SYSTEM INSTALLATION GUIDELINES

1 Introduction

This guideline provides the minimum requirements when installing a Component based Solar home system where array size ranges from 100 Wp- 2 kWp. All systems to be installed shall be designed in accordance with the System Design Guidelines.

An Off-Grid PV System includes the following system configurations:

- d.c. bus systems that consist of solar array(s) connected to the batteries by solar controller(s) and battery inverter(s);
- a.c. bus systems comprising solar array(s) connected to the a.c. side of grid forming battery inverter(s) (a.c bus interactive inverter) by PV inverter(s) (grid interactive inverter);
- PV systems comprising both a.c. and d.c. bus configuration.

The array requirements are generally based on the requirements of IEC 62548: Photovoltaic (PV Arrays-Design Requirements.

Figure 1 shows the configuration of a system that provides d.c. power only. These systems typically shall have an array range less than 1 kWp. Most solar installations installed on rural and urban town residences (poor grid) use this basic design.

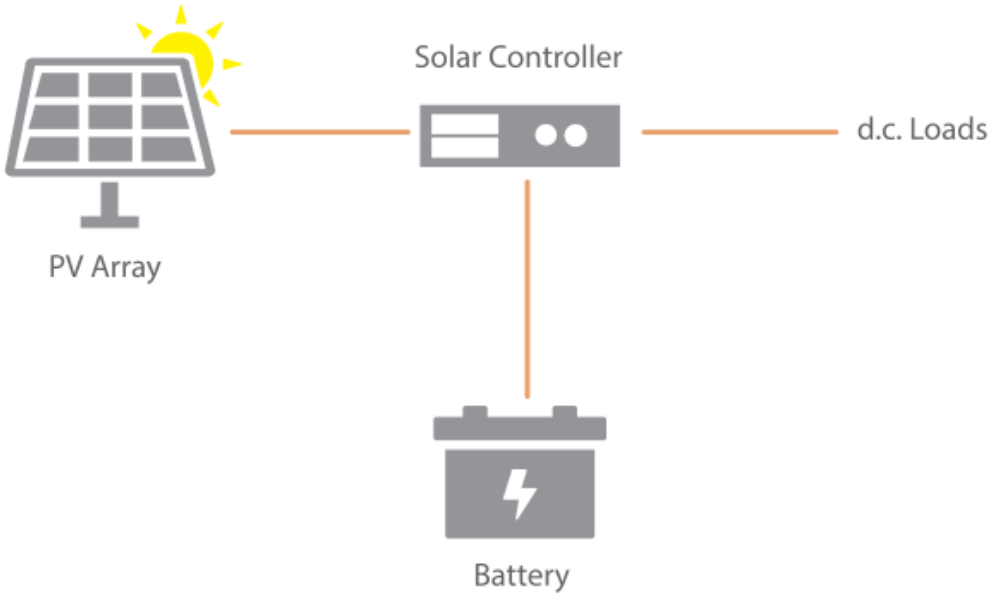

Figure 1: System providing d.c. loads only

Systems that include an inverter providing a.c. power to end-user can be configured as either:

- d.c. bus systems (refer to Figure 2); or
- a.c. bus systems (refer to Figure 3).

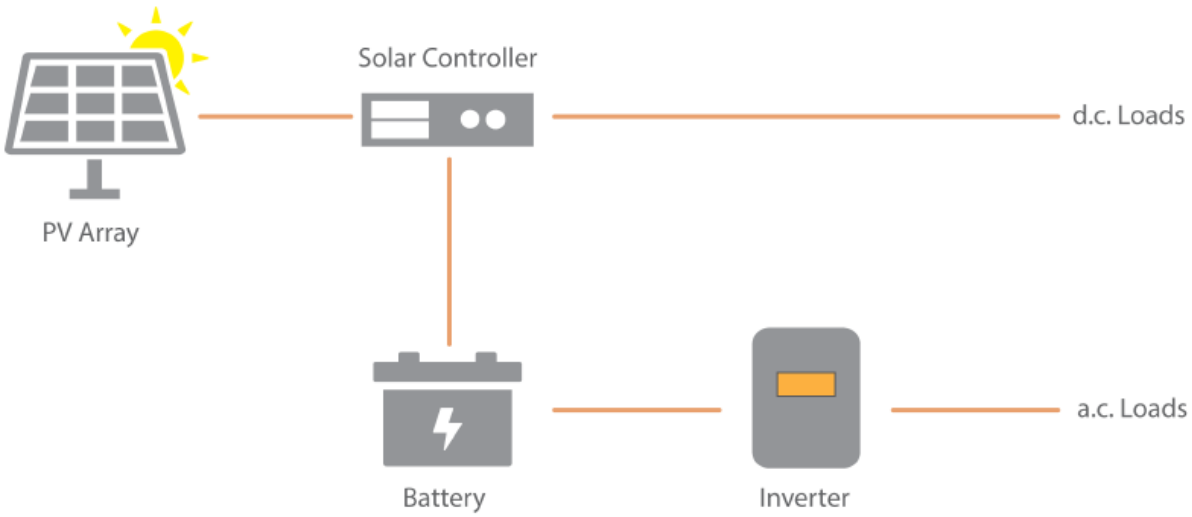

Figure 2: d.c. bus system powering d.c. and a.c. loads

Figure 3: a.c. bus system

Some systems can be a combination of a.c. bus and d.c. bus systems where part of the array is connected by d.c. through a solar controller to the battery and part of the array is connected directly to the a.c. load side via a PV inverter.

2 PV array installation

2.1 General

- Modules that are electrically in the same string shall all be in the same orientation.
- Even for latitudes less than 10°, a minimum tilt of 10° is recommended to take advantage of self-cleaning when it rains. Arrays mounted with a tilt less than 10° may require additional maintenance [cleaning] and this should be included in the recommended maintenance schedule.
- None of the modules connected in a series string should come under shadow during sunny hours that is from 90 minutes after sunrise and 90 minutes before sunset.

2.2 Orientation and tilt

In off-grid PV systems the solar array is generally mounted:

- on an array frame that is tilted to fix the array at a preferred angle (usually used for flat roofs or for ground mounting) or
- “flat” on the roof so it is parallel to the slope of the roof but raised off the roof, or
- on a pole mounted system separate from the building, or
- ground mounted if it is a large system.

Though the maximum output would be obtained using an array frame that is tilted to fix the array at the optimum angle (30-34 degrees for Pakistan), for practical reasons solar arrays are often mounted parallel to the roof in summers.

For best year-round performance, a fixed PV array typically should be mounted facing true south in Punjab and Sindh. The array should be tilted at a minimum of 30-34 degrees depending upon the latitude.

2.3 Roof Mounting PV

- If the modules use crystalline cells, then it is preferable to allow sufficient space below the array (> 150mm or 6 inches) for cooling by natural ventilation. Insufficient cooling will result in high module operating temperatures and lower outputs from the modules.
- It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris.
- All array supports, brackets, screws and other metal parts shall be of low-corrosion materials suitable for the lifetime and duty of the system and use materials that do not increase their rates of corrosion when mounted together in an array or when mounted on the surface of the underlying structure.
- Any roof penetrations must be suitably sealed and remain waterproof for the expected life of the system.
- All fixings must ensure structural security when subject to the highest wind speeds. The installer shall ensure that the array frame that they installed frame meets wind loadings appropriate for that particular location.
- Solar modules should be attached to the array structure either using the mounting holes provided by the manufacturer or via clamps that are suitable for the maximum wind at the site.
- The mounting of the PV modules should allow for the expansion and contraction of the PV modules under expected operating conditions.
- Where modules are installed in such way that a junction box is to the side or at the bottom, care must be taken to ensure this is permitted by the manufacturer.

3 Batteries installation

Batteries are a dangerous component in a PV system due to weight, explosive gases and potentially high fault currents. Their performance, life and reliability are affected by their location and climatic conditions. Correct placement and protection are paramount to minimising risk and maximising performance.

- The battery/ batteries must be installed in a dedicated enclosure. These enclosures can be boxes as shown in figures 10 and 11 or a on wall enclosure as shown in figure 12.
- The enclosure selected must ensure that mechanical protection is guaranteed and limits unauthorised access to the batteries.
- The enclosure shall shelter the battery terminals to limit access and prevent accident short circuits. As well, appropriate covers on battery terminals are recommended particularly for open enclosures (as shown in Figure 12)
- Sufficient space should be available within the enclosure to allow for ease of battery installation and maintenance.
- No uninsulated metal objects --- that could fall across battery terminals and cause a short circuit --- should be kept nearby.
- Explosive and/or corrosive gas-emitting battery systems: should not be located within 500 mm) horizontally of any other equipment from 100 mm below the battery terminals (Figure 9), except where there is a solid separation barrier
- No electrical equipment shall be mounted above explosive and/or corrosive gas emitting batteries.

- No metal devices shall be installed above the batteries or the battery enclosures. These could fall onto the batteries when the enclosure is open.
- The location where the batteries are installed should be dry.
- Batteries must be raised off the ground or concrete floor.
- The enclosure should not be located in direct sunlight and should be in a location that keeps the batteries as cool as possible.
- For valve regulated lead acid batteries, if possible, the outlet ventilation should be to the outside of the building in which the battery system is located. However, if this is not possible the room in which the battery enclosure is installed should be large enough to allow any emitted gases to easily disperse.
- Best practice is to provide the input ventilation vents on the enclosure wall below the level of battery and the output vents on an outside wall on the opposite side of the batteries as high as possible in the enclosure to prevent hydrogen build up.
- Li-ion battery types (LFP and NMC) are permissible to be included in the system. None other type of Lithium-ion battery is allowed to be packaged with CB-SHS.

4 Solar controller installation

The solar controller shall be installed as to the manufacturer`s instructions

- Installation of solar controllers (either PWM controllers or MPPTs) should be near batteries or at a convenient monitoring location as close as practical to the batteries.
- Never install controllers on top or above the enclosure of batteries that emit explosive gases, or near the ventilation vents.
- Solar controllers dissipate heat, there must be sufficient ventilation for these sensitive pieces of equipment.
- Always follow the manufacturer's recommendations for installation, ventilation and clearances around controller heat sinks.
- Solar controllers are not to be installed in direct sunlight.

5 PV Inverter Installation

The PV inverter shall be installed as to the manufacturer`s instructions.

- The PV inverter shall be installed in a location that is appropriate for the IP rating of the PV inverter. Where this is not possible then the PV inverter/s should be in an appropriate weatherproof enclosure that has adequate ventilation.
- PV inverters are not to be installed in direct sunlight.
- The PV inverter shall be installed with recommended clearances around the PV inverter as specified by the manufacturer.
- PV inverters should be installed in dust free locations;
- PV inverters can be heavy; it is important that the surface on which the PV inverters will be mounted is appropriately weight-bearing.
- The PV inverter heat sink shall be clear of any obstacles that may interfere with cooling of the PV inverter.
- Cables connected to the inverter shall be mechanically secured in such a manner that they cannot be inadvertently unplugged from the inverter. This can be achieved by:
    - Having the inverter housed in an enclosure (with cables suitably supported).

- The use of an inverter which has the cable connection area of inverter covered by a removable enclosure/cover which protects the supported cables so that there are no exposed, unsupported cable loops.
- The use of conduit and secure wall fixings:

- Where the inverter requires d.c. connectors to be used, a maximum allowable distance of no more than 200mm) of unprotected d.c. cable shall be permitted between connectors and conduit provided the location is not subject to mechanical damage.
- Where the inverter is exposed to the weather there shall be no open ends of conduit. If a cable is required to exit from a conduit, an appropriate cable gland shall be installed on the end of the conduit to ensure the IP rating is maintained.

6 Safe Installation practices

A dangerous situation occurs when the person installing the system is able to come in contact with the positive and negative outputs of the solar array or sub-array when the output voltage is rated DVC-C (that is greater than 120V d.c.). This could occur with d.c. bus systems using MPPT's as the controller or with a.c. bus systems using PV inverters.
Most systems use approved solar modules which are connected using double insulated leads with polarised shrouded plug and socket connections.

For a.c. bus systems or d.c. bus systems using MPPTs, a dangerous situation is only likely to occur at:

- the PV array switch-disconnector (isolator) before the PV inverter or MPPT ; and
- the sub-array and array combiner boxes (if used).

To prevent the possibility of an installer coming in contact with live wires it is recommended practice that one of the interconnect cables of each string (as shown in Figure 13) is left disconnected until all the wiring is complete between the array and the inverter. Only after all switch-disconnectors and other hard wired connections are completed should the interconnecting cable of the array be connected.
The installer shall ensure that all connectors used are waterproof and connected securely to avoid the possibility of a loose connection. Only connectors of the same type from the same manufacturer are allowed to be mated at a connection point.

When mounted on a roof, the solar module interconnect cables must be supported clear of the roof surface to prevent debris build up or damage to insulation.

Note: All national and regional rules and regulations with respect to protection of persons be followed in particular for installation of AC circuits.

7 PV array wiring

7.1 Selection of d.c. Cable for PV Array

PV string cables are those that interconnect modules in a string. The PV array cable is the cable between the array and the solar controller.

Cables used within the PV array wiring shall:

- Be suitable for d.c. applications.
- Have a voltage rating equal to or greater than the PV array maximum voltage determined in Table 2.

- Have a temperature rating appropriate to the application.
- If exposed to salt environments, used tinned copper, multi-stranded conductors to reduce degradation of the cable over time due to corrosion.
- In all systems operating at voltages above DVC-A, cables shall be selected so as to minimise the risk of
- earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables,
- particularly for cables that are exposed or laid in a metallic tray or metal conduit.

7.2 Installation of the PV array wiring

Plastic cable ties should not be used as the primary means of support.

- Cables shall not lie on roofs or the ground without an enclosure or conduit.
- All external wiring must be protected from UV either by using UV rated cables or installing the cables in enclosures/conduit.
- All conduits exposed to direct sunlight shall be suitably UV rated.
- The installer shall ensure that all cable connectors used are connected securely to avoid the possibility of a loose connection.
- Keep bending radius of cables more than 40mm or as recommended by module manufacturer.

7.3 Installation of Cable Between PWM Solar Controller and Battery

The cables between the PWM solar controller and the battery shall have a voltage rating greater than the maximum voltage rating of the battery when being charged.

- The current carrying capacity of the cable between the controller and battery shall be capable of carrying the maximum charge current from the array.
- The current-carrying capacity of the cable between the battery and solar controller shall be based on the d.c. current rating of the associated over-current protection.
- The d.c. cables between the solar controller and the battery bank can be single insulated if the battery bank is Extra Low Voltage (ELV).
- Cables and conduits shall be installed so that they are adequately supported.

8 Installation of Cable Between MPPT Controller and Battery

- The cables between a non-separated MPPT and the battery shall have a voltage rating greater than the maximum voltage of the array.
- The cables between a separated MPPT and the battery shall have a voltage rating greater than the maximum voltage of the battery.
- The current carrying capacity of the cable between the controller and battery shall be capable of carrying the maximum charge current from the MPPT.
- The current-carrying capacity of the cable between the battery and MPPT shall be based on the d.c. current rating of the associated over-current protection.

9 Installation of Cable Between Battery and Battery Inverter

- For systems using PWM solar controllers, the cable shall have a voltage rating greater than the battery voltage when being charged.
- For systems using a separated MPPT controller, the cable shall have a voltage rating greater than the battery voltage when being charged.
- For systems using non-separated MPPT the cable shall have a voltage rating greater than the maximum voltage of the array.

If the PV array has a rated output voltage greater than 120 V (DVC-C) and the solar controller is a nonseparated MPPT unit, the d.c. cables between the battery and the battery inverters shall be double. insulated.

8 Voltage drop

- The voltage drop between the PV array – charge controller and the battery bank should never exceed 5%
- The voltage drop between the battery bank and any d.c. load should never exceed 5%
- The voltage drop between the PV array and PV inverter should never exceed 3% (a.c. bus)

9 Location for Protection and Isolation in an Off-Grid PV system

- All cables shall be electrically protected from fault currents that could occur.

Notes:

- A PV array d.c. switch disconnector is recommended because it helps with maintenance and troubleshooting. However, many standards allow the battery bank switch fuse to meet the isolation requirement. A switch disconnector will be required to be a protection device (e.g., a non-polarised d.c. circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery bank.
- A load d.c. switch disconnector is recommended because it helps with maintenance and troubleshooting. However the battery bank switch-fuse can meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g., a non-polarised d.c. circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables.

10 Earthing (Grounding) of array frames for a PV Array

- All exposed metal module frames and array mounting frames shall be earthed (grounded) if the PV array has a PV array maximum voltage greater than ELV (DVC-C).
- Minimum cable size of 4 mm2 (NEC states it shall be no smaller than 14 AWG) shall be used but if the array structure is to be earthed (grounded) for lightning protection then it should be minimum 16 mm2 (6 AWG).

11 Commissioning

The commissioning sheets provided with these guidelines (Appendix 1) should be completed by the installer. A completed copy shall be provided to the customer as part of the system documentation and a copy retained by the installer that has been initialled by the customer showing it to be a true copy of the commissioning sheets provided to the customer.

11 Documentation

All complex systems require a user manual for the customer. The documentation for system installation that shall be provided includes:

- List of equipment supplied with each item's model, description and serial number.
- List of action to be taken in the event of any issues.
- Contact details of Focal person to be contacted for aftersales services or any other issues.
- Shutdown and isolation procedures for emergencies and for maintenance
- Maintenance procedures and timetable
- Commissioning sheet and installation checklist
- Warranty information
- System performance estimate including completed load assessment forms.
- Recommended maintenance procedures
- Equipment manufacturer's documentation and handbooks for all equipment supplied.

Appendix 1: Installation and Commissioning Sample

Installer's name	
Installer's signature	
Solar vendor's name	
Testing and Commissioning date	
Customer's name	
System Location (Address)	
MFI's name	
Equipment Data	
PV module manufacturer	
PV module model number	
PV module peak power rating (Wp)	
PV Module rated short circuit current (Isc) A	
PV Module rated maximum power current (Imp) A	
PV Module rated open circuit voltage (Voc) V	
PV Module rated maximum power voltage (Vmp) V	
Number of Modules	
Battery manufacturer	
Battery model:	
Battery Voltage V	
Battery Capacity Ah	
Solar controller manufacturer	
Solar controller model	
Solar controller input and output	
current rating A	

Solar controller voltage ratings V	
a.c. systems 3 phase or 1 phase	
Inverter manufacturer	
Battery Inverter Input current ratings A	
Inverter Input d.c. voltage rating V	
Inverter Power Rating W or VA	
Battery Inverter model	
Testing of System (System Not On Yet)	
Solar Irradiance at same angle of solar module W/m2	
Module No 1: Isc A	
Module No 1: Voc V	
Module No 2: Isc A	
Module No 2: Voc V	
Continuity between PV array, d.c. switch-disconnector and controller:	
Array Positive (Tick if correct	
Array Negative (tick if correct)	
Correct polarity between PV array and solar controller	
Continuity between solar controller, light switch and lights	
Positive (Tick if correct)	
Negative (tick if correct)	
Correct polarity between controller and d.c. loads (This could be expanded if testing d.c. circuits if they have been installed as part of system installation) Battery Voltage at Terminals (V)	
If 2V cells than this would be expanded to record each cell voltage	

Turn System On - including d.c. loads	
Array voltage at Controller input V	
Array current A	
Battery voltage at controller V	
Voltage at furthest d.c. load (array turned off) V	
Battery Inverter a.c. voltage V	
Solar charging the batteries (tick if correct)	
Controller operating correctly (tick if correct)	
Inverter operating correctly (tick if correct)	
d.c. loads operating correctly (tick if correct)	