Solar photovoltaic (PV) power supply systems

This article looks to aid the understanding of some of the complex issues associated with PV installations.

By Mark Coles

Photovoltaic (PV) systems are unique. Common logic used in other methods of electricity generation, such as motor-generators, wind turbines, UPS and Stirling Engines cannot be applied. Significant changes are occurring in standardisation at international standard level where PV systems are concerned.

Standards

Section 712 of BS 7671:2008 is Solar photovoltaic (PV) power supply systems; the section is likely to remain largely unchanged in the first amendment of the standard, due for publication in June 2011. The origins of Section 712 of BS 7671:2008 can be found in IEC 60364-7-712 as no CENELEC HD currently exists. Note that IEC 60364-7-712 is intended to provide requirements for the installation of PV systems. Requirements for the equipment – IEC 62548 Installation and Safety Requirements for Photovoltaic (PV) Generators (currently in development by IEC TC 82) – will set out general installation and safety requirements for the PV equipment.

Systems

The Scope of Section 712 in BS 7671:2008 includes PV power supply systems including systems with a.c. modules but, currently, excludes any form of battery storage. There are many systems across the world that feature battery storage but no single standard has as yet been developed to reflect this.

System components

There are many possible configurations of PV systems but, first we'll look at the components and their function.

Modules

Photovoltaic or PV cells convert sunlight directly into

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PV system on open ground

electricity and generate d.c. A typical single PV cell is a thin semiconductor wafer made of highly purified silicon; crystalline silicon is the most widely used. During manufacture, the wafer is doped: boron on one side, producing a surplus of electrons; phosphorous on the other side, which has a deficit of electrons. When the wafer is bombarded by sunlight, photons in the sunlight knock off some of the excess electrons creating a voltage difference between the two sides as the excess electrons try to move to the deficit side. In silicon cells this produces an open circuit voltage of around 0.6 volts.

PV cells are interconnected to form a PV module. The module is manufactured with the cells laminated between a transparent front sheet (usually glass) to allow sunlight to pass and a protective waterproof material on the back. A module is the smallest commercially available unit bought as a panel.

Modules can be linked together to create a string, i.e. connected in series.

PV system incorporated into a building

Strings can, of course, be connected in a parallel formation to create an array.

Optimum operation is achieved when modules are in direct sunlight but electricity is still generated on cloudy days.

Depending on the location and land available, PV arrays are frequently roof-mounted, sometimes integrated directly into the fabric of a building, but they can also be fixed to framework on open ground.

Figures 712.1 and 712.2 of BS 7671:2008 show bypass

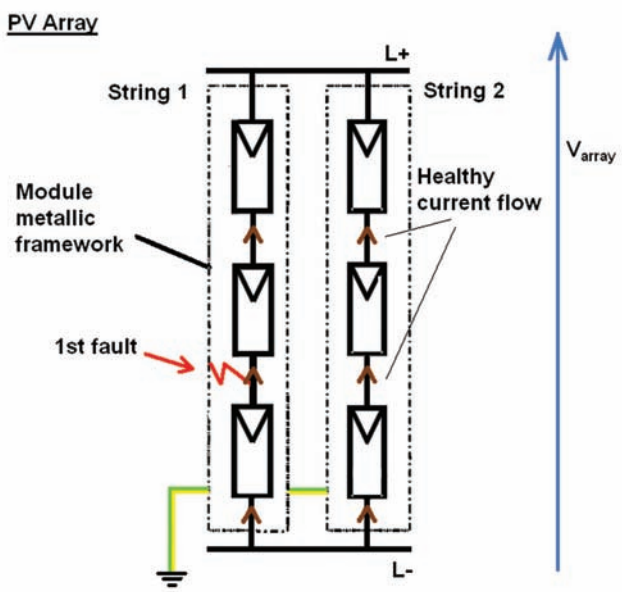


Fig 1 First fault on a PV array

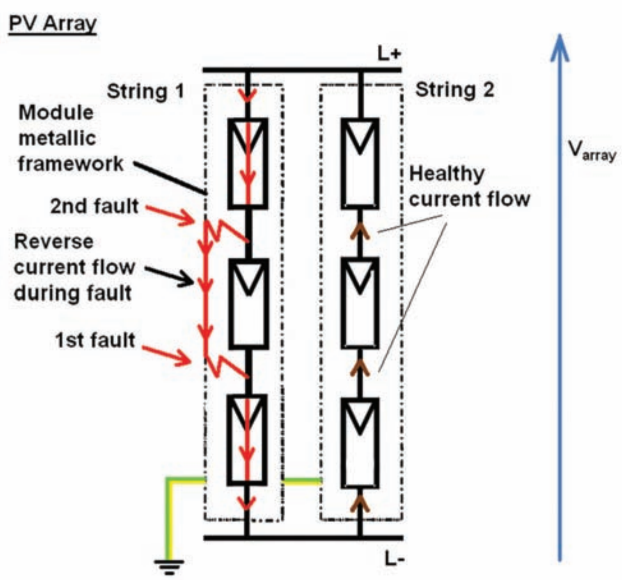


Fig 2 Second fault on a PV array

and blocking diodes and reference is made to blocking diodes in Regulation 712.512.1.1. Diodes, which pass d.c. in one direction only, are used to bypass or block reverse currents caused by faults.

Consider the scenario where a fault has developed on one d.c. module connecting a current-carrying part with the module's metallic framework, shown as first fault (Fig 1).

There are many PV configurations, for example, for functional reasons, some are earthed on the positive side whilst some on the negative . Some are referenced to the mains supply through a non-separated (transformerless) inverter and some are effectively floating. Note that Figures 1 and 2 show a floating system as neither conductor (L+ or L-) is connected to Earth. The module's metallic framework is shown to feature protective bonding as may be required in certain installations

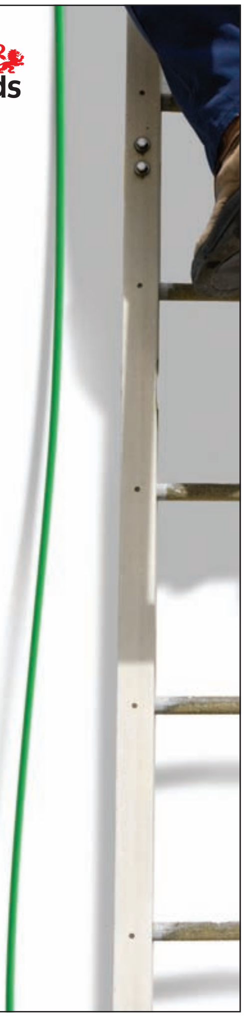
Unlike a TN-S electrical supply, for example, where the neutral or star point of a generator is connected to Earth, a PV system is effectively floating, hence, this first fault doesn't affect the operation of the array nor does it present any great risk of electric shock. The problems arise when a second fault occurs.

Depending on where the faults occur, circulation currents will flow and, as shown in Figure 2, modules can be driven into a reverse current situation. Each module will have a maximum permitted reverse current as stated by the manufacturer but, of course, the manufacturer has no idea where the fault will occur. High reverse currents will overstress and overheat the units which can result in fire if overcurrent protection is not fitted.

For a design where the number of parallel connected strings is such that the potential reverse fault current exceeds the manufacturers permitted reverse current, some form of overcurrent protection is required. This is usually achieved by the use of string fuses.

Blocking diodes can be installed in series with each string and are sometimes suggested as a method of preventing reverse currents that could result in such fires. Blocking diodes are prevalent in systems installed in Japan but evidence demonstrates that such diodes can fail to short-circuit (through voltage transients), which negates the reverse current protection without anyone being aware of the failure. Therefore, blocking diodes should not be used as a replacement for overcurrent protection in PV strings.

Bypass diodes are installed in parallel with modules to prevent reverse voltage conditions that could develop on modules as a result of shading, caused by, for



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Manufacturer's label fixed to a module

example, buildings obstructing direct sunlight, a covering of snow or array loading conditions.

The design of some types of modules require that one of the live conductors is connected to the main earthing terminal of the a.c. electrical system (functional earthing) as they need to be electrically biased in order to operate correctly. Such a conductor may carry current in the event of a first fault. To mitigate this issue, some manufacturers require that the functional earthing of their equipment is through a protective device which would operate upon detection of the first fault.

Much discussion has taken place within PV committees on how to deal with module failures and faults. Some inverters are pre-programmed to run an insulation resistance test initiated at sunrise just as the modules begin to generate. This is compounded by debates over the class of PV modules, i.e. whether they are class I or class II. Many manufacturers state that modules are class II but research on very large arrays has shown that, particularly on thin film modules, low resistance readings, e.g. 500kΩ on systems circa 1,000 modules, are common at daybreak. Module cracking and delamination can occur under some conditions, which compromises the module's insulation leading to opinions that modules are not class II. Once a first fault is found or detected it is paramount that owners of the system repair/replace/remove the faulty module immediately as research has shown that a second fault on that module is not far off.

Inverters

Inverters are used to change d.c. generated by PV modules into a.c for use on a.c. systems. The output of the inverter may, in some cases, be connected and synchronised to the local electrical distribution network and operate under the UK's feed-in tariff scheme (see *Wiring Matters* Autumn 2010 Issue 36 for more information) and also the Electricity, Safety, Quality and Continuity Regulations 2002 (as amended) (ESQCR).

BS 7671:2008 has a particular requirement for inverters in Regulation 712.411.3.2.1.2. The Regulation requires that if simple separation is not provided between the a.c. and d.c. side of the system then a type B RCD is to be installed to provide fault protection. Simple separation is a component part of Electrical Separation in Regulation 413.1.1:

413.1.1 Electrical separation is a protective measure in which:
(i) basic protection is provided by basic insulation of live parts or by barriers or enclosures in accordance with Section 416, and
(ii) fault protection is provided by simple separation of the separated circuit from other circuits and from Earth.

Simple separation can be provided by having separate windings within a transformer or, particularly for PV installations, the manufacturer may state that the inverter provides this function.

The current standard for type B RCDs, which will be reflected in Section 712 of BS 7671:2008(2011), is IEC 62423:2009; note that there is not an EN or BS version of this standard as yet. Regulation 712.411.3.2.1.2 does not state an operating time or residual operating current; refer to Section 411 and Table 41.1 of BS 7671:2008.

The concern is that d.c. fault currents can feed into the a.c. side of the electrical installation and corrupt upstream devices, such as type A and type AC RCDs. Type B RCDs will provide protection against d.c. earth fault currents; see Guidance Note 1 - Selection and Erection for more information. Type B RCDs are able to provide protection against alternating residual sinusoidal currents up to 1,000Hz, pulsating direct residual currents and smooth direct residual currents.

One other issue regarding RCDs is pertinent here. In a domestic installation which will not be under the supervision of a skilled or instructed person, Regulations 522.6.6 and 522.6.7 would require that additional protection by an RCD meeting the requirements of Regulation 415.1 is installed. This differs from the RCD requirement in Regulation 712.411.3.2.1.2 which calls for a type B RCD to provide fault protection.

Further reading

BS 7671:2008 Requirements for Electrical Installations

IEC 62423:2009 - Type F and type B residual current operated circuit breakers with or without integral overcurrent protection for household and similar uses

Guidance Note 1 – Selection and Erection, The IET, 5th Edition

Electricity, Safety, Quality and Continuity Regulations 2002 (as amended)

Thanks

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Large array installation