SOLAR PHOTOVOLTAIC POWER SUPPLY SYSTEMS by John Ware

IT IS PLANNED for BS 7671:2008 to include a new Section 712 providing additional requirements for safety applicable to solar photovoltaic (pv) power supply systems. The additional requirements planned for inclusion in BS 7671:2008 along with some explanations are discussed in this article. As with any low voltage installation, the general requirements in Parts 1 to 6 of BS 7671:2008 have also to be met which include in Part 5, Section 551, requirements for low voltage generating sets.

Please note that a list of definitions is included at the end of this article.

The risks
The particular risks associated with solar photovoltaic systems are:

- PV systems cannot be switched off. Modules produce electricity when exposed to daylight. Hence, unlike most other electrical installation work, the installation of a PV system typically involves working on a live system. Regulation 14 of the Electricity at Work Regulations gives requirements that must be met. Special precautions should be made to ensure live terminals are either not accessible or cannot be readily touched during installation and maintenance. Such terminals will be live at all times during daylight hours. It is important that anyone opening an enclosure is aware of this.

- An electrician who has come to work on the electrical installation needs to be aware that there is a second source of energy which will also need to be isolated.

- PV modules are current-limiting devices which require a non-standard approach when designing fault protection systems for the dc side, as fuses are not likely to operate under short-circuit conditions. A different approach to fault protection is often needed, such as sizing the conductors for the maximum fault current that can flow at any given point in the circuit.

- PV systems include dc wiring, with which few electrical installers are familiar.

- PV presents a unique combination of hazards – due to risk of electric shock, falling and simultaneous manual handling difficulties. All of these hazards are encountered as a matter of course on a building site, but rarely all at once. While roofers may be accustomed to minimising risks of falling or injury due to manual handling problems, they may not be used to dealing with the risk of electric shock. Similarly, electricians would be familiar with electric shock hazards but not with handling large objects at heights.

The particular requirements of Section 712 of BS 7671:2008 apply to electrical installations of PV power supply systems which will only work when connected in parallel with an electricity supply. The requirements in this section are not intended for PV systems for standalone operation. The requirements are for PV systems assembled from items of equipment, not supplied as a complete unit.

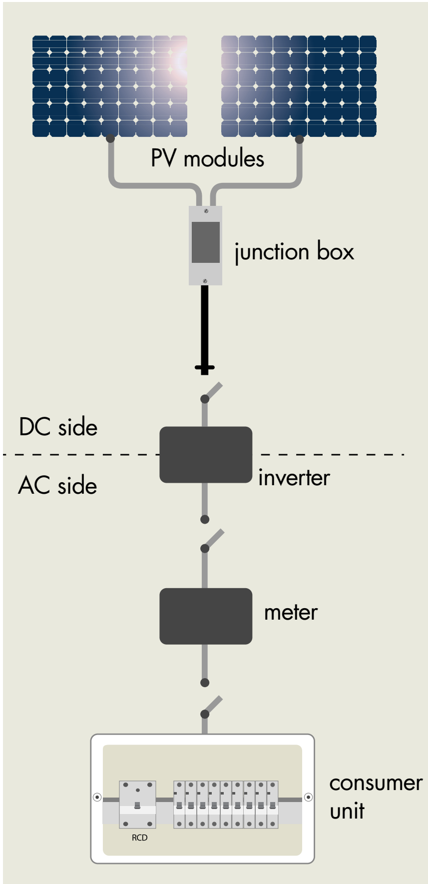

Figure 1: Block diagram of a PV system

The Electricity Safety, Quality and Continuity Regulations 2002
A solar photovoltaic (PV) power supply systems described in Section 712 is required to meet the requirements of the Electricity Safety, Quality and Continuity Regulations 2002 as it is an embedded generator. Where the output does not exceed 16 A per phase the PV system is considered as a small-scale embedded generator (SSEG) that is exempted from certain of the requirements provided that:

- the equipment should be type ▶

◀ tested and approved by a recognised body,

- the consumer's installation should comply with the requirements of BS 7671,
- the equipment must disconnect itself from the distributor's network in the event of a network fault, and
- the distributor must be advised of the installation before or at the time of commissioning.

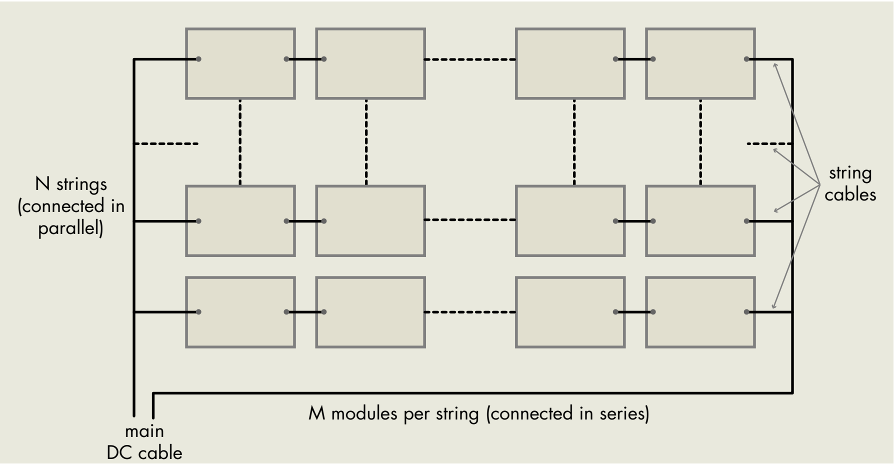

Figure 2: Simplified circuit of dc side

Connection of a PV system to the electrical installation

A PV system used as an additional source of supply in parallel with another source should preferably be connected on the supply side of all the protective devices for the final circuits of the installation. If a PV system is to be connected on the load side of all the protective devices for a final circuit of the installation additional requirements given in Regulation 551.7 of BS 7671: 2008 must be met.

PROTECTION FOR SAFETY

Protection against electric shock

PV equipment on the dc side must be considered energized, even when the system is disconnected from the ac side.

Protection by the use of Class II or equivalent insulation should preferably be adopted on the dc side. Protection by non-conducting location or earth-free local equipotential bonding is not permitted on the dc side.

On the ac side, the PV supply cable should be connected to the supply side of the protective device for automatic disconnection of circuits supplying current-using equipment.

Where an electrical installation includes a PV power supply system without at least simple separation between the ac side and the dc side, an RCD installed to provide fault protection by automatic disconnection of supply should be type B. B type residual current circuit-breakers provide specific protection of single and three-phase installations and people even in the presence of dc fault currents on the network generated by controllers and variable speed drives, battery chargers and inverters and power supplies

They are a requirement for single and three-phase supplied applications, where Class l equipment installed downstream from the RCCB is likely to produce dc component fault currents (pure dc fault). Type B RCDs also provide protection against sinusoidal ac residual currents (AC type) and pulsed dc residual currents (A type).

However, where the PV convertor is, by construction, not able to feed dc fault currents into the electrical installation, a type B RCD is not needed.

Protection by extra-low voltage: SELV and PELV

For SELV and PELV systems, $U_{OC\ STC}$ replaces Uo and must not exceed 120 V dc

Protection against overload on the dc side

Overload protection may be omitted to PV string and PV array cables when the continuous current-carrying capacity of the cables is equal to or greater than 1.25 times $I_{SC\ STC}$ at any location. Overload protection may be omitted to PV main cables when the continuous current-carrying capacity of the PV main cable is equal to or greater than 1.25 times $I_{SC\ STC}$ of the PV generator.

Protection against short-circuit current

The PV supply cable must be protected against short-circuit current by an overcurrent protective device installed at the connection to the ac mains.

Isolation and switching

To allow maintenance of the PV converter, means of isolating the PV converter from the ac side and the dc side must be provided.

ac side. Means of isolation should be provided on the ac side. A switch-disconnector should be installed adjacent to the inverter. The device should switch all live conductors and should be able to be locked off. A further means of isolation should be provided at the consumer unit or distribution board. At the point of installation of any ac isolator, the public supply should be considered as the source and the PV system should be considered as the load.

dc side. A switch disconnector must be provided on the dc side of the PV converter. The dc switch should switch all live conductors and must be suitably rated for the required dc operation. Switching ac is less demanding than switching dc – with an ac supply, the voltage passes through 0 V many times a second. A switch planned to be used on the dc side must be rated to break dc; an equivalent ac-rated switch is not acceptable or safe.

dc connectors. Connectors, where used to connect PV modules, PV strings or the inverter should be dc rated and touch safe (i.e. the IP rating should be not less than IP21). They should be of Class II design, shrouded and of a design totally dissimilar in appearance to any other connectors used in the installation.

Selection and erection

PV modules should comply with the requirements of the relevant equipment standard, e.g. BS EN 61215 for crystalline PV modules. PV modules of class II construction or with equivalent insulation are recommended if $U_{OC\ STC}$ of the PV strings exceeds 120 V dc The PV array junction box, PV generator junction box and switchgear assemblies should comply with BS EN 60439-1.

Electrical equipment on the dc side must be suitable for direct voltage and direct current.

PV modules may be connected in series up to the maximum allowed operating voltage of the PV modules ($U_{OC\ STC}$ of the PV strings) and the PV converter, whichever is lower. Specifications for this equipment shall be obtained from the equipment manufacturer.

If blocking diodes are used, their reverse voltage shall be rated for 2 x $U_{OC\ STC}$ of the PV string. The blocking diodes shall be connected in series with the PV strings.

As specified by the manufacturer, the PV modules should be installed in such a way that there is adequate heat dissipation under conditions of maximum solar radiation for the site.

Cables routed behind a PV array should be rated for a temperature of at least 80°C. Cable should be installed so as to minimise the risk or earth faults and short circuits. Cables should be sized such theat the voltage drop between the array and inverter is less than 3 per cent. External cables ▶

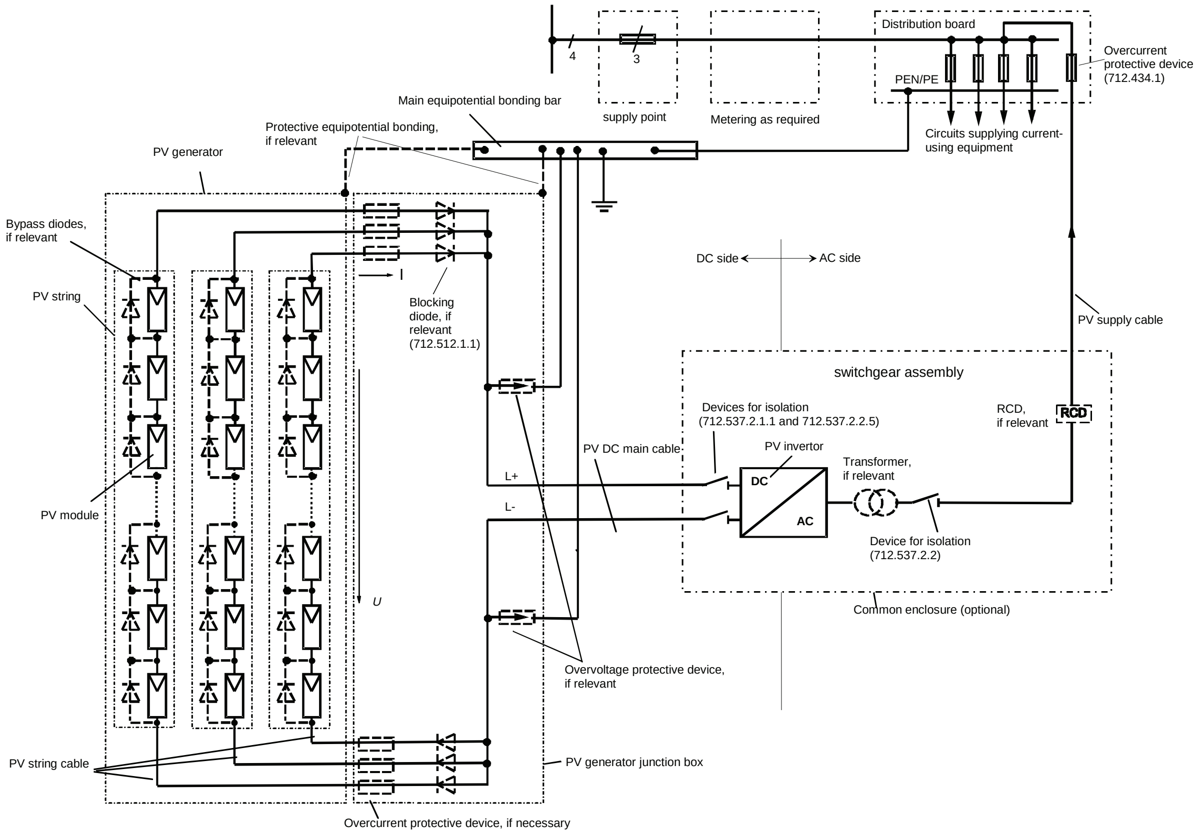

Figure 3: **PV system – general schematic, one array**

◀ should be UV stable, water resistant and flexible. For the dc system, it is recommended that Class II equivalent wiring, connections and equipment is used wherever possible as this will reduce fire risk.

PV string cables, PV array cables and PV dc main cables must be selected and erected so as to minimise the risk of earth faults and short-circuits. This may be achieved for example by reinforcing the protection of the wiring against external influences by the use of single-core sheathed cables.

The cable connecting the inverter to the consumer unit or distribution board must, as for any circuit, have overcurrent protection which includes both overload and fault protection.

The inverter should carry a current Engineering Recommendation G77/1 type test certificate. A key requirement is that the inverter will disconnect the PV system when the distribution system is not energised. This is to prevent the hazardous situation of the photovoltaic system feeding the network or local distribution system during a planned or unscheduled loss of mains. Such an event is termed 'islanding' and presents a potential danger to those working on the network/distribution system.

Accessibility. The selection and erection of equipment shall facilitate safe maintenance and shall not adversely affect provisions made by the manufacturer of the PV equipment to enable maintenance or service work to be carried out safely.

Earthing arrangements and protective conductors

Where protective equipotential bonding conductors are installed, they shall be parallel to and in as close contact as possible with dc cables and ac cables and accessories.

Lightning protection system

Where there is a perceived increase in risk of lightning strike as a consequence of the installation of a PV system advice should be taken from a lightning protection system specialist as to whether a separate lightning protection system should be installed. Additionally, if the PV array has a metal frame which is not required to be earthed because it is of Class II construction, advice should be taken as to whether it should in fact be connected to the Main Earthing Terminal when considering lightning protection implications. Where a lightning protection system is already

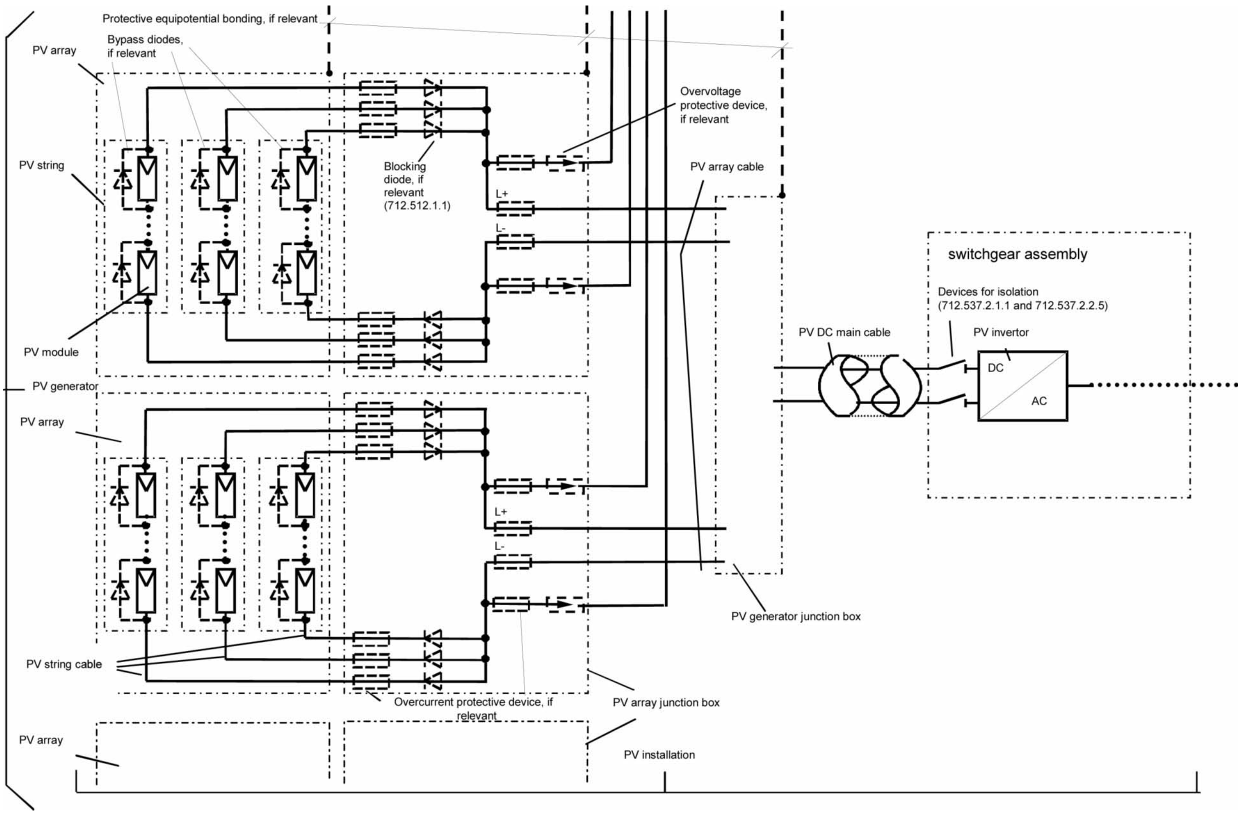

Figure 4: **PV system – general schematic with more than one array**

present, it is considered best practice to main bond the array frame to the Main Earthing terminal.

Where an LPS is installed or is to be installed, PV system components should be mounted away from lightning rods and down leads. Long leads, for example dc main cables connecting the array to the inverter that are over 50m in length, should be installed in earthed metal conduit or trunking.

To minimize voltages induced by lightning which could result in electromagnetic interference, the area of all wiring loops should be kept as small as possible.

LABELLING

Junction boxes. All junction boxes (PV generator and PV array boxes) must carry a warning label indicating that parts inside the boxes may still be live even after isolation from the PV converter.

The dc isolator should be labelled as 'PV array dc isolator', with the ON and OFF positions clearly marked. Switch enclosures should also be labelled with 'Danger, contains live parts during daylight'.

The ac isolator should be labelled as 'PV system isolator' with the ON and OFF positions clearly marked.

Additional source. As the installation includes a generating set, the PV system, which is used as an additional source of supply in parallel with another source, and warning notices should be affixed at the following locations in the installation:

- At the origin of the installation
- At the meter position, if remote from the origin
- At the consumer unit or distribution board to which the generating set is connected
- At all points of isolation of both sources of supply.

The warning notice should have the following wording:

WARNING - DUAL SUPPLY

Isolate both mains and on-site generation before carrying out work.

Isolate the mains supply at....................
Isolate the generator at..........................

All labels shall be clear, easily visible, constructed and affixed to ▶

◀ last and remain legible for the life of the installation.

Parallel operation
Further requirements with regard to a PV installation operating in parallel with the public supply system are given in Regulation 551.7 of BS 7671.

Definitions, and explanations
PV – Solar photovoltaic.
PV cell – Basic PV device which can generate electricity when exposed to light such as solar radiation.

A photovoltaic cell acts as a current source, hence PV modules are current limiting devices – even under short circuit conditions, the output current of a module will not rise above a certain level (Isc). Operating a module in short circuit is in general of little consequence, indeed many charge controllers in battery charging systems routinely short circuit an array output.
PV module – Smallest completely environmentally protected assembly of interconnected PV cells.

Some modules have an electrical output that is considerably higher during the first weeks of operation. This increase is on top of that produced by temperature/irradiance variation. Typically, operation during this period will take Voc, Isc (and nominal power output) well above any value calculated using a standard multiplication factor. To avoid oversizing for this eventuality the array could be left disconnected for that initial period. Refer to the manufacturer for this information.
PV string – Circuit in which PV modules are connected in series, in order for a PV array to generate the required output voltage.

PV module string circuits cannot rely on conventional fuse protection for automatic disconnection of supply under fault conditions. This is because the short circuit current is little more than the operating current – a fuse would simply not operate.

Figure 5: PV system

PV array – Mechanically and electrically integrated assembly of PV modules, and other necessary components, to form a dc power supply unit.
PV array junction box – Enclosure where all PV strings of any PV array are electrically connected and where protection devices can be located if necessary.
PV generator – Assembly of PV arrays.
PV generator junction box – Enclosure where all PV arrays are electrically connected and where devices can be located if necessary.
PV string cable – Cable connecting PV modules to form a PV string.
PV array cable – Output cable of a PV array.
PV dc main cable – Cable connecting the PV generator junction box to the dc terminals of the PV inverter.
PV inverter – Device which converts dc voltage and dc current into ac voltage and ac current.
PV supply cable – Cable connecting the ac terminals of the PV inverter to a distribution circuit of the electrical installation.
PV ac module – Integrated module/invertor assembly where the electrical interface terminals are ac only. No access is provided to the dc side.
PV installation – Erected equipment of a PV power supply system.
Standard test conditions (STC) Test conditions specified in IEC 60904-3 for PV cells and modules.
Open-circuit voltage under standard test conditions $U_{OC\ STC}$ Voltage under standard test conditions across an unloaded (open) generator, or on the dc side of the convertor.
Short-circuit current under standard test conditions $I_{SC\ STC}$ Short-circuit current of a PV module, PV string, PV array or PV generator under standard test conditions.
dc side Part of a PV installation from a PV cell to the dc terminals of the PV inverter.
ac side Part of a PV installation from the ac terminals of the PV inverter to the point of connection of the PV supply cable to the electrical installation.
Simple separation Separation provided between circuits or between a circuit and earth by means of basic insulation. ■