CEDRO

GUIDELINES ON NET - METERING:
THE CASE OF LEBANON

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3- Authors

Report prepared by:	Xavier Vallve	Trama TechnoAmbiental (TTA), Barcelona, Spain
	Maria Anzizu	Trama TechnoAmbiental (TTA), Barcelona, Spain
	Marilena Lazopoulou	Trama TechnoAmbiental (TTA), Barcelona, Spain

Report reviewed by:
The EDL Net metering Committee.

UNDP - CEDRO Team:	Hassan Harajli	Project Manager
	Jessica Obeid	Project Coordinator
	Carla Nassab	Energy Engineer
External Support:	Jil Al Amine	UNDP - DREG project manager
	Eric Obeid	UNDP - DREG Energy Engineer

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Table of Acronyms

Abbreviation	Explanation
AC	Aletrnating Current
DC	Direct Current
DG	Distributed Generation
Genset	Generator Set
LV	Low Voltage
MV	Medium Voltage
PV	Photovoltaic
SCADA	Supervisory Control and Data Acquisition
UNDP	United Nations Development Programme
UPS	Uninterruptible Power Supply

Definitions

AC Power Capacity of the PV Generating Plant: The rated maximum power that can be delivered to the AC grid. Usually it is given by the rated power of the inverter. For grid-dependent plants is the continuous power rating of the inverter; for dual type plants (with batteries) is the 30-minute power rating of the inverter.

AC Power Rated Backfeed Capacity of the PV Generating Plant: The maximum power that can be back fed to the distribution grid either because it is the maximum plant capacity or because the plant's net surplus is controlled by load management or generation curtailment or both.

Autonomous Inverter: An inverter that supplies a load not connected to an electric grid. Also known as a "battery inverter" or "stand-alone inverter".

Autonomous Operation: The operation of the generating plant producing electrical energy at the consumer's premises, while not connected to the public distribution grid or with the distribution grid not energised.

Billing Period: The period for which the producer's electricity meter is read by the utility and the consumer is issued with an electricity invoice. Usually a period of one or two months is considered.

Dual - mode inverter: A type of inverter that can operate in both autonomous and grid-parallel modes according to the availability of the utility supply.

Energy Credit: The amount of net electrical energy exported to the utility's distribution grid during a specified Billing Period, which amount, measured in kilowatt hours, shall be credited to the Producer's electricity account in the subsequent Billing Period.

Flicker: The term flicker was originally adopted as a reference to the visible flickering of an incandescent light bulb when subjected to voltage oscillations on a utility line. The perception of flicker is subjective, and depends on the magnitude and frequency of the voltage oscillations. A slow oscillation must be of higher magnitude in order to be as noticeable as a fast oscillation. The short-term flicker (Pst) is measured over 10 minute intervals and long-term flicker (Plt) is measured over 2 hours intervals. The Pst characterizes the probability for the voltage fluctuations to result in perceptible light flicker for the human eye.

Generating Plant: All of the producer's equipment and land at a single site utilised to produce and deliver electrical energy, including but not limited to the generating, metering and protection equipment.

Grid - Dependent Inverter: An inverter that can operate only in grid-parallel with a utility supply. Also known as a grid-tied inverter.

Harmonics: Generically refers to distortions in the voltage and current waveforms. These distortions are caused by the overlapping of the standard sinusoidal waveforms at 50 Hz with waveforms at other frequencies that are multiples of 50 Hz. Generally, a harmonic of a sinusoidal wave is an integral multiple of the frequency of the wave.

Inverter: An electronic component that converts DC electricity into AC electricity.

Net-metering: An electricity payment scheme where the electricity delivered from the consumer's distributed generation facility to the utility's distribution grid offsets the electricity demanded from the utility, during a year.

Parallel Operation: The operation of the generating plant producing electrical energy at the consumer's premises, while it is connected to the energised public distribution grid.

Producer - Consumer (or prosumer): A legal entity that owns a generating plant that produces and delivers electrical energy to the distribution grid of the electrical utility and meanwhile has a valid account to purchase electricity from the distribution grid.

Subscribed Demand: The allocated power capacity, as depicted in the electricity agreement with the utility that the prosumer may not exceed (in terms of kVA or A).

Synchronizing Switch: Measuring relay which is intended to initiate closing of a switch between the grid and the dual inverter when the AC voltage of these sources have predetermined relationship of magnitude, phase and frequency. It can be internal in the inverter or external.

Total Harmonic Distortion: The sum of all the distortions at the various harmonic frequencies. One of the indicators of the quality of the electrical supply.

1. Executive Summary

1.1. Overview

The guideline serve as a basis to asses new renewable energy based distributed generation (DG) plants, interconnected to the low voltage (LV), or medium voltage (MV) distribution grids, and designed to operate under the net metering scheme. The connection of the distributed power plant to the LV or MV grid depends on the total installed capacity of the plant. This guideline focus on the technical and billing considerations in the Lebanese context, where an improperly monitored adoption of the distributed PV systems creates risks on grid stability.

1.2. Technical considerations

The design, installation, maintenance, and operation of the generation facility shall be conducted in a manner that ensures the safety and security of both the generation facility and the distribution grid.

1.2.1. Interface protection

The owner of the distributed system shall ensure the automatic disconnection of the generation facility from the distribution grid, when the grid parameters are outside the allowable thresholds with regards to Voltage and Frequency. If the plant's function is also backup, the protective functions can be an internal transfer/synchronisation switch in the inverter or an external transfer switch at the point of connection to the distribution grid.

1.2.2. Inverters

The inverters shall be provided with an IP per their location. The inverter shall be able to withstand the maximum temperatures.

1.2.3. PV generator

PV arrays for installation on buildings shall have maximum voltages lower than 1,000 Vdc. All the equipment shall withstand the maximum voltage of the array. The PV generation facility's AC voltage, current and frequency shall be compatible with the distribution grid. In any case, the disconnection of the plant should be done according to specific functions and settings, including (EDL agreement).

1.2.4. Distribution Grid parameters for grid interaction.

The nominal output voltage wave form of the PV power Plant shall be of 230/400 V, 50 Hz, with a sinusoidal wave form complying with a THD < 5%. In large interconnected plants, a typical voltage tolerance band for unrestricted generator operation is ±10% of the nominal value and around ±2% of the frequency. However, in distributed PV systems, wider frequency and voltage tolerance are required because the variations can be larger than in a transmission grid with a dedicated line. The recommended values are:

Voltage: The inverter needs to disconnect from the grid in less than 200 ms when the voltage is lower than 0.8 or higher than 1.15 the nominal voltage of the grid.

Frequency: The inverter needs to disconnect from the grid in less than 200 ms when the grid frequency is lower than 47,5Hz or is higher than 51,5Hz.

Islanding protection: The detection of the isolated network and the disconnection from the grid of the inverter needs to be done in less than 5 seconds.

For all those protection functions, the tolerance between the setting values and the actual tripping values must not be higher than +/-1% for voltage and +/-0.1% for frequency.

Harmonics: For plants with an output current I ≤ 16 A per phase, the harmonic components of the current produced and measured at the output terminals shall comply with the standard IEC 61000-3-2 "Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)". The limitation of voltage changes, voltage fluctuations and flicker shall comply with the standard IEC 61000-3-3. For all the plants connected to the LV grid, the voltage quality measured at the Point of Connection shall be in accordance with the IEC 61000-2-2 "Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems" and IEC/TR 61000-3-14.

Current: The inverter shall not contribute to fault currents in the network, nor inject any additional reactive current during voltage dips. Overcurrent protective devices are to be sized based on IEC 60364-7-712 "Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems" for overcurrent protection for strings, sub-arrays or arrays:

For plants interconnected to the medium voltage distribution network, the disconnection times should be programmed as follows (source: Dubai): in less than 200 ms when the voltage is lower than 0.3 the nominal voltage of the grid and in less than 600 ms when the voltage is higher than 1.20 the nominal voltage of the grid.

Following the disconnection, the DG unit shall not be reconnected to the Network before the Voltage at the Connection Point is within the range 95% - 105% of nominal Voltage during a minimum of 60 seconds. The Active Power Output shall not be recovered with a gradient above 20% of the Maximum Capacity per minute. It is assumed that DC section(s) in the plant are separated from the MV AC section by an MV/LV transformer. Therefore, no DC currents injection shall be possible from DC/AC converters to the MV grid.

1.2.5. Metering

There are two meters necessary when connecting the plant either to the low voltage or medium voltage grid: one bidirectional meter recording energy injected to the grid and the energy demanded from the grid and a second one recording the produced energy of the renewable energy plant. In the case of connection at the medium voltage, an automatic transfer switch is placed at the production side to disconnect the production plant in an event of a grid disturbance and avoid unintentional islanding. In order to ensure symmetrical feeding to the MV grid, it is recommended to install three-phase inverters.

Meters adopted for net metering applications are active and reactive energy metering devices in all four quadrants, i.e. they measure and record both imported and exported energy within the predefined billing period.

1.2.6. Electrical protections & cabling

The following paragraphs include the main considerations concerning the electrical protections needed in a net-metering facility, to prevent any damage to the equipment, the cabling or the people.

1.2.6.1. Admissible current – Overload

The cables of the installation should be able to carry a nominal current permanently to temperatures of up to 90ºC. Several overloads are permitted over short periods of time; usually an overload factor is considered (1.25 or 1.3) to avoid tripping.

1.2.6.2. Short circuit protection

The maximum short circuit (SC) should be measured or calculated with the impedance of the cable installed from the MV transformer. Usually the SC current with no impedance (i.e. only the transformer impedance) added is 12 kA. The protections have standardised values of 4 kA, 6 kA or 10 kA and should be selected depending on the impedance from the point of connection. The short circuit current can be calculated as a line-to-neutral fault or line-to-line fault (i.e. 230 V for single phase or 400 V for three phase divided by the impedance).
The minimum short circuit should take into consideration the longest and least cross section line. The short circuit current at that point should be enough to make the magnetic circuit breaker trip. If the value is not sufficient, then the cross section has to be increased or the nominal value of the protection decreased.

1.2.6.3. Voltage drop

Voltage drop across resistances, conductors, connectors and contacts causes energy to be dissipated. The higher the drop voltage is, the more the energy generated will be dissipated into the air in terms of heat. The recommended maximum voltage drop values are shown in Table 6.

Wiring distances	Recommended maximum voltage drop	Reference power
PV modules to PV inverter	3%	STC capacity
PV generator to PV charge controller	2%	STC capacity
Charge controller to battery	2%	STC capacity
Battery to autonomous or dual mode inverter	1%	Inverter 30' rating
Autonomous or dual mode inverter to loads	5%	Inverter 30' rating
Autonomous or dual mode inverter to main grid	1%	Inverter rating

Table 1: Maximum voltage drop for wire sizing (UNDP/CEDRO, 2013)

1.2.6.4. Overvoltage protection

When deciding on the surge protection device (SPD) installation, there is one rule of thumb that can be followed and takes into account the following aspects: Briefly, if there is a lightning rod within a radius of 50 m there should be installed type 1+2 SPD at the entrance of the installation. If there is no lightning rod, only type 2 SPD is required. In addition, if the distance between the equipment and the previously installed spd's inside the building is higher than 10 m then type 2 or type 2+3 SPD should be installed. Type 3 SPD will be installed if sensitive equipment (electronics) is present.

1.2.6.5. Earth fault leakage protection

In order to avoid electrocutions and limit physical danger, all components of an installation should be Class II equipment, from standardised insulation material and all cable interconnections should be enclosed. Depending on the earthing distribution system, the protection will be calculated differently, being the residual current device (RCD) or the miniature circuit breaker (MCB) the main disconnecting device. RCDs of 300mA or less are recommended for any electrical installation TT or TN. For TN and IT systems, the impedance of the line and the magnetic curve of the MCB will be the critical point, whereas for TT systems it will be the earth loop resistance and the RCD sensibility. For the inverters, there is a recommended type of RCD which will perform better.

1.3. Billing

If during a billing period, the prosumer generates more electricity than demanded from the grid, then the difference is credited (1 credit equals to 1 kWh) to the following billing period. In this case, the prosumer is charged with any taxes or fixed chargers. On the contrary, if the electricity supplied by EDL exceeds the electricity exported by the prosumer plus any energy credits carried over from the previous billing period, the prosumer is charged this difference according to the applicable tariff per kWh and the rest of the costs. Energy credits may be carried over from one billing period to another, for so long as the prosumer has a legal contract for the supply of electricity by EDL, up to a maximum of one year. In order to minimize lost credit and ensure that the prosumer is charged as few kWh as possible, it is very important to properly size the renewable energy generator accordingly to match the electricity production with demand.

1.4. Recommended practices to run a net-metering program

In order to execute a successful net metering program is important that the utilities are able to gather information regarding the installed systems. The information should be used to expedite the licensing processes and to keep a record of the main sources and locations (e.g. Energy source information; load information or Feasibility study performed for larger systems).

Besides the details about the load curves and profiles relevant for planning purposes, the utility should collect information about the equipment used in the installation.

The most troublesome parameter in the control configuration is the anti-islanding configuration, as discussed in the previous sections, some standards can be adapted from different jurisdictions to meet the requirements

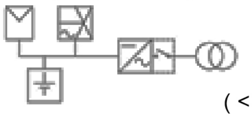
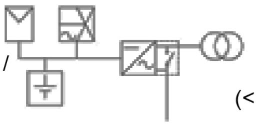
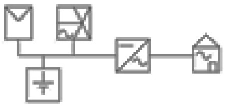
Recommended Settings for Interconnected Net Metered Renewable Energy Micro Power Plants with Inverters							
Type of Plant	References diagram (Single Phase)	Rated Current Nominal Power	Disconnection means	Voltage tolerance	Frequency tolerance	Trip disconnection time	DC Injection
B1: Grid dependent		Current Nominal Power (< subscribed demand)	- Inverter embedded stop function - Inverter external switch - External transfer switch	> 0.80 Um < 1.15 Um	> 45 Hz < 55 Hz	< 2s	< 0.5% ac current in nominal power*
B2: Dual mode Grid dependent / autonomous		Power 30 min (< subscribed demand)	- Inverter internal transfer synchronizing switch - Inverter manufacturer external transfer synchronizing switch	> 0.70 Um < 1.15 Um	> 45 Hz < 65 Hz	< 20ms	
A: Autonomous		Not Possible					

Figure 1: Recommended settings for grid-tied grid-dependent (B1), grid-tied dual mode (back-up) (B2) and autonomous plants for Lebanon (Source: CEDRO, TTA)

in the Lebanese context, the recommended settings for interconnected plants for net-metering in Lebanon are showed in Figure 7.

Other rules of thumb can be applied to expedite the interconnection processes in the early stages of the net-metering programs.

Finally, keep record of the plant's GPS coordinates [Lat, Long] is a fundamental step that informs the utility company to monitor the growth in adoption. It has been established that net-metering early adopters tend to cluster in areas where the installation of the PV systems is financially attractive. Considering that maintaining the grid is a responsibility of the utility, recording the location and detecting these clusters can inform for planning purposes where to invest first in advanced monitoring and grid enhancements.

2. Preamble

The United Nations Development Programme, in partnership with the Ministry of Energy and Water, have initiated the fourth phase of the CEDRO (Community Energy Efficiency and Renewable Energy Demonstration Project for Lebanon) Programme (CEDRO 4) funded by the European Union.

The CEDRO 4 project includes several smaller sustainable energy sub-projects that are designed to promote the same outcome related to renewable and energy efficiency systems.
The CEDRO 4 project aims to implement several renewable energy and energy efficiency tasks for private sector end-user, in collaboration with the public sector, in order to assist in achieving the renewable energy and energy efficiency targets of the Government of Lebanon and the Ministry of Energy and Water. Its objectives also address the issue of climate change through green-house gas (GHG) mitigation and enhance security of supply through increased dependence on national and natural resources and diversifying the energy mix.

To achieve this, the project will work on three levels, including: the implementation of model end-use energy efficiency and renewable energy demonstration projects for private sector buildings and facilities; the set-up of an enabling environment for the conversion of other private sector buildings and facilities into energy efficient modalities, and the assistance in the development of a national sustainable energy strategy and action plan.

Task 4 involves capacity building activities, both for the selected beneficiaries themselves and for various stakeholders and expert groups. As mentioned, the CEDRO IV project features the implementation of several demonstration pilot projects in renewable energies: low & medium penetration PV-Diesel Hybrid Power Plants, bioenergy based on forestry residues and Ground source heat pump. For the promotion of these types of technologies, the need of guidelines to promote and support the awareness has been identified.

Within the CEDRO 4, Trama TecnoAmbiental (TTA) is providing Professional Services of the Technical Backstopping. TTA is an engineering and consultancy firm based in Barcelona, Spain, with more than 25 years in the field of renewable energies and with experience in the design and installation of grid-connected photovoltaic plants and off-grid microgrids.

3. Introduction

This Guideline on Net Metering aims to be a practical manual for installers and evaluators of embedded PV plants designed for self generation and to back feed any excess production to the grid under a net metering scheme with the distribution utility. To harness the benefits of net-metering programs is also important to consider the integration requirements of the inverters, mainly those related to safety and quality of service. Besides technical considerations on grid integration and the connection point, the guidelines focus on the appropriate meters and suppliers, as well as providing with advice about administrative aspects such as the options for billing periods.

4. Overview

The guideline serve as a basis to asses new renewable energy based distributed generation plants, interconnected to the low voltage (LV) up to 600 V, or medium voltage (MV) distribution grids up to 34.5 kV, and designed to operate under the net metering scheme. The connection of the distributed power plant to the LV or MV grid depends on the total installed capacity of the plant. Table 2 presents some typical values in net-metering programs.

DG capacity	LV distribution	MV distribution	HV distribution
< 100 kW	X		
100 - 400 kW	X	X	
400 - 6,000 kW		X	
6,000 - 15,000 kW		X	X

Table 2: Distributed generator ranges reference and recommendation for distribution line coupling (source: Dubai DEWA)

The interconnection of DG plants requires careful technical considerations regarding possible negative effects in the grid. Concerns regarding voltage fluctuations, power quality and overall stability of the centralised grid are usually addressed via standards and advanced controls. Besides those technical issues, the interconnection of DG plants should be also analysed under a legal, tariffing and billing points of view. These guidelines focus on the technical and billing considerations in the Lebanese context, where an improperly monitored adoption of the distributed PV systems creates risks on grid stability. Some of the motivations to require standards for PV installations are as follows:

- Guarantee safety for the users and installations where the power generation units are installed.
- Protect the network (shared asset) from undesired voltage or current injections.
- Protect the distribution system and other users from undesired operations. For example, islanding or reconnect after electric fault.

These standards address issues like protective functions and automatic disconnection from the distribution grid interface when detecting grid parameters outside of the established values (anti-islanding and ride through functions). Also, power quality issues like harmonic distortion, flicker, DC injection and electromagnetic interference are regulated through standards.

The differentiation between the standard's objective is important when considering adaptation for a local implementation. For instance, building standards can have different requirements in Lebanon and European countries. Moreover, standards concerned with grid interaction must be adapted to the parameters seen in the local systems, and tune these regulations to permit successful integration.

5. Applicable Standards

PV installations are subject to different standards depending on their jurisdiction and usually the standards are set in larger markets like United States or Europe. In the Lebanese context, European made inverters are more common; nevertheless, a review of the applicable standards will help inform the decision-making process:

American

- UL: Safety standards from the equipment perspective

1. UL 1741 Covers Power Conversion and Protection Equipment

- IEEE: Interconnection standards, grid compatibility and many others

1. IEEE 1547 Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

- NFPA: Safety standards from the installation perspective (mostly to avoid fires)

European

- IEC 61727:2004 Photovoltaic (PV) systems – Characteristics of the utility interface
- IEC 62116:2008 Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters
- IEC 60364-7-712: Electrical Installations of Buildings: Requirements for Special Installations or Locations – Solar Photovoltaic power supply systems
- IEC 61683 (Power conditioners – Procedure for measuring efficiency

Considering that the most relevant standards for Lebanon are the IEC/European, a review of their applicability can inform decision makers better about the implementation. Some of the standards mentioned in the review are local adaptations of the IEC to local countries. For example, VDE standards are the German adaptation of IEC and IEEE standards. The relevant European standards that can be used as guidance for the Lebanese context are as follows:

• LV connections, the protections shall be chosen and installed according to the criteria and rules set by the standards of the series IEC 60364 “Electrical installations for buildings”.
• A complete standard for the connection of the inverters to the LV distribution grid is the VDE-AR-N 4105:2011-08 “Power generation systems connected to the low-voltage distribution network. Technical minimum requirements for the connection to and parallel operation with low-voltage distribution networks” which is followed by most PV inverter manufacturers and installers.
• EN 50160 “Voltage Characteristics in Public Distribution Systems” defines the values and limits of each of the principle characteristics of the voltage supplied by a LV (low voltage), MV (medium voltage) and HV (high voltage) public network at the users’ connection point.
• The standard IEC 61000-4-30 describes the method of measurement of grid quality parameters: frequency, voltage, harmonics, unbalance and flicker.
• For MV connections, the standards IEC 60255 “Measuring relays and protection equipment” and IEC 61936-1:2010 “Power installations exceeding 1 kV a.c. - Part 1: Common rules” shall apply.
• The IEC 62116:2014 “Utility-interconnected Photovoltaic Inverters – Test Procedure of Islanding Prevention Measures” provides safety requirements, as well as the IEC 60870 “Telecontrol Equipment and Systems” and 61850 “Power Utility 1417 Automation” should be also considered.

Additional standards concerning the interconnection and interoperability of distributed generation plants can be found in the report “Guidelines on PV-Diesel Hybrid Power Plants”, previously published by the EU funded UNDP-CEDRO IV Project.

6. Technical Considerations

The design, installation, maintenance, and operation of the generation facility shall be conducted in a manner that ensures the safety and security of both the generation facility and the distribution grid. Table 3 summarises the guidelines for the DG plants depending on their installed capacity.

Maximum Capacity	Need for an external interface protection	Connection scheme	Contribution to reactive power generation	Contribution to active power limitation	Low voltage ride through (LVRT) capability	Need for a transformer	Remote control	Remote monitoring
<10 kW	No	-	Limited	Required	Yes	Only if the DC component in the output current may not be limited otherwise	Not required	Not required
< 20 kW	Yes	-	Required	Required	Yes	Only if the DC component in the output current may not be limited otherwise	Required	Not required
< 100 kW	Yes	Backup to I.P. trip required	Required	Required	Yes	Only if the DC component in the output current may not be limited otherwise	Required	Not required
< 400 kW	Yes	Backup to I.P. trip required	Required	Required	Yes	if the DC component in the output current may not be limited otherwise, but always recommended	Required	Required
> 400 kW	Yes	Backup to I.P. trip required	Required	Required	Yes	Mandatory	Required	Required

Table 3: Main considerations depending on capacities of DG plant (source: based on Dubai DEWA)

6.1. Interface protection

The owner of the distributed system shall ensure the automatic disconnection of the generation facility from the distribution grid, when the grid parameters are outside the allowable thresholds with regards to Voltage and Frequency. For this, the generation plants should be equipped with automatic disconnection means from the grid. The protective functions can be either embedded in the inverter or can be external switchgears. If the plant's function is also backup, the protective functions can be an internal transfer/synchronisation switch in the inverter or an external transfer switch at the point of connection to the distribution grid.

6.2. Inverters

The inverters shall be provided with an IP65 enclosure for outdoor application and IP20 enclosure for indoor application. In this latter case, lower protection grades shall only be permitted if the characteristics of the room will be properly conceived to protect the equipment. The inverter shall be able to withstand the maximum temperatures with effective heating dispersion and with a power derating smaller than or equal to 25% of its rated power as determined for an ambient temperature of 50°C at the DC design voltage. This is the maximum outdoor temperature at which all equipment, apparatus, materials and accessories used in electrical installations can operate with satisfactory performance.

When placed outdoors, measures should be taken to prevent the increase of the inverters' internal heating (e.g. protections against direct exposition to the sun and installation of shades if needed). Alternatively, they should be placed in rooms or enclosures with effective ventilation, where the ambient temperature shall be kept below the value which determines a power de-rating equal to 25% of the inverter rated power at the DC design voltage.

6.3. PV generator

PV arrays for installation on buildings shall have maximum voltages lower than 1,000 Vdc. All the equipment (PV modules, inverter, cables and auxiliaries) shall withstand the maximum voltage of the array. Arrays with voltages which exceed the abovementioned value of 1,000 Vdc (but not exceeding 1,500 Vdc) may be allowed only for ground mounted solutions, canopies, urban design and any other solutions that do not involve the installation of PV modules, inverters or other related equipment on buildings' roofs. In any case, all the equipment must withstand the maximum voltage reached for the PV generator.

The PV generation facility's AC voltage, current and frequency shall be compatible with the distribution grid. In any case, the disconnection of the plant should be done according to specific functions and settings, including (EDL agreement):

• Over and under voltage trip functions and over and under frequency trip functions.
• A voltage and frequency sensing and time delay function to prevent the generating plant from energising a de-energised distribution grid and to prevent the generating plant from reconnecting to the public distribution grid unless the grid's service voltage and frequency are back within the rated range and are stable.
• A function to prevent the generating plant from contributing to the formation of unintentional islanding (anti-islanding) and to cease to energise the grid automatically when it detects a power outage.

6.4. Distribution Grid parameters for grid interaction.

The nominal output voltage wave form of the PV power Plant shall be of 230/400 V, 50 Hz, with a sinusoidal wave form complying with a THD < 5%.
In large interconnected plants, a typical voltage tolerance band for unrestricted generator operation is ±10% of the nominal value and around ±2% of the frequency. However, in distributed PV systems, wider frequency and voltage tolerance are required because the variations can be larger than in a transmission grid with a dedicated line. Experience indicates that narrow disconnection requirements should be avoided in these types of system to avoid unnecessary reconnections of the PV panels to the grid.
According to German standards VDE-AR-N 4105:2011-08 "Generators connected to the low-voltage distribution network - Technical requirements for the connection to and parallel operation with low-voltage distribution networks", the disconnection thresholds for generating plants connected to the low voltage distribution grid, concerning the voltage and frequency of the grid are the following:

Voltage:
• Voltage drop protection: The inverter needs to disconnect from the grid in less than 200 ms when the voltage is lower than 0.8 the nominal voltage of the grid.
• Rise-in-voltage protection: The inverter needs to disconnect from the grid in less than 200 ms when the voltage is higher than 1.15 the nominal voltage of the grid.

Frequency:
• Frequency decrease protection: The inverter needs to disconnect from the grid in less than 200 ms when the grid frequency is lower than 47,5Hz. The frequency measurement method is not specified.
• Frequency increase protection: The inverter needs to disconnect from the grid in less than 200 ms when the grid frequency is higher than 51,5Hz. The frequency measurement method is not specified.

Islanding protection:
• The detection of the isolated network and the disconnection from the grid of the inverter needs to be done in less than 5 seconds.

For all those protection functions, the tolerance between the setting values and the actual tripping values must not be higher than +/-1% for voltage and +/-0.1% for frequency.

Harmonics:
For plants with an output current I ≤ 16 A per phase, the harmonic components of the current produced and measured at the output terminals shall comply with the standard IEC 61000-3-2 "Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)".
The limitation of voltage changes, voltage fluctuations and flicker shall comply with the standard IEC 61000-3-3.

For all the plants connected to the LV grid, the voltage quality measured at the Point of Connection shall be in accordance with the IEC 61000-2-2 “Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems” and IEC/TR 61000-3-14.

Current:
The inverter shall not contribute to fault currents in the network, nor inject any additional reactive current during voltage dips. According to the IEC 60364-7-712 “Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems” for overcurrent protection for strings, sub-arrays or arrays: The rated current (In) of overcurrent protective devices for PV strings are determined by formula:

$$1.5 \times I_{SC\ string} < I_n \leq 2.4 \times I_{SC\ string}$$

The rated current (In) of overcurrent protective devices for PV sub-arrays or arrays are determined by formula:

$$1.25 \times I_{SC\ array} < I_n \leq 2.4 \times I_{SC\ array}$$

For plants interconnected to the medium voltage distribution network, the disconnection times should be programmed as follows (source: Dubai):
• Voltage drop protection: The inverter needs to disconnect from the grid in less than 200 ms when the voltage is lower than 0.3 the nominal voltage of the grid.
• Rise-in-voltage protection: The inverter needs to disconnect from the grid in less than 600 ms when the voltage is higher than 1.20 the nominal voltage of the grid.

Following the disconnection, the DG unit shall not be reconnected to the Network before the Voltage at the Connection Point is within the range 95% - 105% of nominal Voltage during a minimum of 60 seconds. The Active Power Output shall not be recovered with a gradient above 20% of the Maximum Capacity per minute.

Harmonics
For plants with an output current I > 16 A per phase, the harmonic components of the current produced and measured at the output terminals shall comply with the standard IEC 61000-3-12 “Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase”. The limitation of voltage changes, voltage fluctuations and flicker shall comply with the standard IEC 61000-3-1 ”Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection·.
At the network assessment stage, a special harmonic evaluation shall be performed to verify that an MV-connected plant does not contribute to exceed the harmonic content limits at the Point of Connection.

It is assumed that DC section(s) in the plant are separated from the MV AC section by an MV/LV transformer. Therefore, no DC currents injection shall be possible from DC/AC converters to the MV grid.

6.5. Metering

There are two meters necessary when connecting the plant either to the low voltage or medium voltage grid: one bidirectional meter recording energy injected to the grid and the energy demanded from the grid (with current transformer when connecting to the medium voltage) and a second one recording the produced energy of the renewable energy plant. In the case of connection at the medium voltage, an automatic transfer switch is placed at the production side to disconnect the production plant in an event of a grid disturbance and avoid unintentional islanding. The meter should be positioned in a place within the generator’s facility which allows easy access for the authorised personnel to perform necessary readings or maintenance. In order to ensure symmetrical feeding to the MV grid, it is recommended to install three-phase inverters.

Meters adopted for net metering applications are active and reactive energy metering devices in all four quadrants, i.e. they measure and record both imported and exported energy within the predefined billing period. Those meters have an internal relay for disconnection of user and, optionally, a current transformer (CT) for medium voltage connections. Some meters offer the possibility to communicate with a SCADA software for monitoring purposes, remotely display the data logging or save them to a web server and bill the customers without the need for on-site meter reading. Additionally, the SCADA can remotely configure the parameters of the meters and change any configurations. Meters with four quadrants are either single-phase or three-phase directly connected or through a transformer. Additionally, meters can include load control functions when equipped with a ripple control receiver. Reference specifications are presented in Table 4.

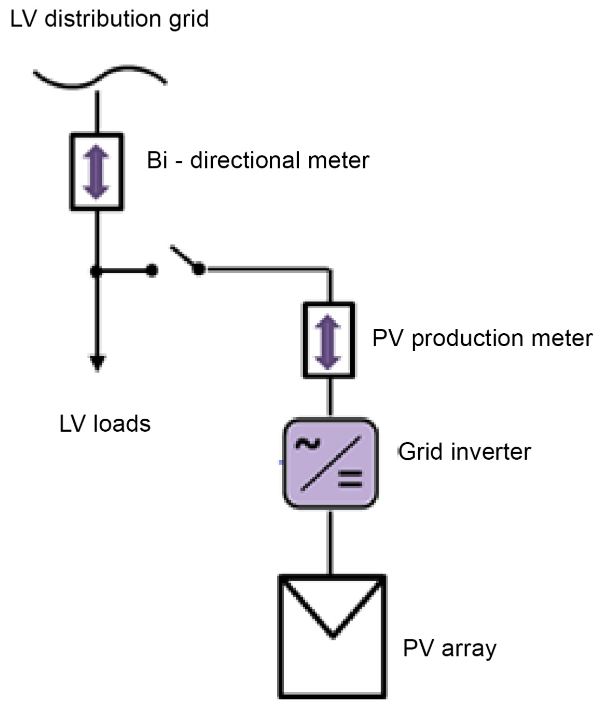


Figure 2: Connection scheme of PV plant for net metering connected to the low voltage grid

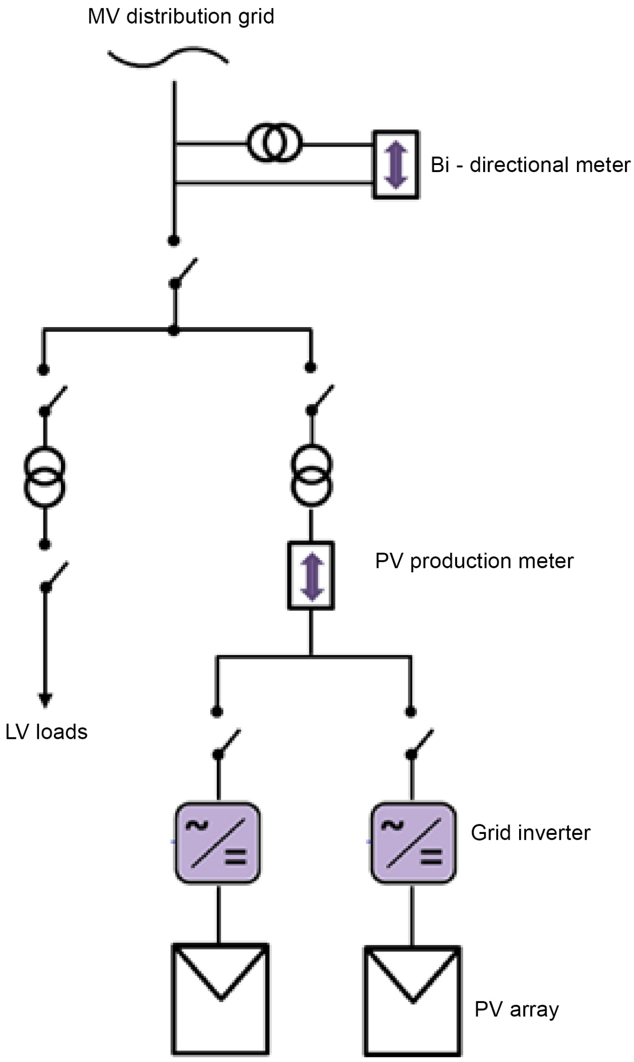


Figure 3: Connection scheme of PV plant for net metering connected to the medium voltage grid

Examples of events registered by meters can be power outage, power over-limit, reverse current flow, influence of magnetic field, opening of meter cover, opening of terminal cover, clock setting, parameter change, internal error and firmware update.

Suppliers of meters (adapted from Greek code) are found in Table 5.

Meters shall be sealed by the utility under the presence of the prosumer or a representative. The utility can break the seal during testing or maintenance and reseal it also under the presence of the prosumer or representative.

Characteristic	Single-phase	Three-phase	Three-phase with CT
Quadrants	4		
Nominal voltage	230 V	3x230 (400) V	
Tolerance	80% - 115% Vn		
Nominal frequency	50 Hz		
Tolerance	±5%		
Self-consumption	< 2W		
Nominal current In	5 - 10 A	5 - 10 A	5 A
Maximum current Imax	40 - 80 A	100 - 125 A	6 - 10 A
Minimum current Imin	< 0.5 x In		
Start-up current Ist	< 0.04 x In		< 0.001 x In
Accuracy: Active energy	IEC 62053-21 class 1 and 2, EN 50470-3 class B		IEC 62053-22 class 0.5s, EN 50470-3 class C
Accuracy: Reactive energy	IEC 62053-23 class 2		
IP	20 without protective enclosure 51, 53 in protective enclosure		
Operating temperature	-25ºC – 70ºC		
Humidity	95%		
Standards	EN 60101, EN 50470-1, EN 50470-2		
LED pulse frequency	1000 imp/kWh		10.000 imp/kWh
Communications	RS-232, RS-485, Ethernet, Modbus RTU, DNP 3.0, Infrared, GSM/GPRS, DLMS, IEC62056-21, Zigbee		
Measurements	• Active power • Reactive power • Apparent power • Power factor • Current • Voltage • Frequency		
Tariff rates	1-6		
Extra features	Anti-tamper, event logbook		

Table 4: Specifications and recommended ranges for meters

Manufacturer	Single - phase	Three - phase
Siemens	9300 Series	
Landis & Gyr	EM1200, ZCF120	ZMD310, ZMG310, ZMD410CT, ZMG410CT
Elgama Elekronika		EPQS, GAMA300, G3B144
Itron		ACE6000, SL7000
EDMI	ATLAS Mk7A	ATLAS Mk10A WC or CT
EMH		NXT4, LZQJ-XC
Circutor	Cirwatt B410	Cirwatt B410T

Table 5: Benchmarking of meters and suppliers

6.6. Electrical protections & cabling

The following paragraphs include the main considerations concerning the electrical protections needed in a net-metering facility, to prevent any damage to the equipment, the cabling or the people.

6.6.1. Admissible current – Overload

The cables of the installation should be able to carry a nominal current permanently to temperatures of up to 90ºC. Higher values will age the insulation material faster than expected and will represent a risk for the installation. Several overloads are permitted over short periods of time; usually an overload factor is considered (1.25 or 1.3) to avoid tripping. The amount of the dissipated heat varies depending on the application of the cable and its location, i.e. whether it is into a tube, into a tray, with multiple other cables, into the wall, etc. Several tables are available in various standards like the Spanish REBT-19 or the IEC 60287 “Current Capacity of Cables - Rated Current”.

6.6.2. Short circuit protection

The selection of the short circuit (SC) protection should consider both the maximum and minimum SC, i.e. protections should be installed with the ability to stop very high or very low flows of current, respectively. The maximum short circuit should be measured or calculated with the impedance of the cable installed from the MV transformer. Usually the SC current with no impedance (i.e. only the transformer impedance) added is 12 kA. The protections have standardised values of 4 kA, 6 kA or 10 kA and should be selected depending on the impedance from the point of connection. The short circuit current can be calculated as a line-to-neutral fault or line-to-line fault (i.e. 230 V for single phase or 400 V for three phase divided by the impedance).

The minimum short circuit should take into consideration the longest and least cross section line. The short circuit current at that point should be enough to make the magnetic circuit breaker trip. If the value is not sufficient, then the cross section has to be increased or the nominal value of the protection decreased.

6.6.3. Voltage drop

Voltage drop across resistances, conductors, connectors and contacts causes energy to be dissipated. The higher the drop voltage is, the more the energy generated will be dissipated into the air in terms of heat.

The voltage drop depends on the cable cross section and distance to the energy meter, or the impedance of the line and the impedance of the connection point of the inverters. If the impedance is too high, there is a large voltage drop, which causes the inverter to see an overvoltage into its terminals. Thus, the inverter will limit its power and then disconnect due to overvoltage.

One solution to avoid such disconnection is to reduce the grid impedance (from the inverter terminals) by upgrading the cross section and minimising the length of the cable. Ohmic losses should be considered when sizing cables and the recommended maximum voltage drop values are shown in Table 6.

Wiring distances	Recommended maximum voltage drop	Reference power
PV modules to PV inverter	3%	STC capacity
PV generator to PV charge controller	2%	STC capacity
Charge controller to battery	2%	STC capacity
Battery to autonomous or dual mode inverter	1%	Inverter 30’ rating
Autonomous or dual mode inverter to loads	5%	Inverter 30’ rating
Autonomous or dual mode inverter to main grid	1%	Inverter rating

Table 6: Maximum voltage drop for wire sizing (UNDP/CEDRO, 2013)

6.6.4. Overvoltage protection

When deciding on the surge protection device (SPD) installation, there is one rule of thumb that can be followed and takes into account the following aspects: the presence of a lightning rod within a radius of 50 m from the building and the distance from the connection point to the main switchboard. The next flowchart in Figure 4 shows a brief description of that rule of thumb. The DC and AC parts will be treated similarly in this case.

Briefly, it shows that if there's a lightning rod within a radius of 50 m there should be installed type 1+2 SPD at the entrance of the installation. If there is no lightning rod, only type 2 SPD is required. In addition, if the distance between the equipment and the previously installed spd's inside the building is higher than 10 m then type 2 or type 2+3 SPD should be installed. Type 3 spd will be installed if sensitive equipment (electronics) is present.

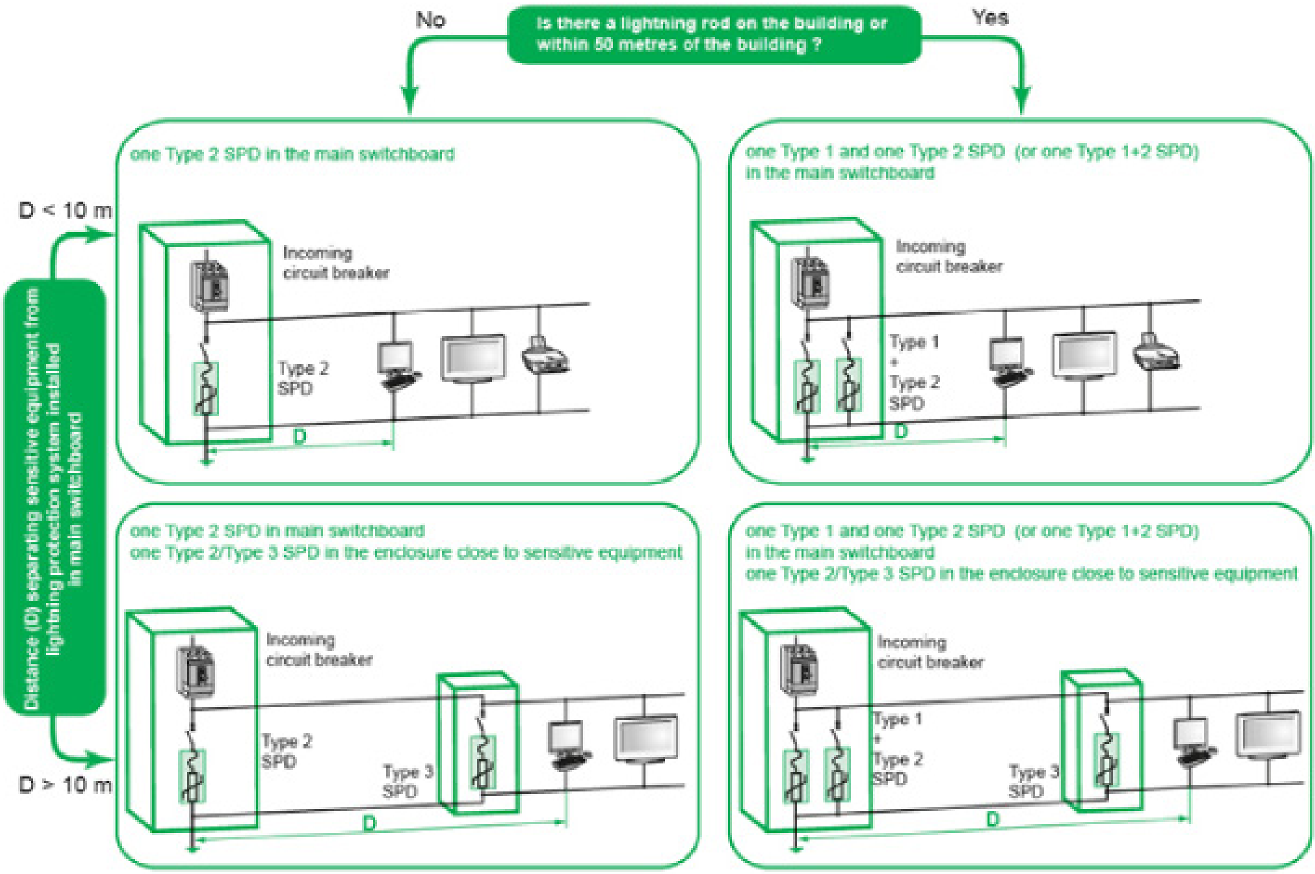


Figure 4: Quick selection guide for SPC (source: Schneider Electric)

6.6.5. Earth fault leakage protection

In order to avoid electrocutions and limit physical danger, all components of an installation should be Class II equipment, from standardised insulation material and all cable interconnections should be enclosed. However, most of the inverters are Class I so additional protection should be added (for indirect contact protection). Depending on the earthing distribution system, the protection will be calculated differently, being the residual current device (RCD) or the miniature circuit breaker (MCB) the main disconnecting device.

For earth fault currents higher than 300 mA, high risk of fire is stated. RCDs of that value or less are recommended for any electrical installation TT or TN.

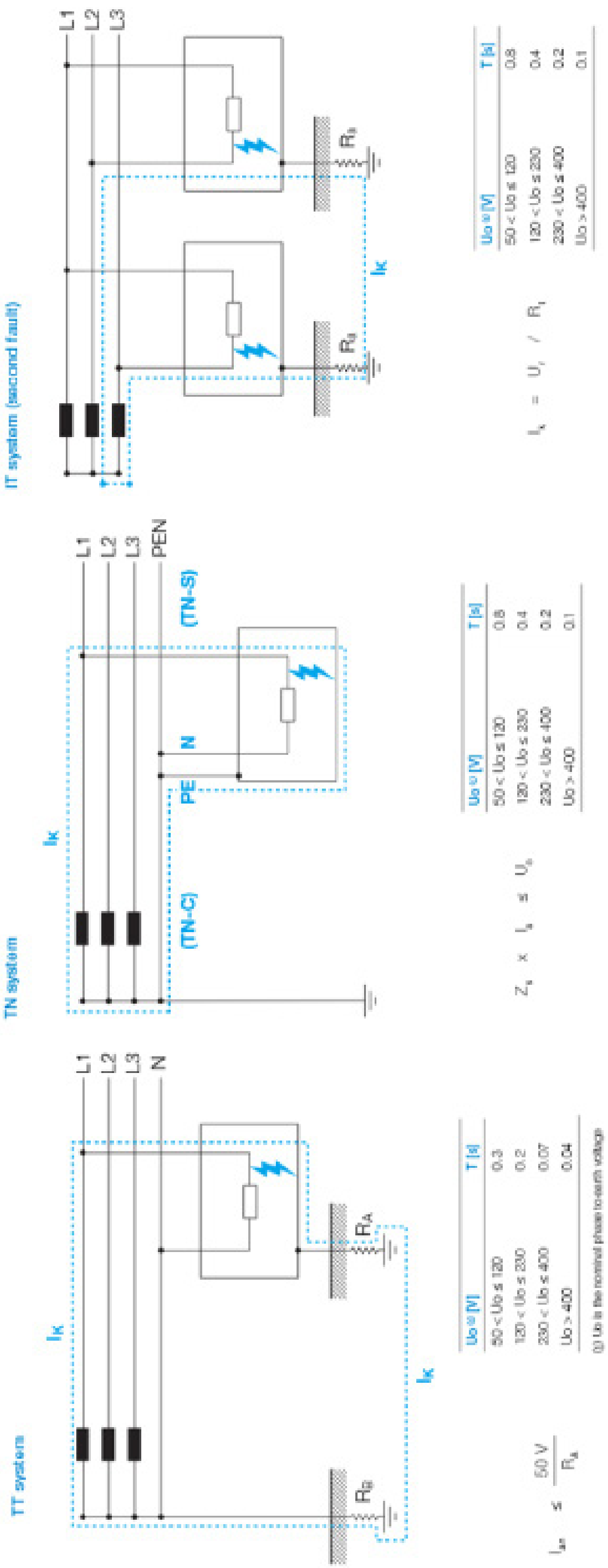


Figure 5: Voltage and time of available voltage at different earthing distribution schemes (source. ABB)

The limiting factor will be either the contact voltage or the maximum time of that voltage available for the users. For TN and IT systems, the impedance of the line and the magnetic curve of the MCB will be the critical point, whereas for TT systems it will be the earth loop resistance and the RCD sensibility.

For the inverters, there is a recommended type of RCD which will perform better. Following, a guide is presented on the RCD selection for protection requirements and waveform of the equipment.

Type of RCD	Type of protection		
	protection against indirect contacts (if Idn is coordinated with ground system)	additional protection (if Idn < 30 mA)	protection against fire risk (if Idn < 300 mA)
AC	■	■	■
A	■	■	■
F	■	■	■
B	■	■	■
A S (selective)	■		■
B S (selective)	■		■

Table 7: Selection table for RCD at different type of protection (source: ABB)

Type of RCD	Types of wave form detected by RCDs				
	alternating current 50/60 Hz	alternating current up to 1000 Hz	pulsating current with DC components	multifrequency current generated by the single - phase inverter	multifrequency current generated by the three - phase inverter
AC	■				
A	■		■		
F	■		■	■	
B	■	■	■	■	■
A S (selective)	■		■		
B S (selective)	■	■	■	■	■

Table 8: Selection table for RCD at different waveforms (source: ABB)

7. Billing

If during a billing period, the prosumer generates more electricity than demanded from the grid, then the difference is credited (1 credit equals to 1 kWh) to the following billing period. In this case, the prosumer is charged with any taxes or fixed chargers, for example for the maintenance of the distribution grid. On the contrary, if the electricity supplied by EDL exceeds the electricity exported by the prosumer plus any energy credits carried over from the previous billing period, the prosumer is charged this difference according to the applicable tariff per kWh and the rest of the costs.

Energy credits may be carried over from one billing period to another, for so long as the prosumer has a legal contract for the supply of electricity by EDL, up to a maximum of one year. This “net metering period” lasts for one complete year defined by the grid operator (in Lebanon it is defined from January 1st to December 31st). At the closure of the net metering period, the utility resets the net metering counter and starts all over from 0. If the balance is positive, accumulated credit cannot be transferred to the following year and is therefore lost.

In order to minimize lost credit and ensure that the prosumer is charged as few kWh as possible, it is very important to properly size the renewable energy generator accordingly to match the electricity production with demand.

Clients with high consumption are billed for their reactive power[1]. This is done when the connected system consumes reactive power, however, a distributed system works at FP1, which should not have reactive power. This is a general problem for industrial clients which becomes a matter of the configuration of the inverters.

As an example, it is assumed that a household typically consumes 6907 kWh of electricity annually and peaks in the summer season due to energy-intensive HVAC loads. It is estimated that such a demand can be covered by a 3.6 kWp PV plant under the climatic conditions of Beirut. The graph of the monthly production and demand is as follows in Figure 6: Energy production and consumption of a typical household with 3.6 kWp installed PV plant production with demand.

As an example, it is assumed that a household typically consumes 6907 kWh of electricity annually[2] and peaks in the summer season due to energy-intensive HVAC loads. It is estimated that such a demand can be covered by a 3.6 kWp PV plant under the climatic conditions of Beirut. The graph of the monthly production and demand is as follows in Figure 6: Energy production and consumption of a typical household with 3.6 kWp installed PV plant.

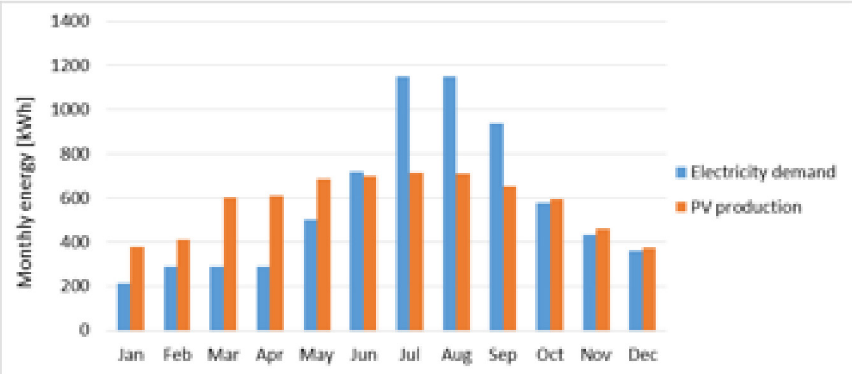


Figure 6: Energy production and consumption of a typical household with 3.6 kWp installed PV plant (Source: TTA)

The following table shows the monthly energy balance if the net metering period is one calendar year.
In the end of the calendar year, a household with strong summer profile will be charged for 726 kWh of net demand, besides any fixed charges.

Month	Demand [kWh]	Production [kWh]	Monthly balance [kWh]	Net metering [kWh]	Credit charged to prosumer [kWh]
Jan	216	378	162	162	0
Feb	288	408	121	282	0
Mar	288	601	313	595	0
Apr	288	610	322	917	0
May	504	685	181	1.099	0
Jun	719	697	-23	1.076	0
Jul	1151	713	-438	638	0
Aug	1151	710	-442	197	-442
Sep	935	651	-284	0	-284
Oct	576	595	20	20	0
Nov	432	459	27	47	0
Dec	360	373	13	60	0
TOTAL	**6907**	**6879**			**-726**

Table 9: Net metering balance for household metered from January to December

[1]: According to EDL, MV customers whose reactive power consumption exceeds 75% of their active power consumption, are penalized by billing them 50 LBP for each additional kvarh
[2]: Houri, Ahmad and Ibrahim-Kordali, Samira. Residential energy consumption patterns: the case of Lebanon. International Journal of Energy Research [Int. J. Energy Res. 2005; 29: 755-766]

8. Recommended practices to run a net-metering program

In order to execute a successful net metering program is important that the utilities are able to gather information regarding the installed systems. The information should be used to expedite the licensing processes and to keep a record of the main sources and locations.

Some of the recommended details that the utility should obtain are:

- Energy source information
- Main energy source: [Wind, Solar, Biomass]
- Expected daily and annual energy output [kWh]
- List of assets [Inverters, Batteries, Diesel Gen Sets]
- Load information
- Expected peak load (peak load when DG is not online) [kW]
- Expected net peak load (peak load most of the time) [kW]
- Expected daily and annual energy consumption [kWh]
- Feasibility study performed for larger systems.
-

Besides the details about the load curves and profiles relevant for planning purposes, the utility should collect information about the equipment used in the installation. Achieving this goal requires having a basic scheme of the plant's devices, as shown in Figure 7. In some cases, parts of the equipment are integrated into a single unit, for instance, DC disconnect is usually part of the inverter. Nevertheless, it is important for the utility to keep it as a separate unit and check for the proper operation when performing inspections.

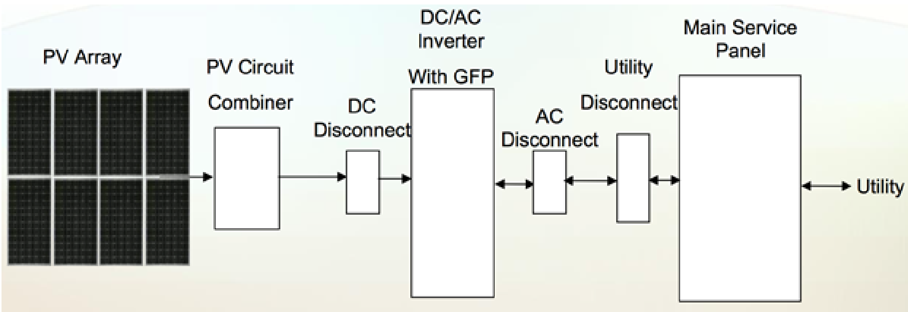


Figure 7: Minimum Equipment Required in the Installation

The most troublesome parameter in the control configuration is the anti-islanding configuration, as discussed in the previous sections, some standards can be adapted from different jurisdictions to meet the requirements in the Lebanese context, the recommended settings for interconnected plants for net-metering in Lebanon are showed in Figure 7.

Recommended Settings for Interconnected Net Metered Renewable Energy Micro Power Plants with Inverters

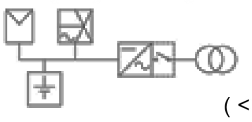
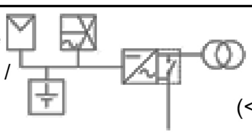
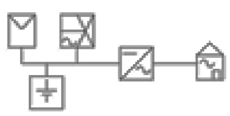
Type of Plant	References diagram (Single Phase)	Rated Current Nominal Power	Disconnection means	Voltage tolerance	Frequency tolerance	Trip disconnection time	DC Injection
B1: Grid dependent		(< subscribed demand)	- Inverter embedded stop function - Inverter external switch - External transfer switch	> 0.80 Um < 1.15 Um	> 45 Hz < 55 Hz	< 2s	< 0.5% ac current in nominal power*
B2: Dual mode Grid dependent / autonomous		Power 30 min (< subscribed demand)	- Inverter internal transfer synchronizing switch - Inverter manufacturer external transfer synchronizing switch	> 0.70 Um < 1.15 Um	> 45 Hz < 65 Hz	< 20ms	
A: Autonomous		Not Possible					

Figure 8: Recommended settings for grid-tied grid-dependent (B1), grid-tied dual mode (back-up) (B2) and autonomous plants for Lebanon (Source: CEDRO, TTA)

Any inverter compliant with IEC 62116 should be able to be configured with these parameters.
Other rules of thumb can be applied to expedite the interconnection processes in the early stages of the net-metering programs, for example:

- If the total daily energy produced exceeds 50% of the total daily energy demanded, it is likely that the system will require a deep interconnection study that should include:
- Power Flow analysis
- Max and Min expected voltages
- Short Circuit current analysis
- Protection coordination with the utility.

Finally, keep record of the plant's GPS coordinates [Lat, Long] is a fundamental step that informs the utility company to monitor the growth in adoption. It has been established that net-metering early adopters tend to cluster in areas where the installation of the PV systems is financially attractive. Considering that maintaining the grid is a responsibility of the utility, recording the location and detecting these clusters can inform for planning purposes where to invest first in advanced monitoring and grid enhancements.

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Beirut, Maarad street, Building 287 B, 1st floor, Lebanon
T/F: +961-1-981944
info@cedro-undp.org
www.cedro-undp.org