109-1 – Safety of power converters for use in photovoltaic power systems - Part 1: General requirements.
2) IEC 62109-2 – Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters.
3) EN 50530 – Overall efficiency of grid connected photovoltaic inverters.
4) EN 50524 – Data sheet and name plate for photovoltaic inverters.
5) IEC 62116 – Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures.
6) IEC TS 62910 – Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements.
7) IEC 62920 – Photovoltaic power generating systems - EMC requirements and test methods for power conversion equipment.
8) IEC 61000-3-2 – Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase).
9) IEC-61000-3-7: The limits of flicker severity of a solar PV system connected to Distribution Network.
10) IEC 61000-3-12 – Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase.
11) IEC/TR 61000-3-15 – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

**INTERFACE PROTECTION**

1) IEC 62116 – Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures
2) IEC 61727 – Photovoltaic (PV) systems - Characteristics of the utility interface

**SOLAR CABLES AND CONNECTORS**

1) EN 50618 – Electric cables for photovoltaic systems.
2) IEC 62930 – Electric cables for photovoltaic systems with a voltage rating of 1.5 kV DC
3) EN 50521- Connectors for photovoltaic systems – Safety requirements and tests
4) CEI 20-91- Fire retardant and halogen free electric cable with elastomeric insulation and sheath for rated voltages not exceeding 1 000 V a.c and 1 500 V d.c for use in photovoltaic system (PV)

**PV STRING COMBINER BOXES**

1) EN 50178 – Electronic equipment for use in power installations.
2) IEC 62477-1 – Safety requirements for power electronic converter systems and equipment - Part 1: General.

3) IEC 62477-2 – Safety requirements for power electronic converter systems and equipment - Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC
4) IEC 62093 – Balance-of-system components for photovoltaic systems - Design qualification natural environments.

**SYSTEM INSTALLATION**

1) IEC 60364-1 & IEC 60364-7-712: Low voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions, and Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
2) UL 1741: Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
3) UL 2703: Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels
4) IEC 61439-1– Low-voltage switchgear and control gear assemblies – General Rules
5) IEC 61439-2– Low-voltage switchgear and control gear assemblies - Part 2: Power switchgear and control gear assemblies.
6) IEC 62548 – Photovoltaic (PV) arrays - Design requirements
7) IEC 62817 – Photovoltaic systems - Design qualification of solar trackers
8) IEC TR 63149 – Land usage photovoltaic (PV) farms – Mathematical models and calculation examples

**EARTHING**

1) IEC 60364-5-54 for all LV installations;
2) IEC 60364-7-712 and IEC 62548 specifically for PV Systems;

**LIGHTNING**

1) IEC 62305 - Lightning protection standard

**COMMUNICATION**

1) IEEE-2030; Communication standard for Integrating Solar PV system to Distribution Network.

**SAFETY**

1) NEC-Article 690: Safety standard for Installation of PV Systems.

***DISCLAIMER***

***The listed standards are related only to the major solar PV equipment. Standards for other electrical components, such as transformers, switches, circuit breakers, switchgears, etc., shall follow the standards accepted and approved by Kahramaa in their regulations.***

# 5 Technical Requirements

## 5.1 General Requirements

A solar PV System can be connected to Kahramaa Distribution Network, either LV or MV, at an appropriate point called *Connection Point*. It is the responsibility of Kahramaa to determine the appropriate Connection Point and assess the integration capacity of his network to host the connecting solar PV System at that point whilst maintaining a stable and reliable operation of the distribution network for all operating conditions.

According to the Transmission Code, if the results of such process highlight that the connecting solar PV System is likely to cause the network to possibly operate outside of Kahramaa statutory performance standards, Kahramaa has the right to reject the connection application or to propose modifications (for example in terms of Connection Point and/or characteristics of the solar PV System) or alternative solutions (for example in terms of network reinforcements) to enable the connection.

The Maximum Connected Capacity of the solar PV System to be proposed by the Customer will be determined in agreement with the specific clauses of Power and Water Purchase Agreement (PWPA) and Qatar Transmission Grid Code.

## 5.2 Connection Schemes

A solar PV System shall comply with the connection requirements of Kahramaa, and especially shall meet the following requirements:

- The synchronisation, operation, and disconnection of the System under normal network operating conditions, i.e., in the absence of faults or malfunctions, shall bear no consequences to the power quality of the network as established in Section D2.6 of the Qatar Transmission Grid Code.
- The protection schemes and settings needed for the Solar PV System shall be coordinated with the distribution network protection. Kahramaa and the Customer (though his Consultant/Contractor) shall define the protection settings coordination with the following purpose:
    - Faults and malfunctions within the Solar PV System shall not impair the normal operation of Kahramaa distribution network. In particular, any faults that include earth faults with leakage current internal to the Customer's installation will be detected and cleared below or at the connection point before any Kahramaa protection operates.
    - The protection schemes and settings for electrical faults within the Customer's installation must not affect the performance of the Solar PV System.
    - The protection schemes of the Solar PV System shall be coordinated with those of the distribution network in order to operate properly in case of faults either within the Solar PV System or within the distribution network.

To satisfy the above requirements, Figure 1 and Figure 2 present the typical equipment which shall be at least installed for a safe and reliable interconnection of a solar PV System to the LV and MV distribution network.

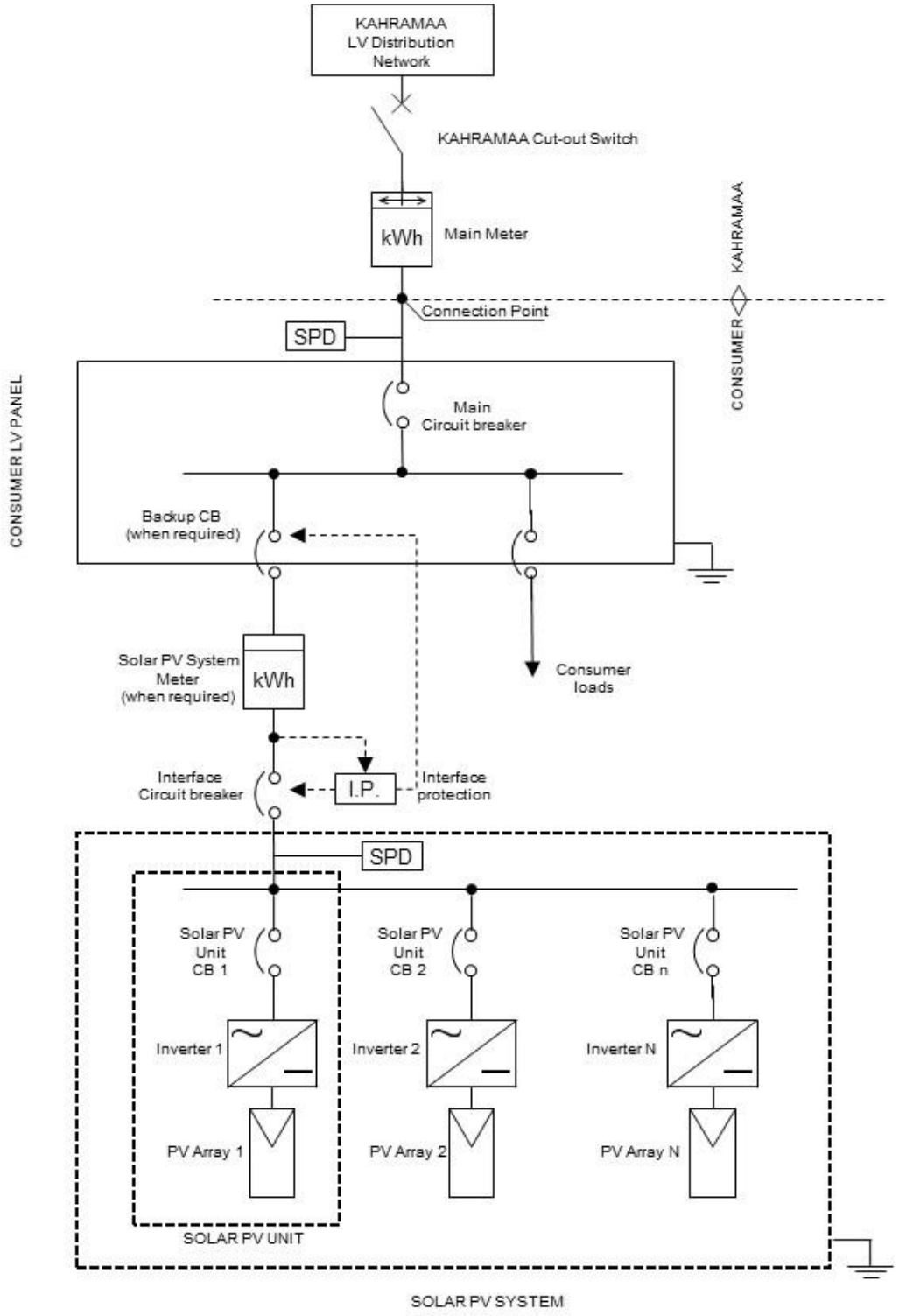



*Figure 1: Schematic representation for the connection of a Solar System to LV Distribution Network*

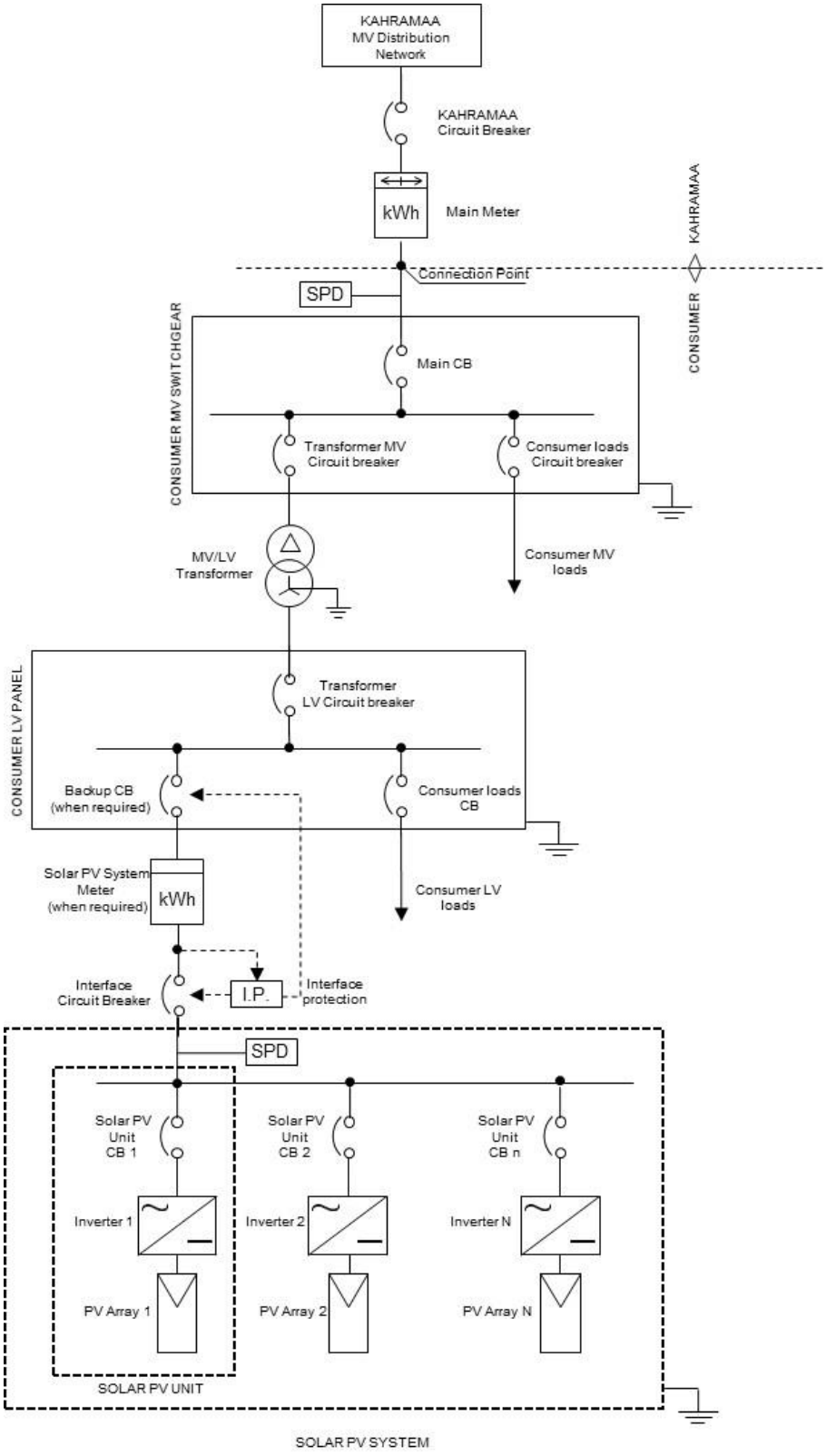



*Figure 2: Schematic representation for the connection of a Solar PV System to MV Distribution Network*

The typical equipment in Figure 1 and Figure 2 are the following:

- The Main Circuit Breaker shall be installed as close as possible to the *Connection Point* and operated by a protection system in case of internal faults. If agreed with Kahramaa, it is possible to install more than one main circuit breaker in order, for example, to have two separate circuits, one dedicated to the Customer's loads and one dedicated to the solar PV System. An example of this is given in Figure 13 in ANNEX A.

- The Interface Circuit Breaker, operated by an Interface Protection, shall be envisaged in the Customer installation to separate the portion of it containing one or more Solar PV Units from both the remaining part of the Customer's installation containing only loads and Kahramaa distribution network. For Solar PV Systems whose power exceeds 20 kW, a Backup Circuit Breaker is necessary in case of failure on this circuit breaker opening.
- The Solar PV Unit Circuit Breaker shall be installed as electrically close as possible to the terminals of each Solar PV Unit for the protection and the connection/disconnection of that unit. For the protection issues, the recommendations and requirements of the manufacturer of the equipment shall apply.

ANNEX A presents typical connection schemes that can be adopted to connect a Solar PV System to Kahramaa Distribution Network. Different arrangements may be used if previously agreed with Kahramaa.

***DISCLAIMER***

***In case the nominal voltage of the inverters does not match the nominal voltage of the distribution Network, a transformer shall be necessary to connect either to the solar PV System or to each single Solar PV Unit. The cost of this transformer shall not for any reason be ascribed to Kahramaa and shall be entirely borne by the Customer.***

## 5.3 Circuit Breakers Selection

***DISCLAIMER***

***In this document and the Single Line Diagrams, the nomenclature, and symbols of the Kahramaa Electricity Wiring Code were used for the protection/disconnection (under normal and fault conditions) and insulation of the PV Systems. These circuit breakers are just indicative and, for that reason, shall be carefully considered by the Consultants during their design according to the specific case and need. These circuit breakers cannot be directly applied or copied by the Consultant without conducting a technical assessment for the specific PV System they are designing. They have to be replaced by the proper symbol and disconnection device following what is established in Kahramaa's Electricity Wiring Code.***

This circuit breaker and its corresponding symbol, shall be replaced by the proper device as per the Electricity Wiring Code, depending on choices made by the PV System designer (Consultant / Contractor).

For each of the circuit breakers mentioned above, the choice of the type to be installed shall be based on:

- The functions the circuit breaker shall carry out.
- The characteristics of the Customer's installation.
- The characteristics of Kahramaa Distribution Network at the Customer's Connection Point.

Especially, the following criteria shall be adopted:

- The circuit breakers, panels and switchgear shall be compliant with the requirements of the Transmission Code,
- The circuit breaker(s) of the Solar PV Unit(s) shall be compliant with the Manufacturer's requirements,

- Electronic switches shall not be used for protective (overcurrent & Earth) functions.
- For Solar PV Systems connected to the MV Distribution Network and with the Interface Circuit Breaker on the MV side of the plant (see Figure 17 in ANNEX A), the Interface Circuit Breaker shall be a three-pole automatic circuit breaker operated by an undervoltage release along with an isolator (either upstream or downstream of the circuit breaker).

  The above requirement shall be incorporated into the standard type of panels for MV applications approved by Kahramaa.

  - Considering the requirement for solar/distributed generation, a new standard type of Switchgear panel shall be designed. In the case of MV panels, a dedicated panel type shall be proposed by the Consultant/Contractor with the required protection & control functions to use for such applications.

  The consensus to the reclosure of the Interface Circuit Breaker shall be given by the Interface Protection itself, which has then to sense the voltages on the network side (as represented in the Connection Schemes, Figure 16 and Figure 17) and not on the Solar PV System side of the Interface Circuit Breaker.

- For Solar PV Systems connected to the MV Distribution Network and with the Interface Circuit Breaker on the LV side of the plant (see Figure 16 in ANNEX A) or for Solar PV Systems connected to the LV distribution network (see schemes from Figure 11 to Figure 15 in ANNEX A), the Interface Circuit Breaker shall consist of motorised automatic switch to allow automatic reclosure once the network disturbances that have led to the trip of the Interface Protection have been cleared. The consensus to reclosure of the Interface Circuit Breaker shall be given by the Interface Protection itself, which has then to sense the voltages on the network side (as represented in the Connection Schemes, from Figure 11 to Figure 15) and not on the Solar PV System side of the Interface Circuit Breaker.
- Any circuit breaker shall have a breaking and making capacity coordinated with the rated values of the Customer's installation, considering both the generating plant and the contribution to the short circuit from the Distribution Network.
- The short time withstand-current of the switching devices shall be coordinated with the maximum short circuit current/power at the Connection Point[1].
- In case of loss of auxiliary supply power to the switchgear, a secure disconnection of the Interface Circuit Breaker is required immediately.

The function of the Interface Circuit Breaker can be combined with either the Main Circuit Breaker or the Solar PV Unit Circuit Breaker in a single switching device[2]. In case of a combination of these, the single combined switching device shall be compliant with both the requirements of the Interface Circuit Breaker and of either the Main Circuit Breaker or PV Unit Circuit Breaker, according to the combination chosen. Consequently, at least two circuit breakers in series shall always be present between a solar PV Unit and the Connection Point. For further details, please refer to the indicative Connection Schemes in ANNEX A.

[1] Kahramaa shall deliver to the Demand Facility Owner an estimate of the minimum and maximum short-circuit currents to be expected at the Delivery Point as an equivalent of the network.

[2] For connection schemes using a single main switch, the combination of the interface switch with the main switch will lead to the disconnection of the overall Customer's facility when the interface switch is opened, that is a lack of supply will also affect the Customer load.

## 5.4 Protection against Faults

The electrical protections required for connecting a Solar PV System to Kahramaa Distribution Network are also of concern in the present document. These additional protections shall be checked and approved by Kahramaa. Other protections shall also be installed to protect the Customer's electrical assets as per Kahramaa protection policy. All protections shall be graded and coordinated with Kahramaa upstream protections and downstream protections within the solar installation. Any faults down to the Connection Point shall be cleared at the same point or below without impacting Kahramaa distribution network.

Where **overcurrent and earth protection** is required for the safety of the equipment, whether this be part of the Solar PV System or not, automatic disconnection of the faulted circuit shall be accomplished.

The Customer shall comply with the relevant Kahramaa material standards & specifications and the applicable requirements and specifications of the latest issue of Kahramaa Protection Guidelines/Standard ET-P26-G1 (Guidelines for Protection/Energy meter requirements for Power supply to Bulk Customers).

Deviation (if any) from the standard shall notify Kahramaa for reviewing and approval at the initial stage of the project itself.

The Customer shall provide required new protection or modify existing protection of the Kahramaa interfacing bays.

The Customer shall agree with Kahramaa on protection schemes and settings relevant to the Demand Facility.

Kahramaa will review the Connection Equipment protection scheme and settings. The protection and settings of all other equipment and circuits in the Demand Facility are under the responsibility of Demand Facility Owners.

Protection schemes and devices shall cover the following events and equipment:

1. External and internal short-circuits
2. Over- and under-voltage at the Delivery Point to the ETN
3. Over- and under-frequency
4. Demand circuit (cable/line)
5. Transformer
6. Switchgear malfunction
7. Circuit Breaker failure
8. Busbar

Customer shall provide Protections as mandatory for interfacing bay at both ends and the required modifications to match the local end of Kahramaa Substations' remote end.

The protection document required by Kahramaa at each stage of the project shall be submitted to Kahramaa for review/approval/record.

Electrical protection of the Customer's Facility shall take precedence over operational controls while respecting system Security, health and safety of the staff and public. Kahramaa and the Customer shall agree on any changes to the agreed protection schemes.

The maintenance of all protection equipment at the premises of the Demand Facility, including those of Connection equipment, is the Customer's responsibility in coordination with Kahramaa, as applicable.

The Customer shall comply with Kahramaa Interlocking requirements and test such interlocking in Kahramaa's engineer presence.

## 5.5 Operating Ranges

A Solar PV System shall be capable of remaining connected to the Distribution Network and operating stably, as specified in this document. The frequency and voltage ranges for the time periods specified in the tables below should be as per Qatar Transmission Grid Code, paragraphs E.4.1 and E.4.2, regardless of the type and settings of the protection systems.

*Table 1: Frequency operating range*

| Frequency ranges | Time periods for operation |
|---|---|
| **47.5 Hz – 49.5 Hz** | Maximum 30 min |
| **49.5 Hz – 50.5 Hz** | Unlimited |
| **50.5 Hz – 51.5 Hz** | Maximum 30 min |

After 30 minutes of over frequency, the Generating Facility operator must consult the NCC to continue operation.

*Table 2: Voltage operating range*

| Voltage Level (1 pu) | Voltage range | Time period for operation |
|---|---|---|
| **11 kV – 33kV (limited to 33 kV as per this document scope)** | 0.85 pu - 0.90 pu | Maximum 30 min |
| | 0.9 pu – 1.1 pu | Unlimited |
| | 1.1 pu - 1.15 pu | Maximum 30 min |

The following figure defines the profiles of the periods of time for limited and unlimited operation according to the above tables. The Generating Units shall be capable of remaining connected to the Distribution Network in the event of simultaneous overvoltage and under-frequency or simultaneous under-voltage and over-frequency. In case of deviation of the Voltage at the Connection Point from its nominal voltage, the PV Unit shall be disconnected from the network with a delay consistent with settings indicated in Annex B. The voltage values for points A and B shall be agreed upon between the Generating Facility Owner and Kahramaa:

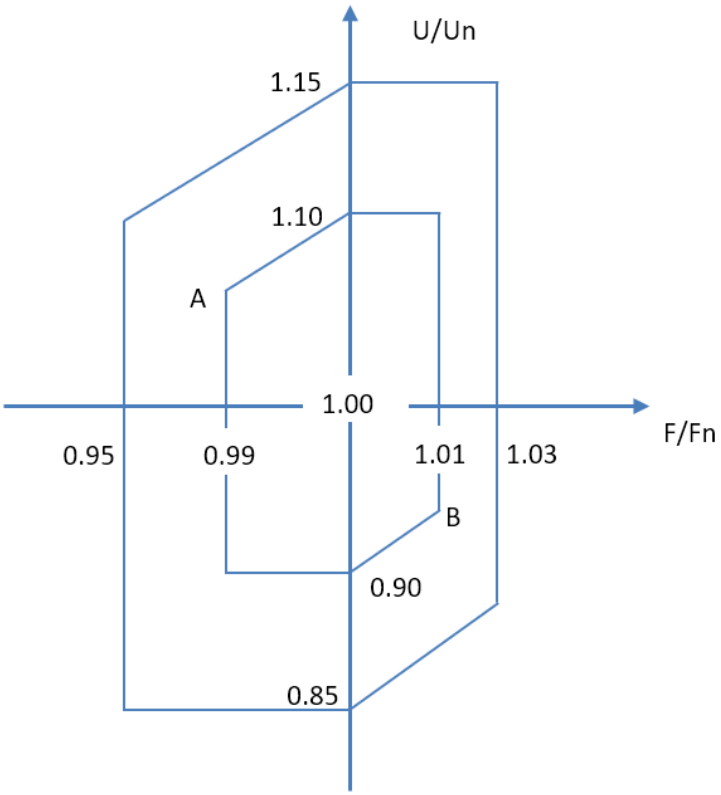



*Figure 3: Simultaneous UF profile*

## 5.6 Immunity to Disturbances

### *5.6.1 Low Voltage Ride Through (LVRT) Capability*

Solar PV Systems shall contribute to the stability of the overall power system by providing immunity toward dynamic voltage changes, especially those due to faults on the higher voltage level networks. The requirements below apply to all kinds of disturbances (1ph, 2ph and 3ph faults) and are independent of the Interface Protection settings (see 5.9.4), which overrule the technical capabilities of a Solar PV System. Therefore, whether the Solar PV System will stay connected or not will also depend on the settings of the Interface Protection.

A Solar PV System with a Maximum Connected Capacity greater than 11 kW shall be capable of staying connected to the distribution network as long as the voltage at the Connection Point remains above the voltage-time diagram in Figure 4. The minimum voltage during the fault shall be 5% of the rated voltage. The p.u. voltage shall be calculated with respect to the nominal voltage at the Connection Point. For three-phase generating systems, the smallest phase-to-phase voltage shall be evaluated. The compliance to such LVRT requirements shall apply to all equipment that might cause the disconnection of the solar PV System, i.e., Inverters and Interface Protection.

After the fault is cleared and the voltage returned within the normal operating range (see 7.5), the pre-disturbance operating conditions (active & reactive power) shall be recovered as fast as possible with a tolerance of ±10% of the solar PV System rated power.

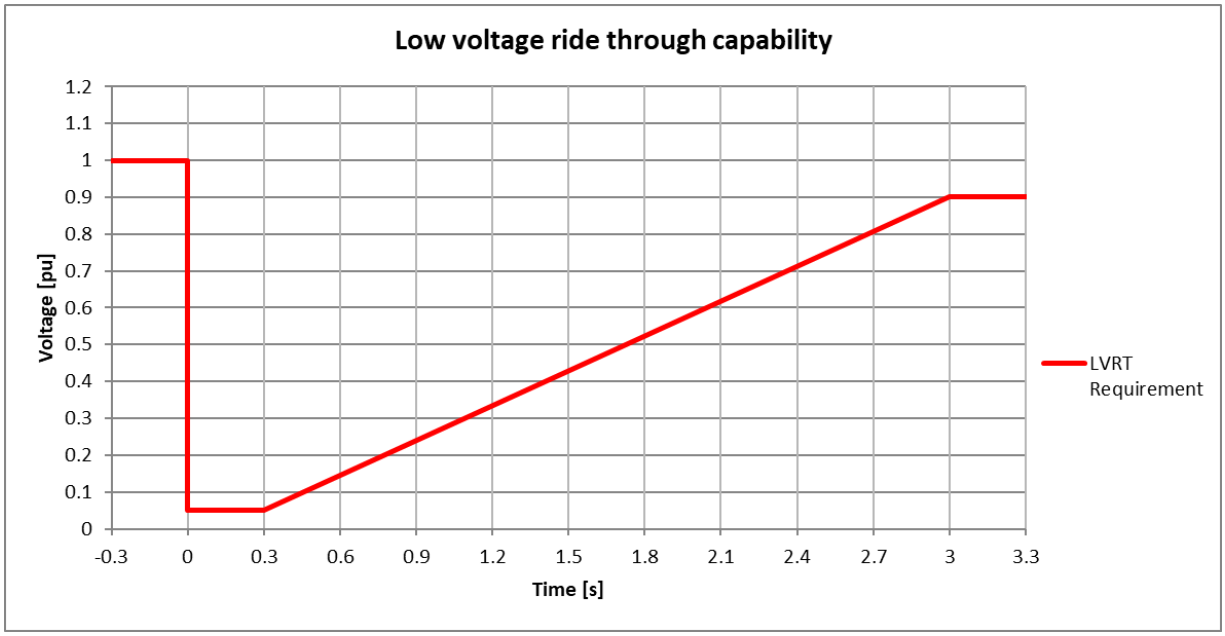



*Figure 4: LVRT characteristic for solar PV System > 11 kW*

### *5.6.2 ROCOF Withstand Capability*

The solar PV Systems, when generating power, shall be able to go through frequency transients with frequency within the normal operating range (see 5.5) and with ROCOF value up to 2.5 Hz/s [3].

In the case that the Loss of Mains (LOM) protection implements a ROCOF-based method (as described in 5.9.4), the threshold of the LOM function shall not cause the intervention of the protection within the immunity ranges as specified in this paragraph.

## 5.7 Requirements for the Frequency Stability of the Power System

### *5.7.1 Active Power Response to Frequency Variations*

A solar PV System shall be capable of activating the provision of active power response to over-frequency transients according to the curve of Figure 5, with frequency threshold and droop settings adjustable and specified by Kahramaa.

- The frequency threshold shall be settable at least between 50 Hz and 52 Hz inclusive; if not differently specified by Kahramaa, the threshold shall be set to 50.5 Hz.
- In case of deviation of the network frequency above 51.5 Hz, the Solar PV System shall disconnect from the Transmission Network.
- In case of deviation of the Network frequency from its nominal value below 47.5Hz, the PV System shall be disconnected from the network.
- The generated active power $P_{gen}$ shall be referred to as the actual active power value $P_{act}$ when the threshold is reached, and the active power response is activated.
- The Generating Units shall be capable of activating the provision of active power frequency response according to Figure D.2-2 of the Transmission Grid Code at a

[3] It is recommended to measure the ROCOF over a sliding 500ms time period.

frequency threshold between 50.2 Hz and 50.5 Hz inclusive and Droop settings between 2 % and 12 % specified by Kahramaa.

- The settings of the disconnection protection (threshold, time delay of the tripping) shall be agreed upon with Kahramaa.
- The Slope of the decreasing ramp and the frequency where the power shall decrease may be modified by Kahramaa.

The resolution of the frequency measurement shall be ±10mHz or less. The active power response shall be activated as fast as possible and delivered with an accuracy of ±10% of the nominal power.

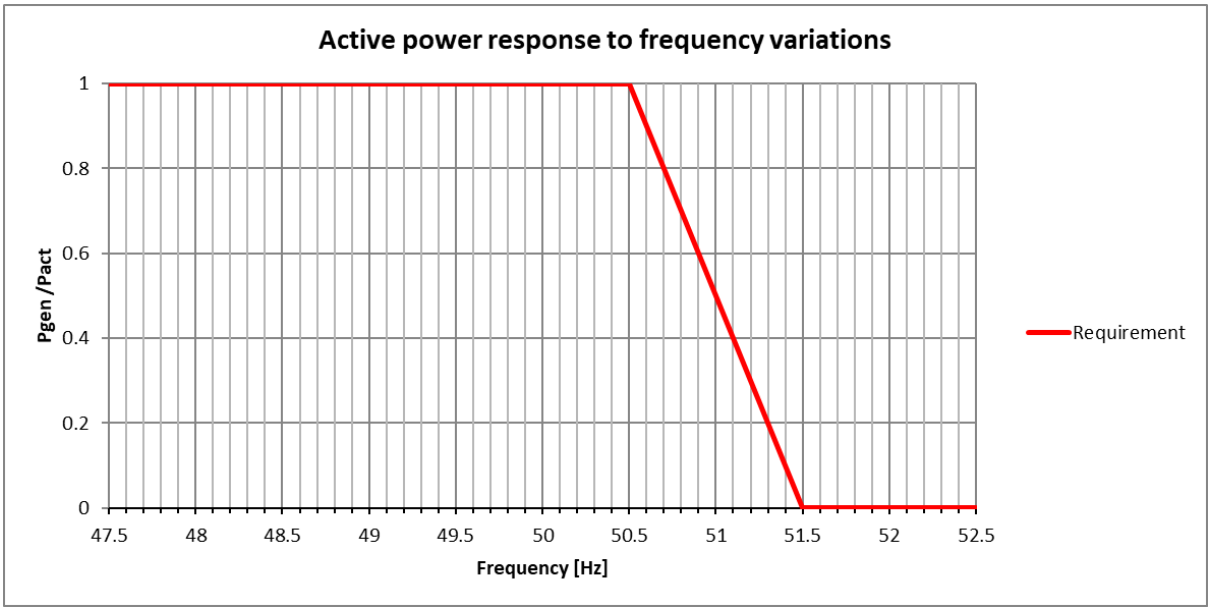



*Figure 5: Active power frequency response for solar PV System*

### *5.7.2 Active power delivery at under-frequencies*

When a solar PV System works in under-frequency operating conditions due to the Distribution Network, the reduction of the maximum active power shall be kept as low as technically feasible; in any case, any decrease of the maximum reachable active power output shall be kept above the curve of Figure 6.

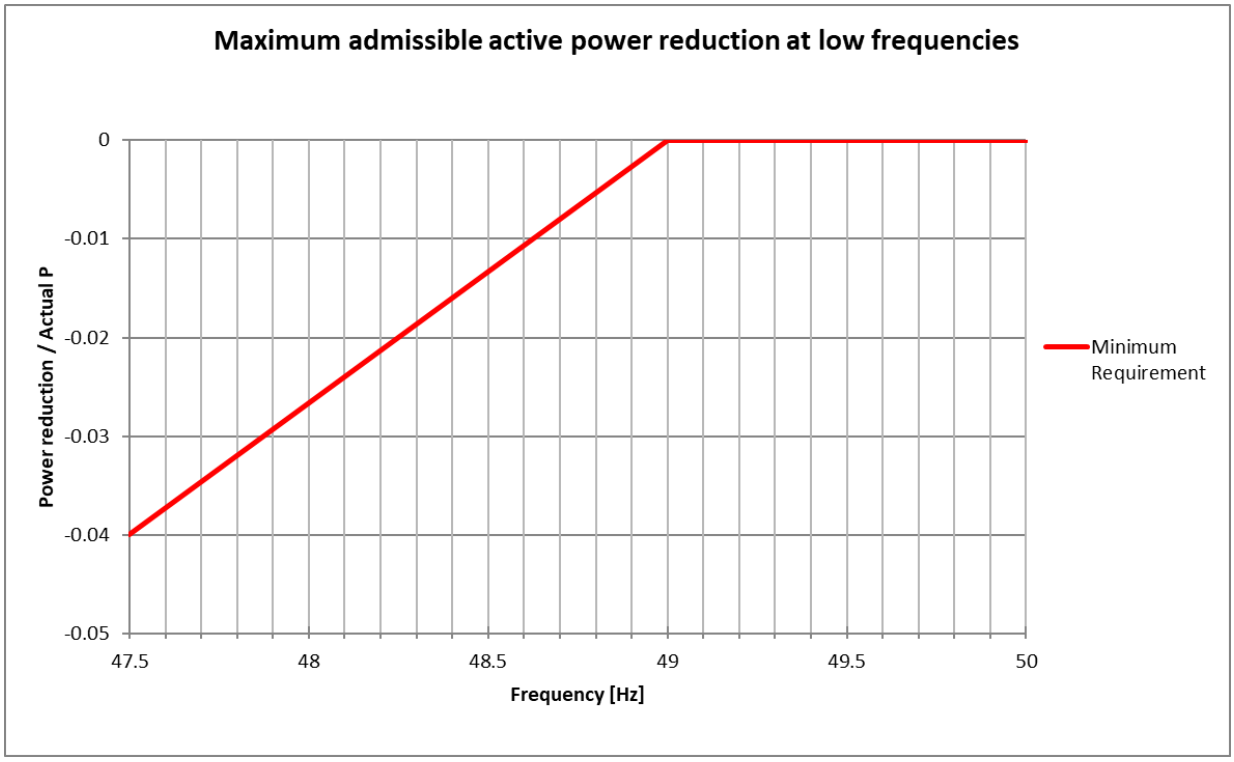



*Figure 6: Maximum permissible output power reduction at under- frequencies*

### *5.7.3 Remote Limitation of Active Power*

A solar PV System with a Maximum Connected Capacity greater than 11 kW shall be equipped with an interface (input port) that is able to receive, from a remote-control centre, an instruction requiring the reduction of the active power output.

The reduction of active power shall be carried out as fast as possible and with an accuracy greater than 5% of the nominal active power of the Solar PV System.

Kahramaa shall have the right to specify further requirements in terms of equipment, communication protocol, information to be exchanged and/or time of execution, which allow integration of such features into the control systems of its Distribution Network and which allow to remotely limit the active power output of the solar PV Units connected to its network.

## 5.8 Requirements for the Voltage Stability of the Power System

Requirements as per Transmission Grid Code, par. D.3.4 shall apply.

### *5.8.1 Reactive Power Capability*

When voltage and frequency at the Connection Point are within their normal operating ranges, a solar PV System shall be able to provide reactive power in any operating point within the boundaries of the reactive power capability curves defined in Figure 7[4].

[4] The active power 1 p.u. shall refer to the nominal active power value of the Solar PV System: at 1 p.u. of active power, the reactive power capability of a Solar PV System corresponds to a power factor varying between 0.95 leading (inductive reactive power absorbed) to 0.95 lagging (inductive reactive power generated).

According to this capability, the inverters will either generate or absorb inductive reactive power from the Distribution Network to participate in voltage support at the Connection Point for any of the values of active power generated by the Solar PV System.

Three areas are visible in Figure 7:

- Triangular area, required for inverters included in Solar PV Systems whose Maximum Connected Capacity is smaller than or equal to 11 kW: for an active power ranging from zero to the nominal power of the Solar PV System (i.e., 1 p.u.), the Inverter shall be capable of either generating or absorbing inductive reactive power $Q$ at a power factor $cos\varphi$ of 0.95 (boundary points of the triangular curve in the chart);
- Rectangular area required for inverters included in Solar PV Systems whose Maximum Connected Capacity is greater than 11 kW: these shall be capable of either generating or absorbing inductive reactive power $Q$ within the area. For a value of 1 p.u. of active power, that is, when the generated power is equal to nominal power, this corresponds to a power factor $cos\varphi$ of 0.95 (apex points of the rectangular area for $P$ = 1 p.u.);
- Design free area which can be optionally exploited by the Inverter Manufacturers.

Concerning Figure 7 and Figure 8, when the solar PV System operates in the design-free area (i.e., above its nominal active power because of favourable environmental conditions), it is allowed to reduce the reactive power capability according to the widest possible technical capability of the Solar PV Units.

When the solar PV System operates above a threshold of 10 % of its nominal apparent power Sn, the required reactive power $Q$ shall be provided with an accuracy of ±2% $S_n$. Below the threshold of 10% of $S_n$, deviations above 2% of accuracy are permissible; nevertheless, the accuracy shall always be as good as technically feasible and shall not exceed 10% of $S_n$.

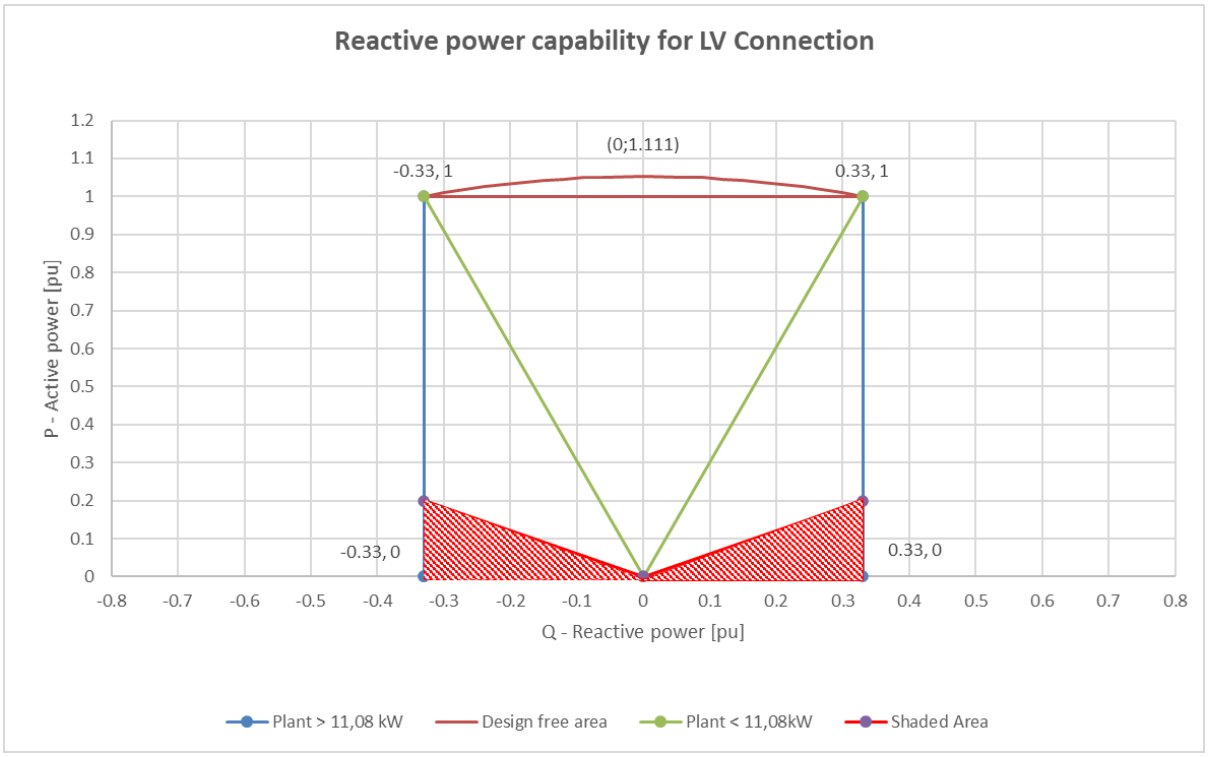



*Figure 7: Reactive power capability For LV connection*

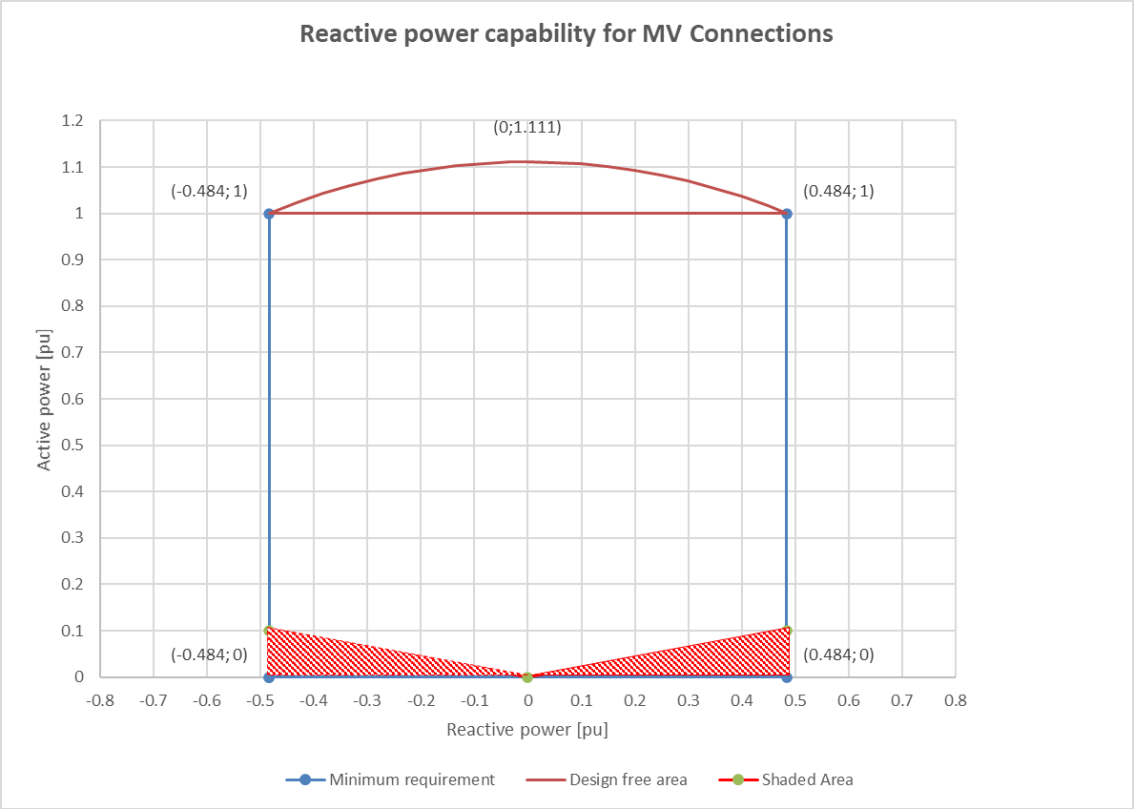



*Figure 8: Reactive power capability For MV connection*

### *5.8.2 Reactive Power Control Modes*

A solar PV System shall be capable of operating in the control modes stated below, within the limits of its reactive power capability as expressed in 5.8.1:

fixed *Q*: the reactive power is controlled to obtain a fixed value.

fixed *cos φ*: the reactive power is controlled to obtain a fixed power factor.

*cos φ (P)*: the reactive power is controlled to obtain a power factor that is a function of the actual active power delivery.

*Q = f(V)*: the reactive power is controlled as a function of the local voltage, according to a characteristic curve.

The above control modes are exclusive; only one mode may be active at a time. The control modes' activation, deactivation, and configuration shall be field adjustable. It is the responsibility of Kahramaa to communicate to the Solar PV System's owner which of the above-mentioned reactive power control mode shall be activated.

#### *5.8.2.1 Fixed Control Modes*

When operated with fixed *Q* or fixed *cos φ* control mode, the solar PV Unit shall control the reactive power or the *cos φ* of its output according to a set point set in the control system of the solar PV System. If not explicitly specified by Kahramaa, the default setpoint values shall be 0 for fixed *Q* control mode and 1 for fixed *cos φ* control mode.

For a solar PV System with a Maximum Connected Capacity greater than 11 kW, the Solar PV System shall also be able to receive remotely from Kahramaa control centre, the set-point following the provisions set forth in 5.9.5.

#### *5.8.2.2 Power Related Control Mode*

The Power Related Control Mode *cos φ* (*P*) controls the *cos φ* of the output as a function of the active power output. A characteristic with a minimum and maximum

value and three connected lines, according to Figure 9, shall be configurable within the control systems of the solar PV System; a change in active power output results in a new cos φ set point according to the characteristic.

The parameters A, B, C and D shall be field adjustable, and their settings are the responsibility of Kahramaa. If not explicitly specified by Kahramaa, these parameters shall be set as indicated below:

| | | |
|---|---|---|
| A | $P = 0\ P_{nom}$ | $cos\ \varphi = 1$ |
| B | $P = 0.5\ P_{nom}$ | $cos\ \varphi = 1$ |
| C | $P = P_{nom}$ | $cos\ \varphi = 0.95$ Lag (with the solar PV System absorbing reactive power from the Distribution Network) |
| D | $P = P_{nom}$ | $cos\ \varphi = 0.95$ Lead (with the solar PV System injecting reactive power towards the Distribution Network) |

where $P_{nom}$ is the active nominal power of the Solar PV Unit.

The response to a new $cos\ \varphi$ set point value shall be as fast as technically feasible after the new value of the active power is reached. The accuracy of the control to each set point shall be in accordance with the requirements of 5.8.1.

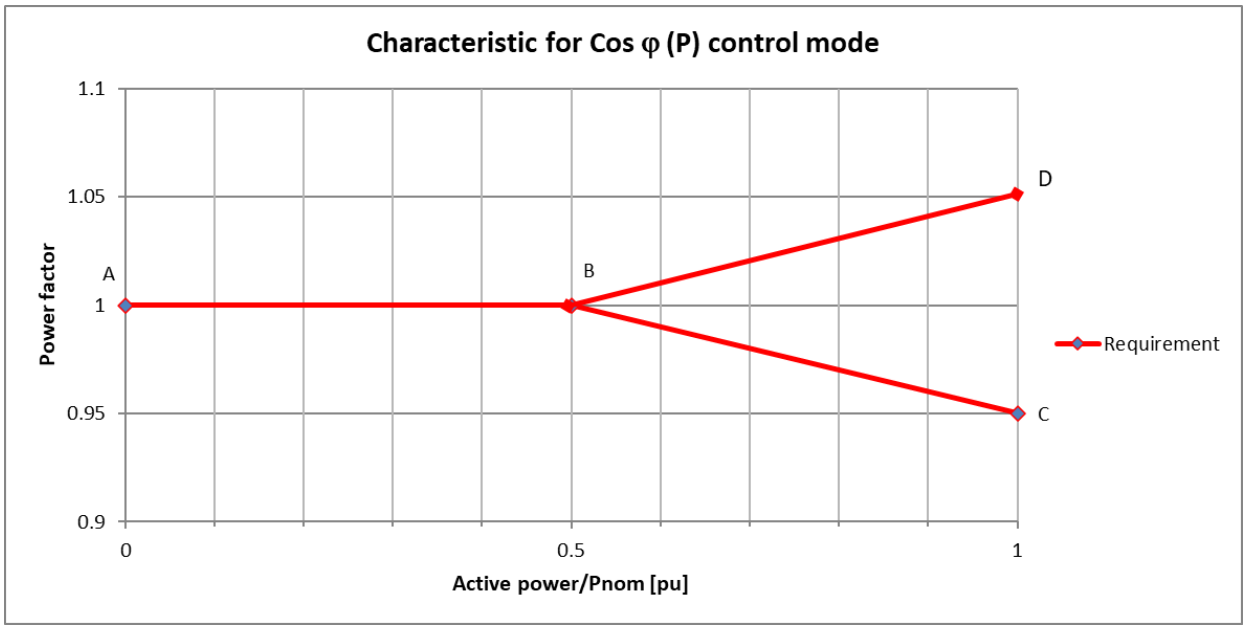



*Figure 9: Characteristic for Cos φ (P) control mode*

The implementation of lock-in and lock-out voltage levels shall be configurable, each in the range of 90% to 110% of the nominal voltage at the Connection Point. The contribution is activated when the voltage at the Connection Point exceeds the lock-in voltage and is deactivated when the voltage drops below the lock-out voltage. When the contribution is not activated, the solar PV System shall be controlled with a unity power factor ($cos\ \varphi = 1$).

*5.8.2.3 Reactive Power Support as a Function of the Voltage Q(V)*

For solar PV Systems with a Maximum Connected Capacity greater than 11 kW, for such control mode, a characteristic with a minimum and maximum reactive power value and three connecting lines, according to Figure 10: shall be configurable.

It is Kahramaa's responsibility to communicate the parameters to be configured in case this support is required from Solar PV Systems.

The values shall be assigned with the following criteria; therefore, the parameter ranges available in the Inverter shall not limit this setting:

- $Q_{max}$ and $-Q_{max}$ correspond to the capability curve boundaries as per Figure 10 (e.g., 0.33 $P_{nom}$, where $P_{nom}$ is the nominal power of the Solar PV Unit)
- $V1$ > [27<] threshold of Interface Protection
- $V4$ < [59>] threshold of Interface Protection
- $V2 < V_{nom} < V3$

Possible default values can be the following unless differently agreed with Kahramaa:

$V_1 = 0.9\ V_{nom}$

$V_4 = 1.1\ V_{nom}$

$V_2 = 0.95\ V_{nom}$, $V_3 = 1.05\ V_{nom}$

where $V_{nom}$ is the nominal Voltage at the Connection Point.

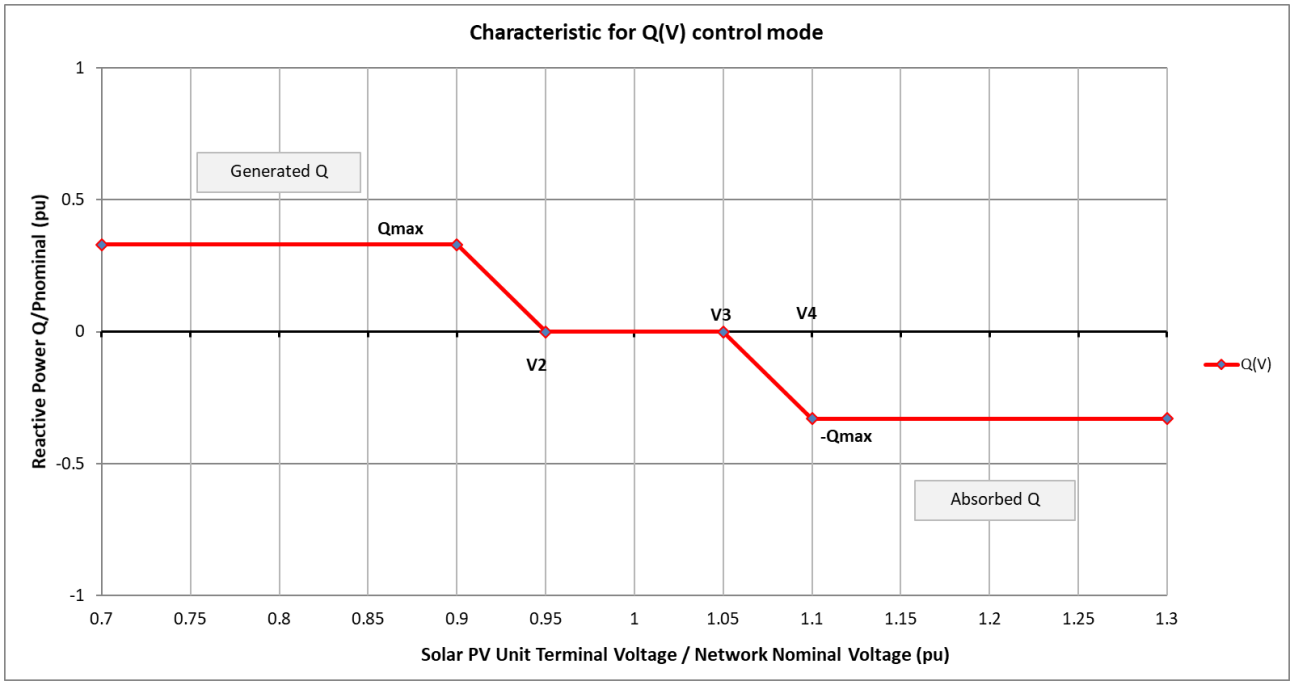



*Figure 10: Characteristic for Q(V) control mode*

### *5.8.3 Power Reduction at Increasing Voltage*

In order to avoid disconnection due to overvoltage protection, a solar PV System is allowed to reduce its power output (active and/or reactive power) as a function of the rising voltage at the Connection Point. The implemented logic can be chosen by the Manufacturer/Customer. Nevertheless, the implemented logic shall not cause steps or oscillations in the system's power output.

## 5.9 Requirements for the Management of the Power System

### *5.9.1 Connection Conditions after Programmed Disconnection*

A solar PV System is allowed to be connected to the network and to start to generate electrical power due to normal operational start-up when the voltage and frequency are within the following range for at least the observation time:

- Frequency range 49.5 Hz ≤ Frequency ≤ 50.05 Hz.
- Voltage range 90% $V_{nom}$ ≤ Voltage ≤ 110% $V_{nom}$ ($V_{nom}$= nominal voltage at the Connection Point).
- Minimum observation time 30s.

Synchronising a solar PV System with the distribution network shall be fully automatic. It shall not be possible to manually close the circuit breaker between the two systems to carry out the synchronisation[5].

The synchronisation of a Solar PV System to the distribution network shall not create a transient voltage variation at the Connection Point of more than 4% of nominal voltage.

After the connection, a Solar PV System shall follow its target active power value with a variable rate not greater than 10% $P_{nom}$/min, where $P_{nom}$ is the nominal active power of the Solar PV System.

The active power target shall be the maximum available active power output that the Solar PV System can generate, taking into account the environmental conditions (irradiation, temperature), except for the operating conditions when the power output shall follow changes due to the provision of some of the services specified in this document (see sections 5.7.1, 5.7.3 and 5.8.3).

### *5.9.2 Remote Disconnection*

A solar PV System with a Maximum Connected Capacity greater than 100 kW shall be equipped with a logic interface (input port) in order to perform remote disconnection.

According to the provisions set forth in 5.9.5, Kahramaa shall have the right to specify further requirements in terms of equipment, time of execution, communication protocol and/or data to be exchanged to integrate such features into the control systems of its distribution network and to allow the remote disconnection of the solar PV Systems connected to its network.

### *5.9.3 Automatic Reconnection after Tripping*

After the trip of the Interface Protection, a solar PV System is allowed to reconnect to the network only if the voltage and frequency are within the following range for at least the observation time:

- Frequency range 49.5 Hz ≤ Frequency ≤ 50.05 Hz.
- Voltage range 90% $V_{nom}$ ≤ Voltage ≤ 110% $V_{nom}$ ($V_{nom}$= nominal voltage at the Connection Point).
- Minimum observation time 300s.

[5] It means that the switch used for the synchronization with the network cannot be a manual switch.

After reconnection, the solar PV System shall return to its target active power value with a variation rate not greater than 10% $P_{nom}$/min, where $P_{nom}$ is the nominal active power of the Solar PV System.

### *5.9.4 Interface Protection*

The purpose of the Interface Protection is to:

- Disconnect the solar PV System from the Distribution Network in the following cases:
  - When the Distribution Network (or the feeder) where the Solar PV System is connected has to de-energise from the main supply source, the de-energisation can happen automatically due to protection system operation or manual/electrical disconnection. Electrical/manual disconnection in the Distribution Network can happen remotely by Kahramaa SCADA system or by local switching.
  - The voltage and/or frequency values at the Connection Point are out of the normal operating ranges as defined in 5.5.
- Prevent the solar PV System, when generating power, from causing over-voltages in the distribution network it is connected to.
- The voltage and nominal frequency of the power grid to be considered as a reference for all the protection functions are:

  - Rated Voltage: (240-415) V in LV side

  - Rated Frequency: 50 Hz

It is not the purpose of the Interface Protection to:

- Disconnect the Solar PV System from the Distribution Network in case of faults within the Customer's installation. For such issues, the requirements for the connection of passive Customers shall apply (refer to Transmission Code).
- Prevent damages to the Customer's equipment (generating units or loads) due to faults/incidents (e.g., short circuits) in the Distribution Network or on the Customer's installation. For such issues, the recommendations and requirements of the equipment manufacturers shall apply.

The Interface Protection shall be a dedicated device that acts on the Interface Circuit Breaker. For a solar PV System with a Maximum Connected Capacity smaller than or equal to 11 kW, it is permitted to integrate both the Interface Protection and the Interface Circuit Breaker into the Inverter (see, for example, Figure 11 in ANNEX A). The use of inverter-integrated Interface Protection for capacities above 11 kW can be decided by Kahramaa on a case-by-case basis.

The Interface Protection shall command the Interface Circuit Breaker. For a solar PV System with a Maximum Connected Capacity greater than 11 kW, unless explicitly agreed by Kahramaa, only one Interface Protection and one Interface Circuit Breaker shall be used.

For a solar PV System with a Maximum Connected Capacity greater than 20 kW, the Interface Protection shall additionally act on another circuit breaker (Backup Circuit Breaker) with a proper delay in case the Interface Circuit Breaker fails to operate (see, for example, Figure 15 in ANNEX A). The Backup Circuit Breaker may consist of a

dedicated circuit breaker or an already existing one[6]. Only manual reclosure shall be possible when the Backup Circuit Breaker is triggered because the Interface Circuit Breaker has failed to open[7]. For a solar PV System with a Maximum Connected Capacity greater than 11 kW, the power supply of the Interface Protection shall include an uninterruptible power supply. The loss of the auxiliary voltage on either the Interface Protection or on the Solar PV System's control system shall trigger the Interface Circuit Breaker without delay.

The protection functions required in the Interface Protection are the following:

- Undervoltage [27]
  - One threshold [27<] in the range [20%; 100%] of the nominal voltage at the Connection Point adjustable by steps of 5%, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s;
  - One threshold [27<<] in the range [0%; 100%] of the nominal voltage at the Connection Point adjustable by steps of 5%, and delay time in the range [0.1s; 5s] adjustable in steps of 0.05s.
- Overvoltage [59]
  - One threshold [59>] in the range [100%; 120%] of the nominal voltage at the Connection Point adjustable by steps of 1%, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s;
  - One threshold [59>>] in the range [100%; 130%] of the nominal voltage at the Connection Point adjustable by steps of 1%, and delay time in the range [0.1s; 5s] adjustable in steps of 0.05s.
- Over frequency [81>]
  - One threshold [81>] in the range [50Hz; 53Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s; 100s] adjustable in steps of 0.1s.
  - One threshold [81>>] in the range [50Hz; 53Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s;5s] adjustable in steps of 0.05s.
- Underfrequency [81<]
  - One threshold [81<] in the range [47Hz; 50Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s; 100s] adjustable in steps of 0.1s.
  - One threshold [81<<] in the range [47Hz; 50Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s; 5s] adjustable in steps of 0.05s.
- Loss Of Mains (Anti-Islanding):

  For the Loss of Mains (LOM) protection function, a wide variety of approaches can be used. Besides the passive observation of voltage and frequency, other active and passive methods are available and used to detect unintentional islanding situations. The present document does not intend to specify the method to be used to achieve the goal but rather its efficacy; for such a reason, the only requirement on LOM protection is that the protection function shall be tested following IEC 62116 or another equivalent standard, which provides procedures to evaluate the performance of islanding prevention measures used with utility-interconnected Solar PV Systems.

The LOM protection functions shall have the possibility to be excluded or the LOM settings to be modified suitably. Whatever solution is chosen for the Loss of Mains

[6] It is anyway recommended not to use the Main Circuit Breaker as Backup Circuit Breaker since it could lead to the disconnection of the overall Consumer's facility in the case the interface switch fails to open, with the consequence of the power supply also being removed to Consumer's loads.

[7] The reasons are that it is required that the plant operator first acknowledges and checks the reasons why the interface switch failed to open, then remedies the technical issues and finally resumes operation.

protection, the relevant settings shall be subject to Kahramaa's provision and approval. The ultimate option is bypassing the protection and this have to be well studied and approved by Kahramaa.

The present standard recognises that it may not be straightforward for IP manufacturers to define settings of the LOM protection, which can be efficient for all the current and future operating conditions of Kahramaa distribution networks. This is especially the case with the most common passive methods currently used to implement such function within a dedicated protection device (i.e., ROCOF and vector jump). The present standard also acknowledges that a LOM protection function implemented within a solar PV Inverter through active methods (for example, frequency shift) can be efficient under all network operating conditions. For such reasons, it is allowed that, for a Solar PV System of capacity larger than 11 kW, the LOM protection function be integrated into every single Inverter of the system, provided that the built-in LOM protection function of the single Inverter has been tested according to IEC 62116 or another equivalent standard.

In these cases, and for the avoidance of doubt, the remaining under/over frequency & voltage protection functions of the Interface Protection have to be built into a dedicated protective device as stated above. In any case, the LOM protection, irrespective of its actual position, i.e., either integrated into a dedicated Interface Protection or built-in in the Inverter, shall detect island operating conditions and cease to energise the Distribution Network within two seconds of the formation of the island, unless differently specified by Kahramaa based on MV feeder auto-reclosure time.

The protection functions for under-voltage [27] and over-voltage [59] shall be fed by all the line voltages, whereas the protection functions for under-frequency [81<] and over-frequency [81>] shall be fed by at least one line voltage.

Appropriate settings shall be applied to the Interface Protection and ensure the correct tripping of the solar PV System under specific conditions. The settings shall be chosen so that, in case a fault within the distribution network triggers the network protection systems (which disconnects the faulty feeder), all the solar PV Systems are disconnected before the attempt of reclosure in the MV distribution network takes place.

ANNEX B proposes default settings for 27, 59 and 81 protection functions. Such settings shall be applied to the Interface Protection of a solar PV System only in case no other settings have been explicitly specified and communicated by Kahramaa.

Moreover, the Interface Protection shall have at least two configurable digital inputs which may be used in the future[8] by Kahramaa for transfer trips, remote tripping or any other function that may be necessary to increase the capacity of the distribution networks to host distributed generation while keeping an acceptable level of reliability and security.

### *5.9.5 Protection and Control Ranking Priority*

All Solar PV Systems shall be designed and manufactured to respect the priority ranking for the protections provided in this section. The priority ranking aims to avoid the conflict between 2 or more functions implemented simultaneously. For instance, if there is an internal fault within the Solar PV System and at the same time there is an underfrequency problem in the network, that indicates that the Solar PV System shall

[8] In a scenario of growing penetration level of distributed generation in the distribution networks of the Qatar

maintain its operation and stay connected. In this case, it has to be determined which of the 2 functions should prevail over the other.

According to the below priority ranking, the internal fault inside a Solar PV System has priority, and the disconnection shall occur. The protection and control devices of a Solar PV System shall be organised following the following priority ranking (from highest to lowest):

1. Protection of the Solar PV System
2. Protection against faults within the Customer's installation
3. Protection of the distribution network (Interface Protection)
4. Remote disconnection
5. Active power response to frequency variations
6. Remote limitation of active power
7. Remote reactive power control modes
8. Local reactive power control modes

### *5.9.6 Monitoring, Remote Control and Information Exchange*

Adequate information concerning the Customers connected to the Distribution Networks is a prerequisite for enabling Kahramaa to maintain its networks' stability, reliability, and security. Kahramaa needs to have a continuous overview of its network state, which may require in some cases, updated information on the operating conditions of the solar PV Systems connected to its Distribution Networks, as well as the possibility to communicate with these plants to direct the operational instructions set forth by the provisions of the present document.

Such requirements are usually needed in case of growing penetration level of the solar PV Systems in the distribution networks; they may also be introduced in the framework of other initiatives dedicated, for example, to optimising the control performances of the network.

Remote monitoring from NCC shall be required only for Solar PV Systems with a Maximum Capacity >11 kW. A solar PV System with a Maximum Connected Capacity greater than 11 kW shall therefore provide bi-directional communication exchange, which can be used to exchange information with Kahramaa. Once actually needed for the operation of the network, according to a cost/benefit approach, Kahramaa shall have the right to specify additional requirements concerning especially:

- Data, which shall be collected and sent to Kahramaa in real-time or periodically, related to the operating conditions of the solar PV System.
- Operational instructions sent by Kahramaa which the solar PV System shall execute; such instructions shall be compliant with the requirements indicated in the present standards (especially the requirements of 5.7.3 and 5.9.2);
- Communications channels and protocols to be used for the above requirements.

If technically possible, Kahramaa may take advantage of already existing communication channels, such as smart metering infrastructure, to facilitate the integration of the monitoring activities into its ICT architecture and reduce implementation costs. Transmission Grid Code, paragraph D.2.4.6 shall apply for the communication and information exchange requirements.

### *5.9.7 Power Factor*

Any installations containing a solar PV System shall comply with the power factor limits, as measured at the Connection Point, indicated in the Transmission Code.

### *5.9.8 Power Quality*

#### *5.9.8.1 Voltage Deviation*

Under normal operating conditions, the connection and operation of a solar PV System shall not cause the voltage to vary from the system rated voltage by more than ±5%. These deviations are measured at the Customer Connection Point and any other Customers' Connection Points in the same Distribution Network.

The values of the voltages will then range in the following intervals as specified in the Transmission Code:

*Table 3: Voltage range under normal operating conditions for the different voltage levels*

| Nominal Voltage | Lowest Voltage | Highest Voltage |
|---|---|---|
| **415/240 V** | 394.2/228 V | 435.7/252 V |
| **11 kV** | 10.4 kV | 11.5 kV |
| **22 kV** | 20.9 kV | 23.1 kV |
| **33 kV** | 31.35 kV | 34.65 kV |

#### *5.9.8.2 Rapid Voltage Changes*

Connection and disconnection of a solar PV System from the distribution networks shall not give rise to voltage variations exceeding 3% of the system rated voltage at the Connection Point according to the recommendations of the IEC/TS 62749.

#### *5.9.8.3 Harmonic and Interharmonic Voltages*

Harmonic and interharmonic voltages at the Connection Point of a solar PV System connected to the MV Distribution Network shall not exceed the limits of the planning levels specified hereinafter according to Kahramaa Transmission Grid Code:

*Table 4: Maximum Continuous Harmonic Levels*

| Odd Harmonics not multiple of 3 | | Odd Harmonics multiple of 3 | | Even Harmonics | |
|---|---|---|---|---|---|
| **Order h** | Harmonic voltage % | Order h | Harmonic voltage % | Order h | **Harmonic voltage %** |
| **5** | 5.0 | 3 | 4.0 | 2 | **2.0** |
| **7** | 5.0 | 9 | 2.0 | 4 | **1.0** |
| **11** | 3.0 | 15 | 2.0 | 6 | **0.5** |
| **13** | 3.0 | 21 | 2.0 | 8 | **0.5** |
| **17 ≤ h ≤ 49** | **1.9×17/h-0.2** | **21 ≤ h ≤ 45** | **0.2** | **10 ≤ h ≤ 50** | **0.25×10/h +0.22** |

**NOTE**: The corresponding planning level for the total harmonic distortion is THD = 3% for both 11 and 22kV voltage levels

For a solar PV System connected to the LV Distribution Network, as suggested by IEC/TR 61000-3-15:2011 and commonly accepted. The requirements mentioned above concerning the voltage harmonics are fulfilled if the harmonic current emissions of the solar PV System do not exceed the limits defined in the standard IEC 61000-3-12, Tables 2 and 3 (where the values with $R_{sce}$ = 33 shall apply).

*5.9.8.4 DC Injection*

Solar PV Systems shall not inject DC current into the network. The requirement is considered to be respected if the injected DC component is lower than 0.5% of the rated AC current value of the PV System. The DC injection clause is considered to be passed when the measured DC injection of a type-tested unit is below the above threshold in all Solar PV Units within the Solar PV System.

The single solar PV System shall be equipped with a DC fault detection system that disconnects the faulty unit when the above limit is exceeded. A valid alternative to such a system is an AC/AC transformer that prevents any DC injection into the network.

*5.9.8.5 Clusters of Single-phase / Two-phase Solar PV Generating Units*

The use of three-phase inverters is required. However, for the connection to the LV Distribution Network of a Solar PV System with a Maximum Connected Capacity up to 11 kW, it is permitted using one or more single-phase/two-phase inverters. These have to be connected either phase-to-neutral or phase-to-phase according to the LV distribution system available at the Connection Point (see ANNEX C for details). In such a case, if multiple single-phase/two-phase inverters are used, these shall be equally distributed over the three phases in order to limit the overall imbalance of power between the phases. The maximum current imbalance between the two phases shall be lower than 16 A (3.84 kW at 240 Vac). Communication links between the single-phase / two-phase inverters may be used to ensure this requirement.

Any extension beyond the above-stated power limits will be possible by using three-phase inverters or by single-phase / two-phase inverters, which are connected through a communication link. In this latter case, a proper control system shall be able to re-establish the power balance between the phases and the single inverters whenever the above limit is exceeded.

## 5.10 Metering System

The following metering system shall be installed:

1. A first smart meter (Main Meter), supplied and installed by Kahramaa at the Connection Point, to measure both the energy injected into the Distribution Network and consumed from this one. For this reason, the meter must be bidirectional.
2. A second smart meter (Solar PV System Meter) supplied and installed by Kahramaa at the Connection Point.

The Main Meter measures the net energy at the Connection Point, whereas the Solar PV System Meter measures the energy produced by only the solar PV System.

The meter shall be installed in a location that facilitates remote communication with Kahramaa Data Centre. From that time on, Solar PV System Meters shall be installed within the Customer Premises, as close as possible to Solar PV inverters.

Requirements of Transmission Grid Code, par. D.2.4.3 shall apply.

## 5.11 Earthing and Lightning Systems

Generally, PV Systems would not cause any variation in how earthing and lightning systems are designed. Typically for earthing systems, there are 4 different types according to BS 7671 standard, e.g., T-T systems, TN-S systems, TN-C-S systems, and TN-C systems; each of these letters indicates the system's classification. Nevertheless, a Consultant/Contractor shall ensure the correct implementation of the earthing classification case by case inside the PV system, and all PV Systems connected to Kahramaa distribution network shall have the following:

- PV array structures, DC equipment, Inverter, AC equipment and distribution wiring shall be earthed as required.
- All metal casing/shielding of the plant shall be thoroughly grounded. In addition, the lightning arrester/masts should also be provided inside the array field.
- Equipment grounding (earthing) shall connect all non-current carrying metal receptacles, electrical boxes, and PV panel mounting structures in one long run. The grounding wire should not be switched, fused or interrupted.
- The complete earthing system shall be electrically connected to return to earth from all equipment independent of mechanical connection.
- Earthing system design should follow the Kahramaa regulations and the standard practices.
- Earth resistance should be tested in the presence of Kahramaa's representative after earthing by a calibrated earth tester.
- A continuity test shall be executed.

For a better implementation of the requirements mentioned earlier, the Consultant / Contractor shall apply the following:

1. **PV System DC side (PV modules, strings, DC side of the PV generator and Inverter):**
   - Positive and negative protected with surge arresters.
   - Common earthing grid along the whole PV extension shall be provided, connecting to earth all the metallic structures present in the ground, to equally potentialize the system and to avoid step and touch voltages in case of phase or earth faults from external systems or in case of induced currents/voltages during lightning strikes.
   - Metallic support structures earthed to the "common" earthing grid. This is also according to Kahramaa Electricity and Wiring Code section 3.6.
   - When the (recommended) class II (double insulation or equivalent insulation) PV photovoltaic modules are used, they are not to be earthed.

2. **PV System AC side of the electrical system:**
   - It is like any other AC system; it shall be (in the customer's premises/boundary limit) a TN-S system for industrial installations (so PE is distributed). Obviously, for widespread unconnected customer areas, the TT system may also apply due to the TN-S system's unfeasibility.
   - The insulation transformer between the Inverter and the rest of the AC electrical system impedes the injection/transfer of phase-to-earth currents (in case of earth fault on the DC side) from the AC side to the DC side. In any case, suitable differential protection shall be provided.
   - The T-T system is only valid from Kahramaa to a single customer since Kahramaa doesn't provide an earthing conductor at such large distances. In both cases, "earth provided" and "earth not provided", the Consultant /

Contractor shall refer to the Kahramaa Electricity and Wiring Code (which is valid for LV) sections 5.1 and 5.2.

On the other hand, lightning systems are influenced by several factors, e.g., air termination networks, down conductors, earth systems, etc. PV Systems usually do not influence how a lightning system is designed. With the presence of PV Systems on the roof of a building, for instance, the PV System designer shall follow Kahramaa's currently applied rules and regulations for lightning system design.

The recommended practice to evaluate the need for lightning protection systems is to perform the IEC 62305 lightning risk assessment, considering the number of connected lines, the dimension of all the structures, including the relevant height, etc. For example, a 20 m structure, even shorter than a 60 m building, may need the Lightning Protection System since connected lines are long. So, a rule to provide Lightning Protection System is not simply related to building height. In any case, the Lightning Protection System is needed above 60m, and for shorter than 60 m, IEC 62305 lightning risk assessment is required.

# 6 Particular Requirements for LV Photovoltaic Systems

## 6.1 LV System Characteristics

As per Electricity Wiring Code, the following characteristics of the LV electrical system in Qatar apply:

- Rated Voltage: 240/415 ± 6%, 3 Phase, 4 Wire.
- Neutral: Solidly Earthed.
- Fault Level: 31 MVA at 415 V.
- The nominal main frequency 50 Hz.
- Under normal operating conditions, there may be a variation of ± 0.1 Hz.
- Industrial conditions in the state may occasionally result in a short-term variation of ± 0.15 Hz. for a duration of only a few seconds.
- In emergency overload conditions, the frequency would be allowed to drop to 48.8 Hz, at which point load shedding would take place.
- The nominal voltage is 415/240. It is Kahramaa practice to maintain the voltage level at a value not exceeding ±6% variation from the nominal value.

## 6.2 DC Injection

The DC component that the solar PV System injects into the network shall not exceed 0.5% of the rated AC current value of the system.

## 6.3 Clusters of Single-phase PV Units

For LV connections, the use of three-phase equipment is required. Anyhow, it is allowed for a solar PV System connected to the LV distribution network to be composed of clusters of single-phase PV Units only if the sum of the currents of all the solar PV Units connected to one phase does not exceed 16 A.

# 7 Compliance with the Standards

The Customer shall ensure that its solar PV System complies with the requirements defined in the present standards throughout the overall lifetime of the facility.

The Customer shall notify Kahramaa of any incident, failure or planned modification of its Solar PV System which may affect the compliance with the requirements defined in the present standards. The Customer shall provide Kahramaa with all the documents, studies and measurements useful to demonstrate the compliance of its solar PV System to the requirements defined in the present standards.

If deemed necessary, Kahramaa shall have the right to request the Customer to carry out additional tests or studies in order to demonstrate the compliance of the solar PV System with the provisions of the present document. Such activities may be requested during the Connection Process and throughout the lifetime of the solar PV System, and more specifically, after any failures, modifications, or replacements of any equipment that may impact the System's compliance with the present standards.

# ANNEX A. Connection Schemes

***In this document and especially this Annex, there are several connection schemes and Single Line Diagrams designed only for illustrative purposes regarding the possible options for designing a PV System. These schemes aim to show the main components needed for connecting a PV System to the electricity distribution network. These schemes are just indicative and, for that reason, shall be carefully considered by the Consultants during their design according to the specific case and need. These schemes cannot be directly applied nor copied by the Consultant without conducting a technical assessment and a feasibility study for the PV System they are designing.***

The schemes proposed in this Annex show examples of possible cases of solar PV Systems connection to the LV or MV Distribution Network of Kahramaa. To summarise in single line diagrams the clauses on the connection as presented in this document, particularly in 5.2 and 5.3. Different arrangements may be used if previously agreed with Kahramaa.

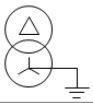
These schemes have to be combined with the general scheme of the installation to feed the Customer's loads.

The cases presented in the following are listed here:

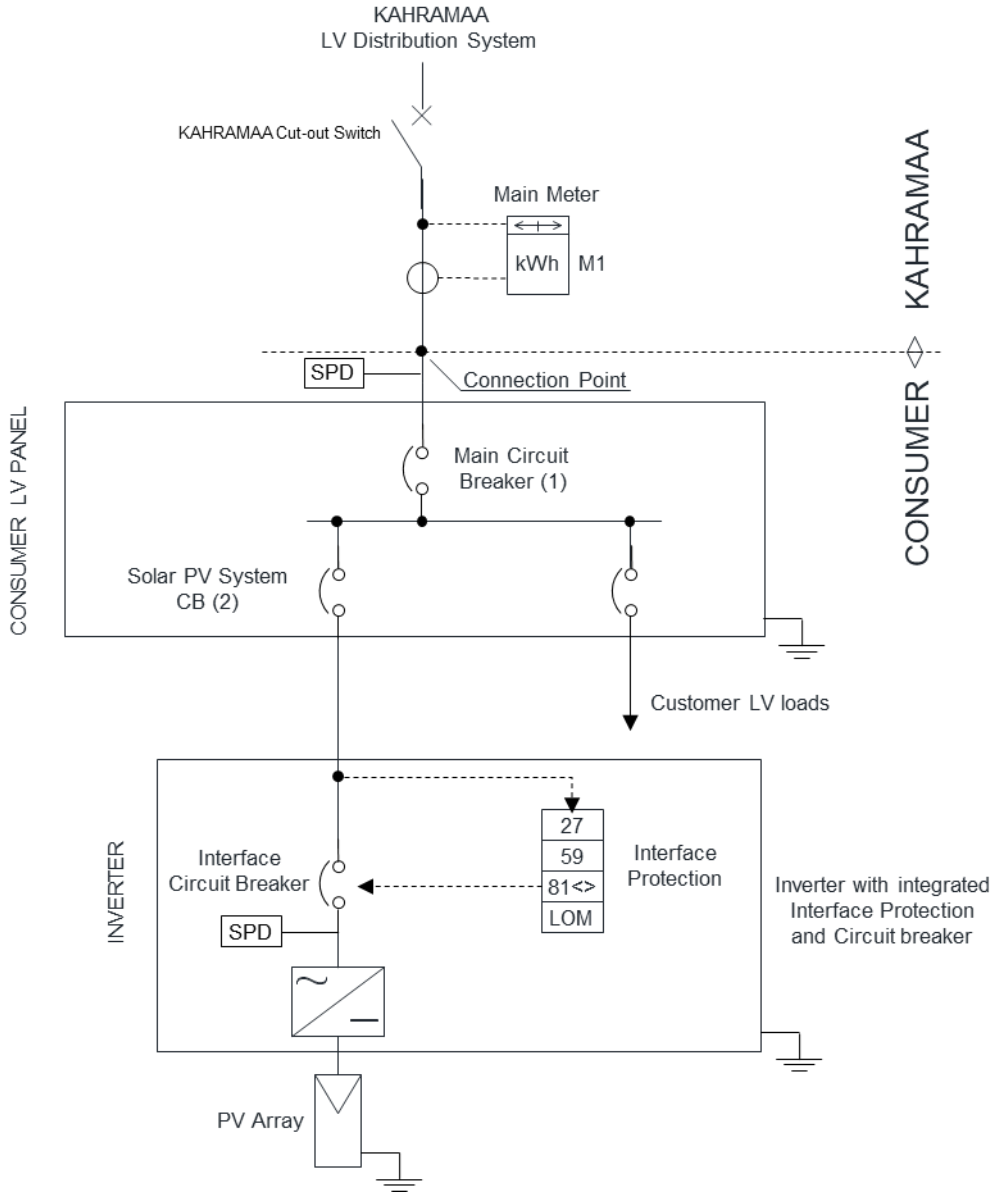
| Figure | Distribution Network (LV/MV) | Maximum Connected Capacity of the solar PV System | Notes |
|---|---|---|---|
| Figure 11 | LV | ≤ 11 KW | One three-phase Inverter (or three single-phase) with integrated Circuit Breaker and Interface Protection |
| Figure 12 | LV | > 11 kW and ≤ 20 kW | External Interface Protection (not integrated into the Inverter) |
| Figure 13 | LV | > 11 kW and ≤ 20 kW | Case of Figure 11 and Figure 12 where more than one Main Circuit Breakers are necessary for the absence of one general Main Circuit Breaker in the Customer's installation |
| Figure 14 | LV | > 11 kW and ≤ 20 kW | Multiple Solar PV Units with external and unique Interface Protection |
| Figure 15 | LV | > 20 kW and ≤ 1.6 MW | Multiple Solar PV Units with external and unique Interface Protection.<br>Backup Circuit Breaker is required.<br>Solar PV System Meter required if Maximum Connected Capacity of the Solar PV System > 100 kW |
| Figure 16 | MV | ≥ 100 kW and ≤ 1.6 MW | Multiple Solar PV Units with external and unique Interface Protection.<br>Interface Protection on the LV side.<br>Backup Circuit Breaker is required.<br>Solar PV System Meter required if Maximum Connected Capacity of the Solar PV System > 100 kW |
| Figure 17 | MV | ≥ 100 kW and ≤ 25 MW | Multiple Solar PV Units with external and unique Interface Protection.<br>Interface Protection on the MV side.<br>Backup Circuit Breaker required. |

| Figure | Distribution Network (LV/MV) | Maximum Connected Capacity of the solar PV System | Notes |
|---|---|---|---|
| | | | Solar PV System Meter required if Maximum Connected Capacity of the Solar PV System > 100 kW |

The meaning of the symbols and codes used in the single line diagrams is explained hereinafter:

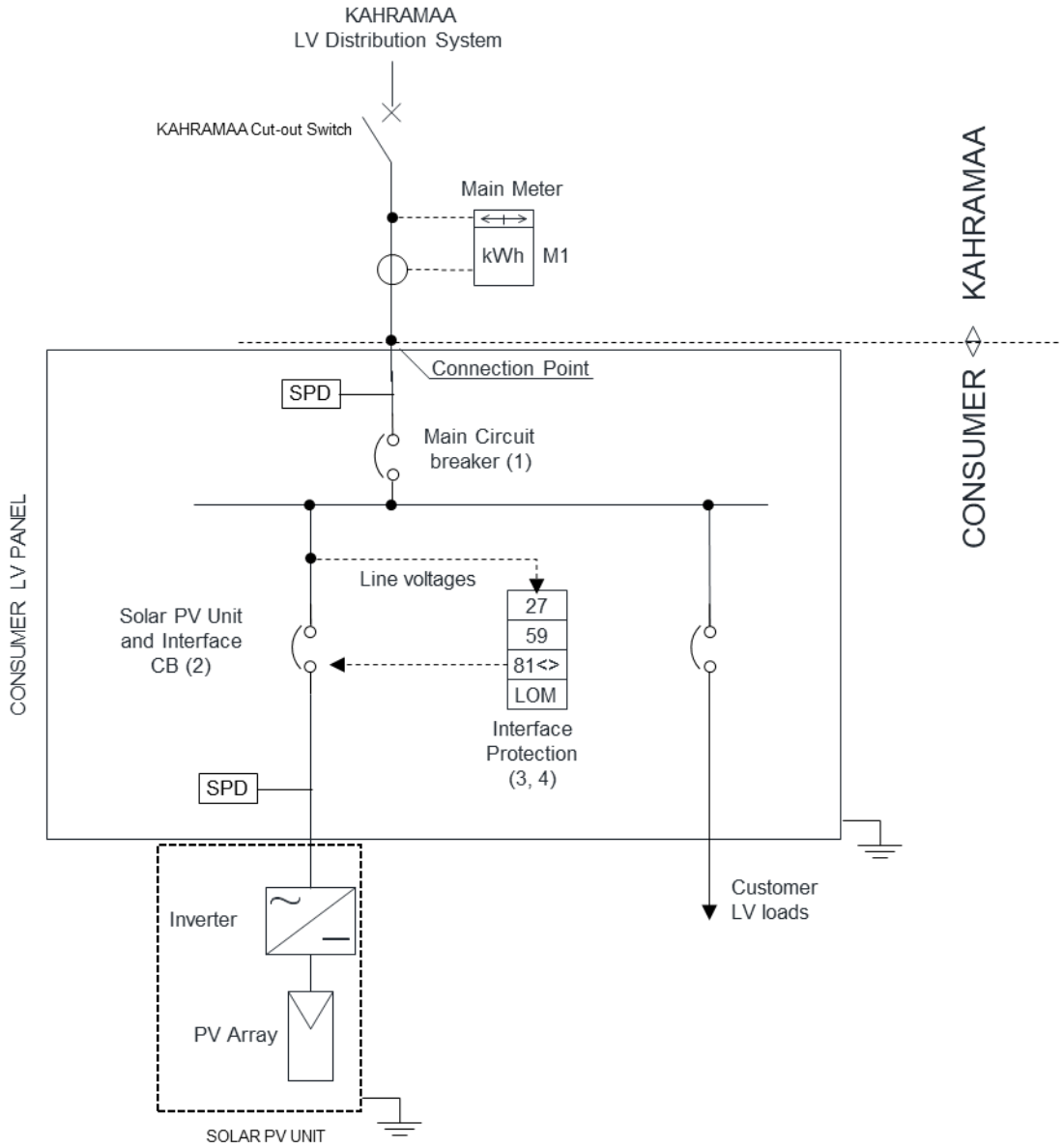
| LEGEND | |
|---|---|
|  | CIRCUIT BREAKER |
|  | SWITCH |
|  | CURRENT TRANSFORMER (CT) |
|  | POTENTIAL TRANSFORMER (PT) |
|  | LOAD |
|  | INVERTER |
|  | PHOTOVOLTAIC ARRAY |
|  | POWER TRANSFORMER |
|   | BI-DIRECTIONAL ENERGY SMART METER (4 QUADRANTS) |

| ANSI CODES FOR PROTECTIONS | |
|---|---|
| 27 | UNDERVOLTAGE PROTECTION |
| 59 | OVERVOLTAGE PROTECTION |
| 81 | UNDERFREQUENCY (81<) PROTECTION<br>OVERFREQUENCY (81>) PROTECTION |
| LOM | LOSS OF MAINS PROTECTION |
| 50 | INSTANTANEOUS OVERCURRENT PROTECTION |
| 51 | IDMTL OVERCURRENT PROTECTION |
| 50N/51N | EARTH FAULT CURRENT PROTECTION |



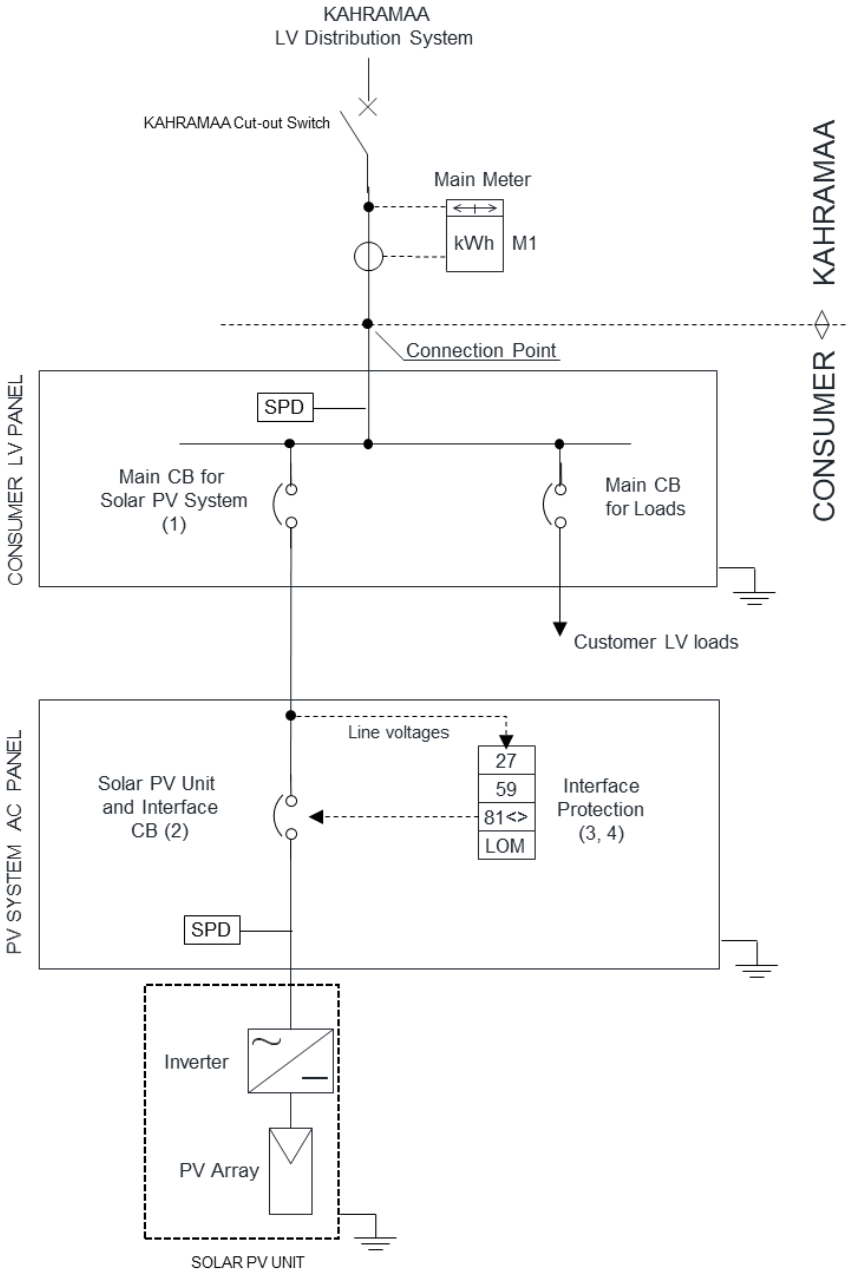

NOTES:
(1) Automatic Circuit Breaker
(2) Automatic Circuit Breaker with:
- Overload Protection
- Short Circuit Protection
- Protection against electric shock (RCD)

*Figure 11: Indicative Scheme for LV Connection– Solar PV System with Maximum Connected Capacity ≤ 11 kW*




NOTES:
(1) Automatic Circuit Breaker
(2) Motorized Automatic Circuit Breaker
(3) LOM protection is not required if it is integrated into the Inverter
(4) Auxiliary power supply from a UPS

*Figure 12: Indicative Scheme for LV Connection– solar PV System with Maximum Connected Capacity > 11 kW and ≤20 kW – External Interface Protection*




NOTES:

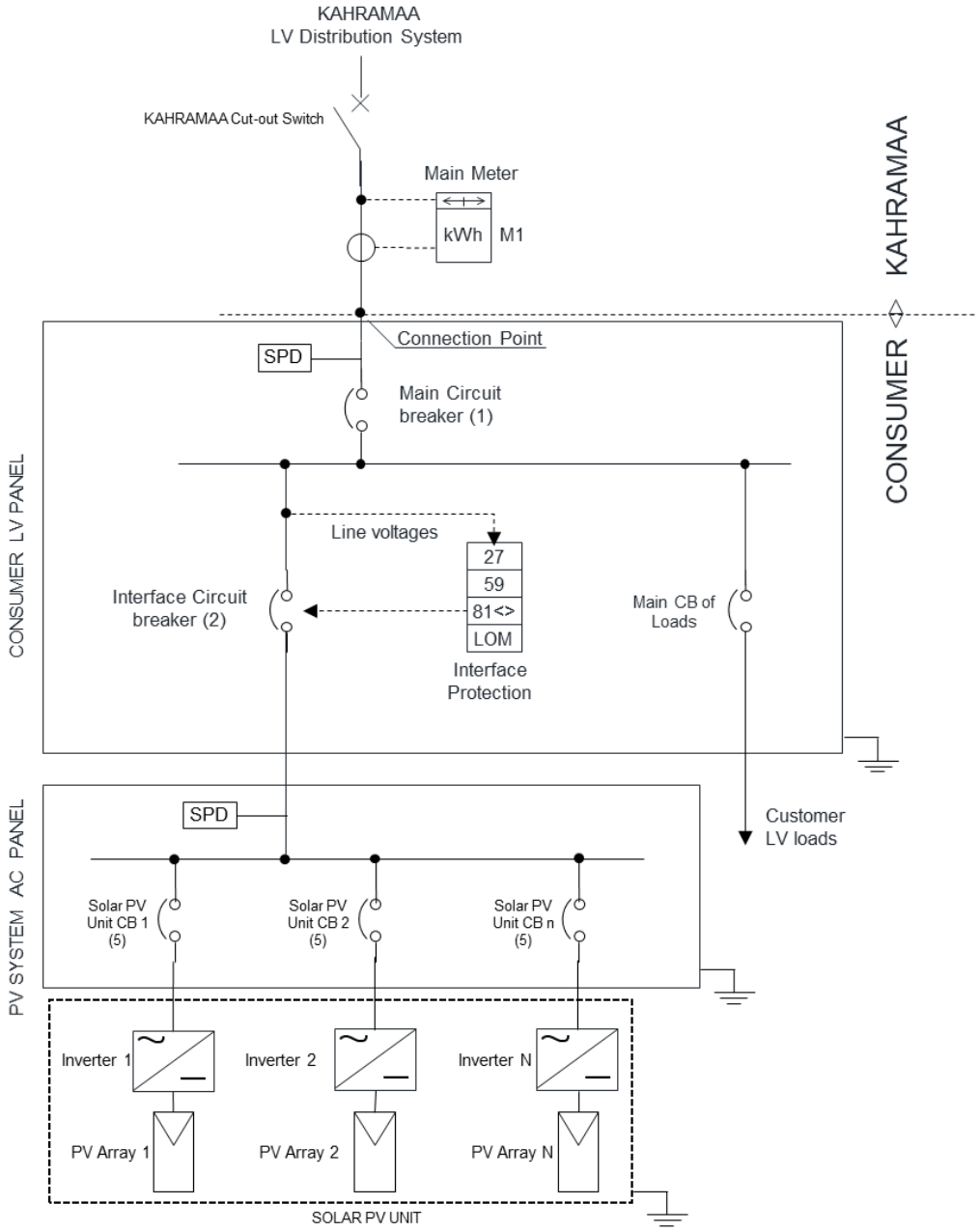
(1) Automatic Circuit Breaker with:
- Overload Protection
- Short Circuit Protection
- Protection against electric shock (RCD)

(2) Motorized Automatic Circuit Breaker

(3) LOM protection is not required if it is integrated into the Inverter

(4) Auxiliary power supply from a UPS

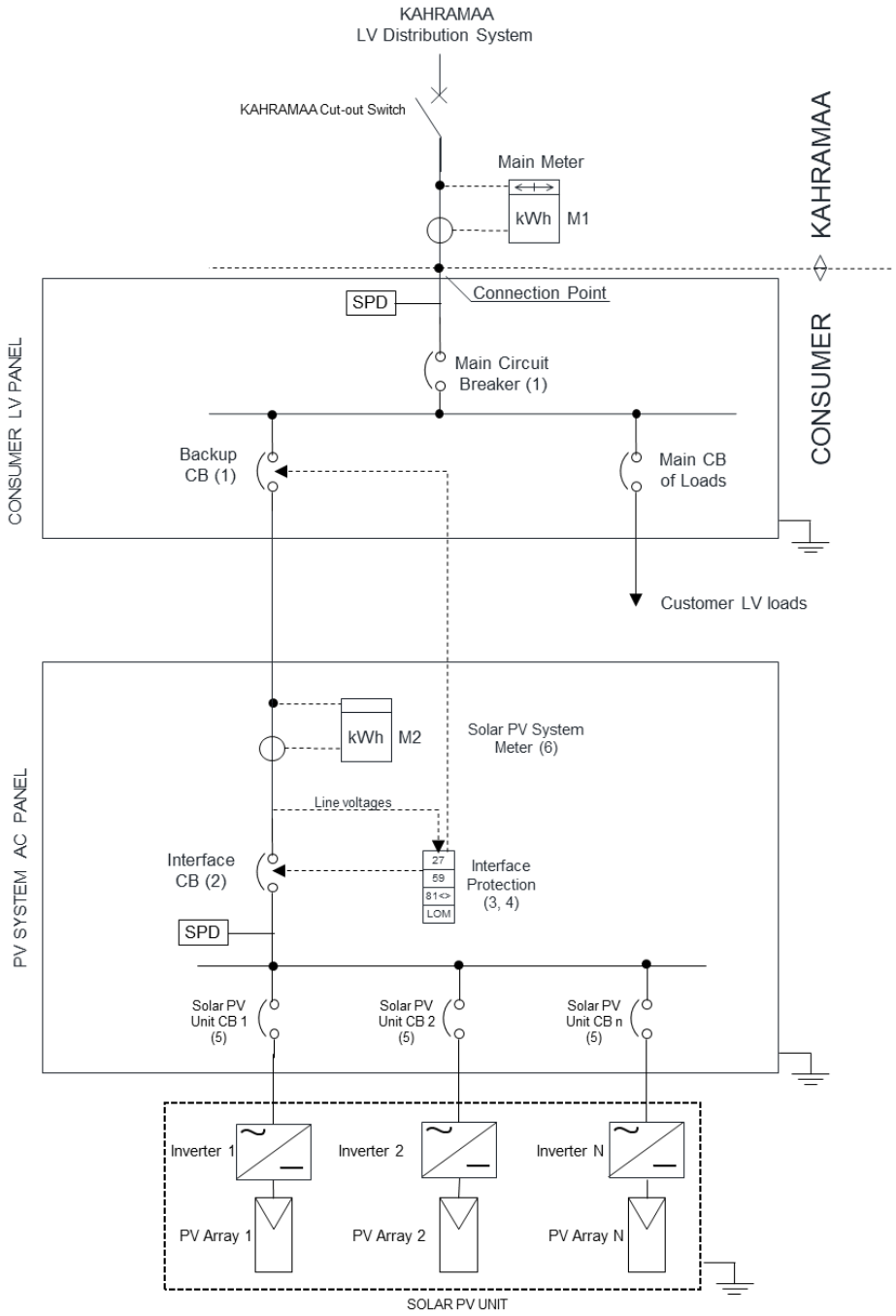
*Figure 13: Indicative Scheme for LV Connection– Case of Two (or more) Main Circuit Breakers in absence of one general Main Circuit Breaker in the incomer from Kahramaa (case as per Figure 11 shown, but this applies to both schemes of Figure 11 and Figure 12)*




NOTES:
(1) Automatic Circuit Breaker
(2) Motorized Automatic Circuit Breaker with:
- Overload Protection
- Short Circuit Protection
- Protection against electric shock (RCD)

(3) LOM protection is not required if it is integrated into the Inverter
(4) Auxiliary power supply from a UPS
(5) Automatic Circuit Breaker

*Figure 14: Indicative Scheme for LV Connection– solar PV System with Maximum Connected Capacity > 11 kW and ≤20 kW – Multiple Solar PV Units with external and unique Interface Protection*




NOTES:

(1) Automatic Circuit Breaker with: Overload Protection, Short Circuit Protection against electric shock (RCD)
(2) Motorized Automatic Circuit Breaker
(3) LOM protection is not required if integrated into the Inverter
(4) Auxiliary power supply from a UPS
(5) Automatic Circuit Breaker
(6) Second meter to be supplied by Kahramaa for Pnom > 100 kW

*Figure 15: Indicative Scheme for LV Connection– solar PV System with Maximum Connected Capacity > 20 kW and ≤ 1.6 MW – Multiple Solar PV Units with external and unique Interface Protection; Backup Circuit Breaker; Solar PV System Meter (only if Nominal Power of the Solar PV System > 100 kW)*

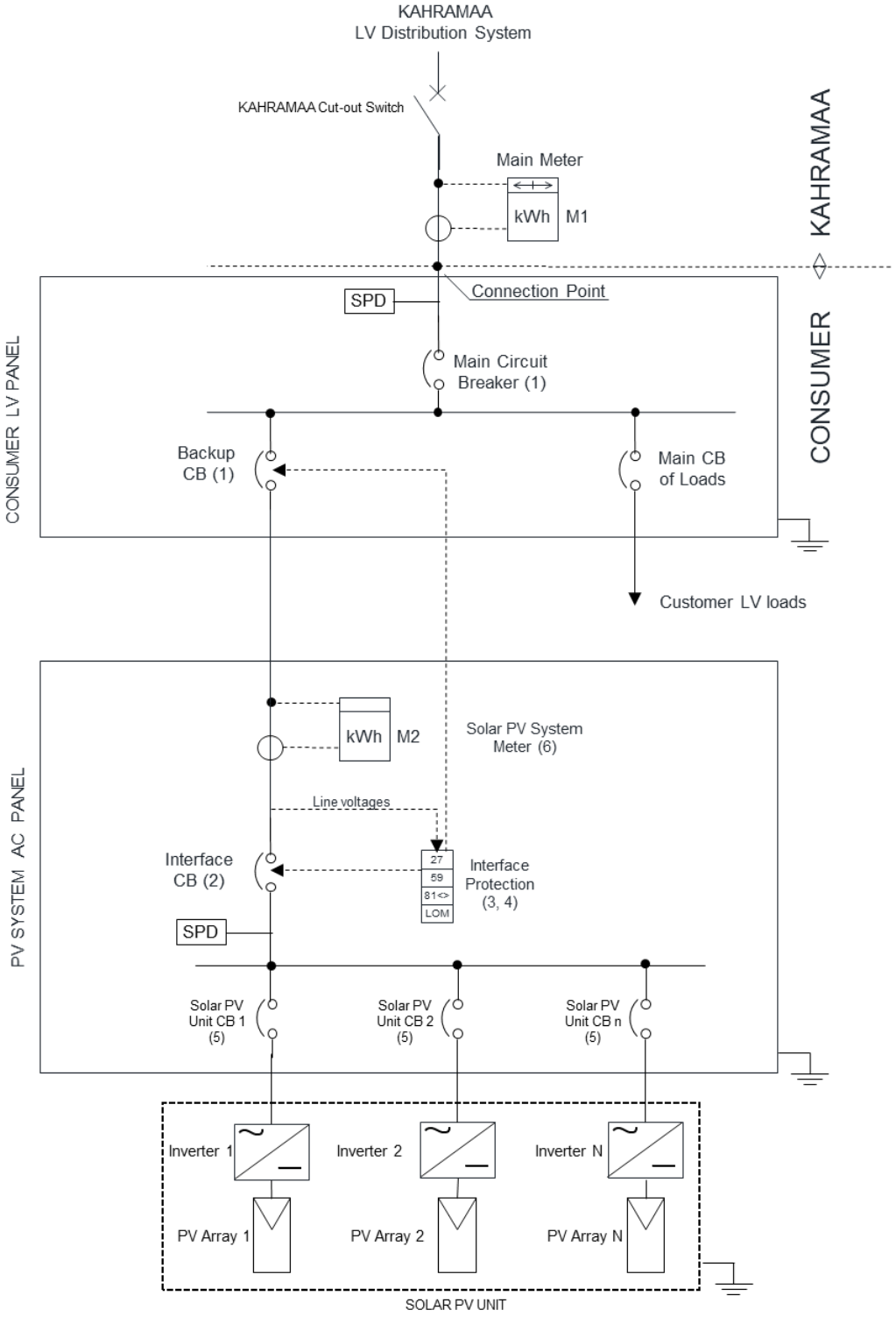
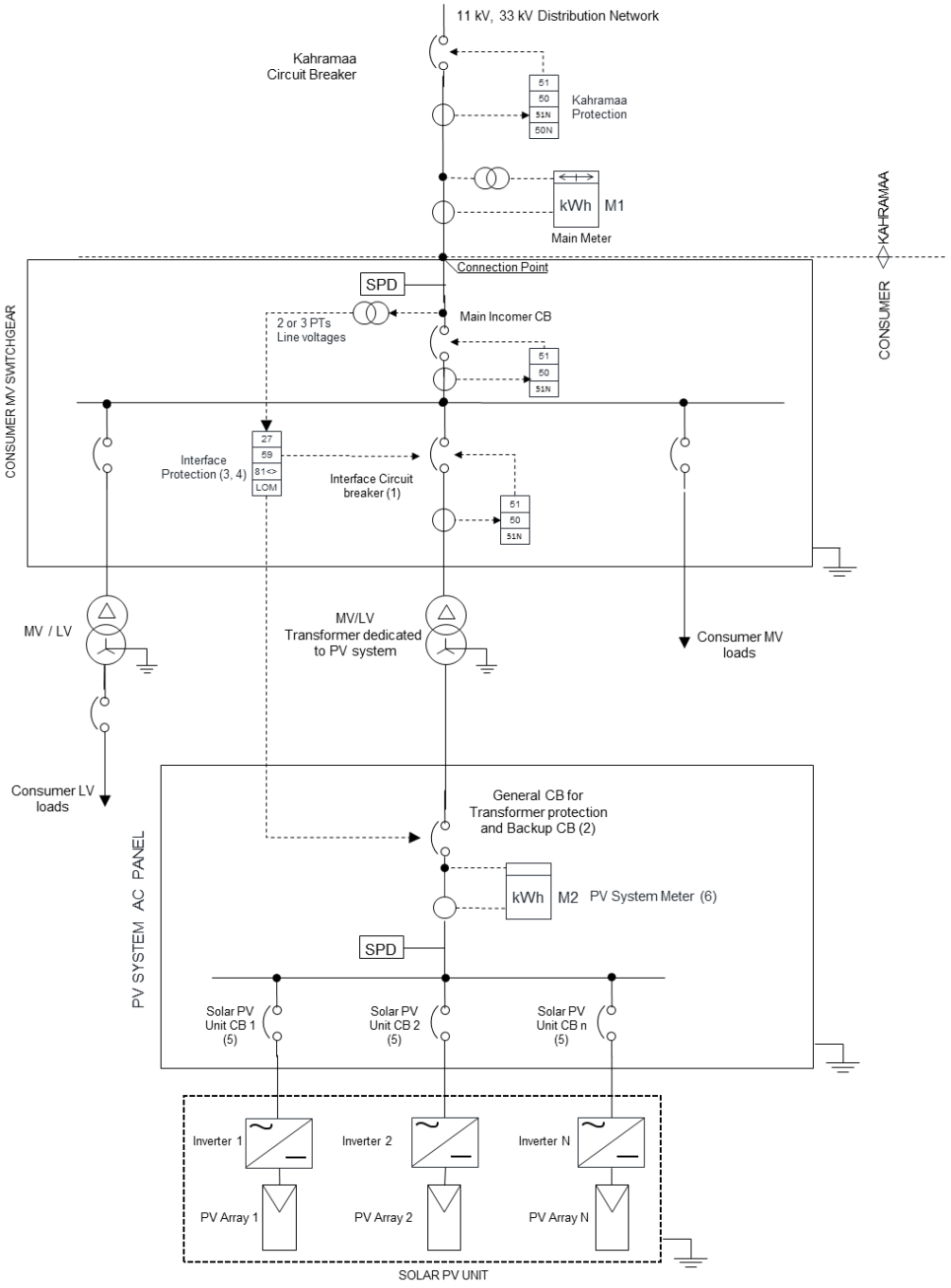



*Figure 16: Indicative Scheme for MV Connection - Interface Protection on the LV side solar PV System with Maximum Connected Capacity > 100 kW – Multiple Solar PV Units with external and unique Interface Protection on the LV side; Backup Circuit Breaker; Solar PV System Meter (only if Nominal Power of the Solar PV System > 100 kW)*




NOTES:

(1) Motorized Automatic Circuit Breaker with Overload Protection (51), Phase Protection (50), Earth Protection (51N)
(2) Automatic Circuit Breaker with Overload Protection, Short Circuit Protection against electric shock (RCD)
(3) LOM is not required if integrated into the Inverter
(4) Auxiliary power supply from a UPS
(5) Automatic Circuit Breaker
(6) Second meter to be supplied by Kahramaa for Pnom > 100 kW

*Figure 17: Indicative Scheme for MV Connection– Interface Protection on the MV side solar PV System with Maximum Connected Capacity > 100 kW – Multiple Solar PV Units with external and unique Interface Protection on the MV side; Backup Circuit Breaker; Solar PV System Meter (only if Maximum Connected Capacity of the Solar PV System > 100 kW)*

# ANNEX B. Default Settings of Interface Protection

The following table reports the default settings to be implemented in the Interface Protection of solar PV Systems when Kahramaa has communicated no other settings.

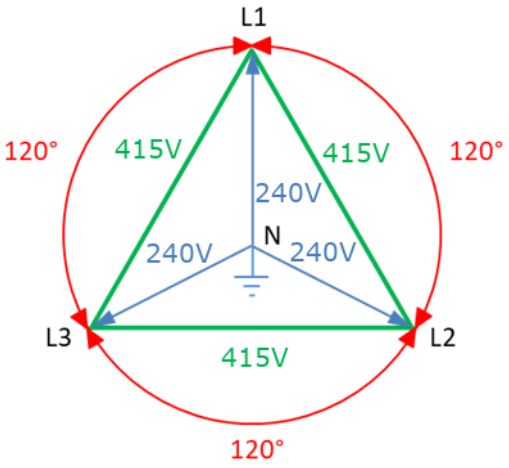
*Table 5: Default settings for the protection functions of the IP*

| Protection function | Settings | |
|---|---|---|
| | Threshold | Time delay |
| **27<** | 90% Nominal Voltage | 3 s |
| **27<<** | 40% Nominal Voltage | 1.5 s |
| **59>** | 110% Nominal Voltage | 3 s |
| **59>>** | 120% Nominal Voltage | 0.2 s |
| **81>>** | 52.5 Hz | 0.1 s |
| **81<** | 47.5 Hz | 4 s |
| **81<<** | 47.0 Hz | 0.1 s |

**NOTE**: in case the Interface Protection is external, the built-in IP can either be excluded (if LOM is made externally) or configured with higher settings

# ANNEX C. Configuration of LV Distribution Systems of Kahramaa

Three-phase four wires 415/240 Vac configuration



# ANNEX D. Service and Environmental Conditions

As per Electricity Wiring Code, par. 1.3.1, Qatar experiences a tropical climate and generally the ground area is at sea level. The climate in Qatar in the summer months is hot and humid and a humidity of 100% at 30°C has been recorded and seem to be as following data:

1. The Maximum sun radiation temperature in summer - 84°C.
2. The Maximum ambient temperature in summer - 52°C.
3. The Average max. Ambient temperature in summer - 45°C.
4. The Minimum ambient temperature in winter - 0°C.
5. The maximum ground temperature is 30°C at a depth of 1 meter.
6. The maximum seawater temperature is 40°C with a maximum tidal variation of approximately 2.40 meters.
7. Atmosphere is salt laden and very corrosive.
8. The prevailing winds are northerly and gales with gusts approaching 140 KPH have been recorded accompanied by a high level of dust in the air.
9. The mean and maximum Relative Humidity during the summer month of April to September inclusive are as follows at the associated temperatures given:

| Mean % RH | |
|---|---|
| °C | % R.H. |
| 27 | 72 |
| 32 | 61 |
| 38 | 48 |
| 43 | 30 |

| Maximum % RH | |
|---|---|
| °C | % R.H. |
| 27 | 97 |
| 33 | 87 |
| 39 | 84 |
| 44 | 51 |

10. The average annual rainfall is 50 mm and generally falls between January and April inclusive.

As per Electricity Wiring Code, Appendix No. 02, the service electrical cabinets will be used in the following climatic conditions:

- Maximum Direct Sunlight Temperature: 75°C
- Maximum Ambient Air Temperature: 50°C
- Maximum Relative Humidity: 100%
- Occasional sandstorms with height salt content.
- Occasional fog mixed with salty sea water mist.
- Occasional torrential rain in winter and up to 15 cm per year.
- Prolonged periods with temperatures between 30oC and 50oC with humidity simultaneously between 30% and 100%.

As per Electricity Wiring Code, paragraph 10.8, all windings shall be tropically impregnated and be designed for operations in a very dusty environment with an ambient of 50° C and of and humidity 80%.

| | |
|---|---|
| Altitude above mean sea level (msl): | a. up to 1000m (normal)<br>b. above 1000m (as required) |
| Ambient Temperature (Outdoor): | Minimum: -5 °C<br>Maximum: 55 °C<br>Monthly average of the hottest month: 40 °C<br>Yearly average: 30 °C<br>Design temperature: 50 °C [as per Wiring code par. 10.8] |

| | |
|---|---|
| Ambient Temperature (Indoor): | Air-conditioned buildings: 25 °C<br>Buildings where no air-conditioning is provided: 40 °C |
| Ambient ground temperature: | 40 °C |
| Maximum relative humidity: | 100% [80% as per Wiring code par. 10.8] |
| Temperature of exposed surfaces due to solar radiation: | 75 °C |
| Soil thermal resistivity one (1) meter and below: | 2.0 °C.m/W |
| Maximum earthquake frequency / severity: | Zone 2 (US Build Code) |
| Soil condition– General: | Corrosive. Widespread salt deposits. |
| Ground water table level: | Varies from deep to very near the surface |
| Soil pH: | 7.0 – 8.5 |
| Salt concentrations (typical) Sulphates (SO3), by weight: 0 – 10 % Chlorides (as NaCl), by weight: | 0 - 5% |
| Contamination level: Equivalent Salt Deposit Density (ESDD) in a period of any six: | 0.3 to 0.5 mg/cm$^2$ |
| Average hydrogen sulphide in the atmosphere: | 40 Mg/m$^3$ (0.03 ppm) |
| Soil salinity: | 0 to 140 g/m$^3$ (0 to 100000 ppm) |
| Average rainfall per year: | 150 mm |
| Maximum wind velocity: | 150 km/h |
| Approximate highest density solar radiation average over the summer months | 1000 W/m$^2$ |
| Isokeraunic level: (average / maximum / above 1000m): | 10 /15 / 50 storm days/year |

1) All equipment/material and accessories shall be designed for satisfactory operation/performance based on the above (Indoor or Outdoor or Ground) service conditions.
2) All outdoor equipment enclosures/material shall be weatherproof, all metal parts shall be corrosion and/or abrasion resistant, and the degree of protection shall be at least IP54 as per IEC 60529. The degree of protection for all indoor equipment shall be IP41 as per IEC 60529.