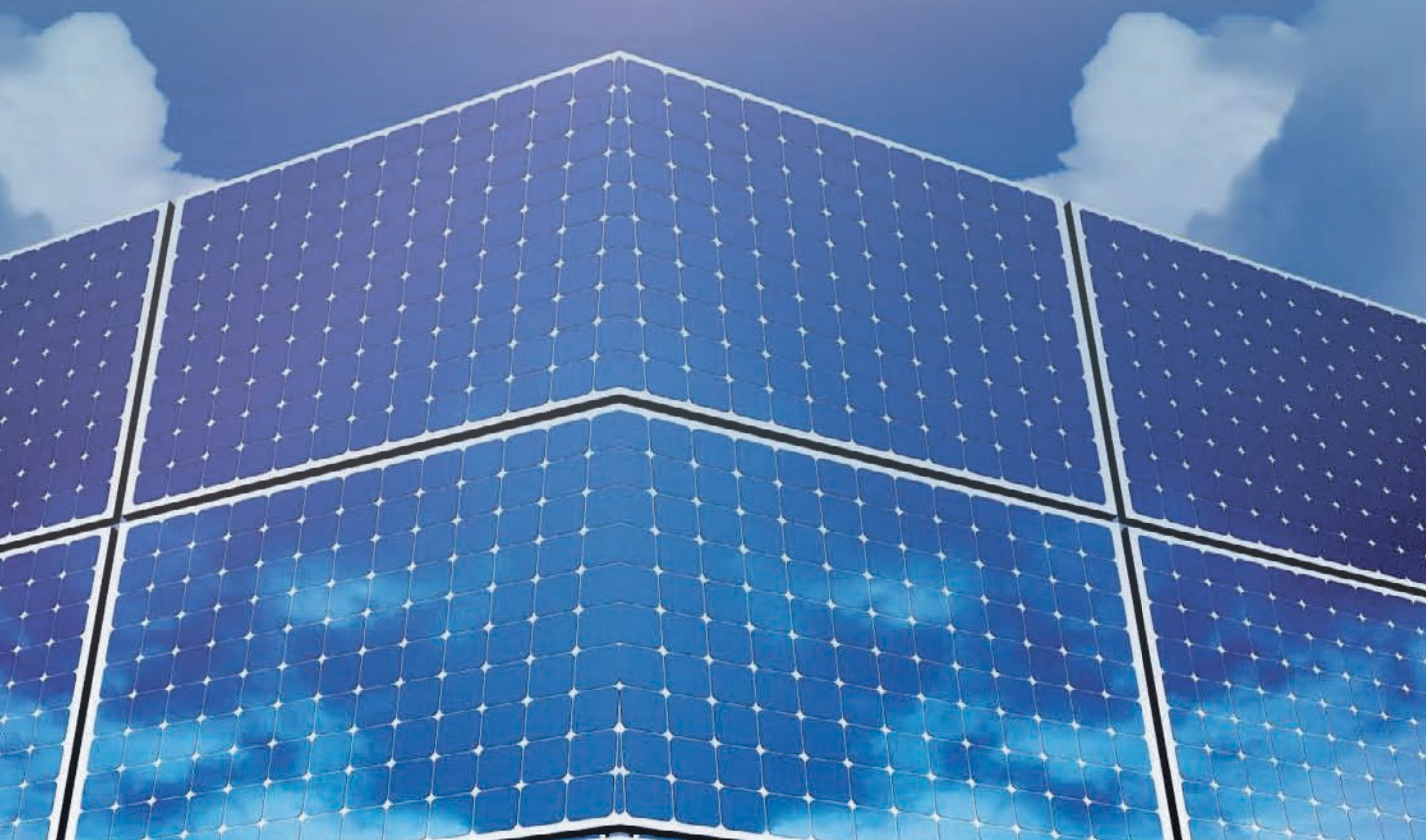
The Certification Mark for Onsite Sustainable Energy Technologies

Representing the best in electrical engineering and building services

Guide to the Installation of Photovoltaic Systems



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The Microgeneration Certification Scheme (MCS) is an industry led certification scheme for microgeneration products and installation services.

Supported by the Department for Energy and Climate Change (DECC), MCS seeks to build consumer confidence and support the development of robust industry standards. It provides confidence in the marketplace and wholly supports government policy within the microgeneration sector.

With support from industry and key stakeholders, MCS has established a number of installation standards and scheme documents for a range of microgeneration technologies. These standards and documents have helped to shape the microgeneration sector, and ensure best practice for the installation and quality of these renewable technology systems.

MCS is pleased to have worked to develop this new guide for the installation of solar photovoltaic systems. We would like to thank the members of the MCS solar photovoltaic technical working group for their time and effort in the significant updates to this new solar photovoltaic installation guide.

For further information about MCS, please visit www.microgenerationcertification.org.

MCS is grateful for the work from the Electrical Contractors Association (ECA).

ECA is recognised as one of the leading trade associations for the electrotechnical sector, and has assisted with typesetting and distributing the hard copy of this co-branded guide, whilst also assisting with technical input throughout.

The ECA has been a Trade Association for nearly 110 years and has been a contributor to a wide number of technical documents within the sector, the “Guide to the installation of Photovoltaic Systems” is just one of these.

For further information about ECA please visit www.eca.co.uk

Guide to the Installation of Photovoltaic Systems

2012

MCS

ECA

Representing the best in electrical engineering and building services

Foreword and Thanks

This guide is based upon the publication “Photovoltaics in Buildings, Guide to the installation of PV systems 2nd Edition” (DTI/Pub URN 06/1972). Whilst this guide is based up the original content of the above publication it has been written independently of any government departments. We do remain consistently grateful and our thanks go to those whom contributed to the original versions for their continued help and support.

Foreword by the Chairman of the MCS Solar Photovoltaic Working Group:

It is over two years since the MCS Solar Photovoltaic technical working group decided to undertake an overhaul of the technical standards and also update the reference guide to the installation of PV systems. With the introduction of the Feed -in Tariff in 2010, those two years have seen a changing industry. The number of installation companies has grown from a small base to over 4000 and recent estimates put total employment in installation alone at around 30,000. The installed capacity has also passed the 1GW milestone, which is a major achievement for the UK.

As the industry has developed, we have learnt how to do many things better. We have also learned that some of the things we were doing that were precautionary have proved, through experience, to be unnecessary. The aim of this update has been to capture these changes so we can deliver an improved yet better value product for our customers who should also be better informed at the time of purchase. We hope you welcome the changes.

Solar PV is here to stay and is the technology that is now no longer an expensive lifestyle product for idealists but an affordable and attractive option. It is a familiar proposition for individuals and companies alike looking to protect themselves from the inexorable rise in the price of grid electricity. The long term outlook for solar PV is in my view a bright one.

Finally, I would like to thank the members of the MCS Solar Photovoltaic technical working group who have volunteered a great deal of their time attending meetings and undertaking additional work outside of those meetings. I would also like to thank those who responded to our consultation suggesting ideas for the Working Group to consider.

Chris Roberts
Chair, MCS solar photovoltaic technical working group
and Director of Poweri Services

Further Acknowledgements

MCS would like to acknowledge the work undertaken by the members of the MCS solar photovoltaic technical working group to develop this guide with particular thanks to the following organisations:

Sundog Energy Ltd.

and

GTEC Training Ltd.

Special thanks are also given to the leaders of the editorial team, Martin Cotterell and Griff Thomas.

Martin Cotterell

Martin Cotterell is one of the UK's foremost experts in the installation of solar PV systems and has played a central role in establishing and improving industry standards in the UK and internationally. Martin was a major author of both previous versions of this guide, has worked on grid connection standards for renewable generators and, as well as sitting on various MCS and other UK technical committees, he co-chairs the international IEC solar PV installation standards working group. Martin has considerable practical experience of PV system installation – he founded Sundog Energy in 1995, since when it has grown to be one of the UK's leading PV companies.

Griff Thomas

Griff Thomas has worked in the renewable technology sector for over 10 years. Formerly a mechanical and electrical contractor Griff brings a wealth of understanding as to how standards affect the everyday installation work of contractors. More recently Griff has worked in a number of roles across the industry on a variety of standards and technical documents. Griff also attends many technical committees in his role as the technical manager of ECA Certification for the Microgeneration Certification Scheme.

Particular thanks also goes to Steve Pester, Principal Consultant in BRE, for his work in developing the performance calculation methodology.

Guide to the Installation of Photovoltaic Systems

Contents

1 INTRODUCTION

1.1 Scope & Purpose

The scope of this document is to provide solar PV system designers and installers with information to ensure that a grid-connected PV system meets current UK standards and best practice recommendations. It is primarily aimed at typical grid connected systems of up to 50kWp (total combined d.c. output). However most of what is contained here will also be applicable for larger systems. Systems that include a battery are addressed in Annex A.

This document has been written to be the technical standard to which MCS registered installation companies are expected to meet in order to gain and / or maintain their MCS certification. To this end this guide is quoted by the MCS Photovoltaic standard (MIS 3002).

1.2 Layout of the Guide

This guide is split into two main parts, the first detailing issues that need to be addressed during the design phase of a project, and the second covering installation and site based work. It is important to note, however, that many ‘design’ issues covered in the first section may have a significant impact on the practical installation process covered in the second.

1.3 Standards and Regulations

The following documents are of particular relevance for the design and installation of a PV system, where referenced throughout the guide the most recent edition should be referred to:

- Engineering Recommendation G83 (current edition) – Recommendations for the connection of small scale embedded generators (up to 16A per phase) in parallel with public low voltage distribution networks
- Engineering Recommendation G59 (current edition) – Recommendations for the connection of generating plant to the distribution systems of licensed distribution network operators.
- BS 7671 (current edition) - Requirements for electrical installations (all parts – but in particular Part 7-712 Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems)
- BS EN 62446 (current edition) - Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection

1.4 Safety

From the outset, the designer and installer of a PV system must consider the potential hazards carefully, and systematically devise methods to minimise the risks. This will include both mitigating potential hazards present during and after the installation phase.

The long-term safety of the system can be achieved only by ensuring that the system and components are correctly designed and specified from the outset, followed by correct installation, operation and maintenance of the system. Consideration of operation under both normal and fault conditions is essential in the design stage to ensure the required level of safety. This aspect is covered in the DESIGN section of this guide.

It is then important to ensure that the long-term safety of the system is not compromised by a poor installation or subsequent poor maintenance. Much of this comes down to the quality of the installation and system inspection and testing regime. This is covered in the installation section of this guide.

Similarly, much can be done during the planning and design stage to ensure that the installation is safe for the installers. In some circumstances the application of the CDM regulations will be required. All key safety issues affecting the design and installation process are discussed in the guide. The main safety issues are:

- The supply from PV modules cannot be switched off, so special precautions should be made to ensure that live parts are either not accessible or cannot be touched during installation, use and maintenance.
- PV modules are current-limiting devices, which require a non-standard approach when designing fault protection systems, as fuses are not likely to operate under short-circuit conditions.
- PV systems include d.c. wiring, with which few electrical installers are familiar.
- The installation of PV systems presents a unique combination of hazards – due to risk of electric shock, falling and simultaneous manual handling difficulty. 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.

1.5 Parallel Generation

A mains-connected PV installation generates electricity synchronised with the electricity supply. Installers are obliged to liaise with the relevant Distribution Network Operator (DNO) in the following manner:

Single installation covered by G83

- Notification to DNO must be completed within 28 days of commissioning.

Multiple installations covered by G83 or installations in close geographical proximity to one another

- Application to proceed prior to commencing works (G83 multiple system application form)
- On commissioning – notification and commissioning form as per single installation

Larger installations covered by G59

- Written approval from DNO to be gained prior to works commencing
- Commissioning process as required by DNO

As stated above, consideration needs to be given to the number of small scale embedded generators (SSEG's) in a close geographical area; this is defined in G83 and associated guidance documents. Where this is the case then the DNO should be consulted and the procedure for connecting multiple installations under G83 may need to be applied.

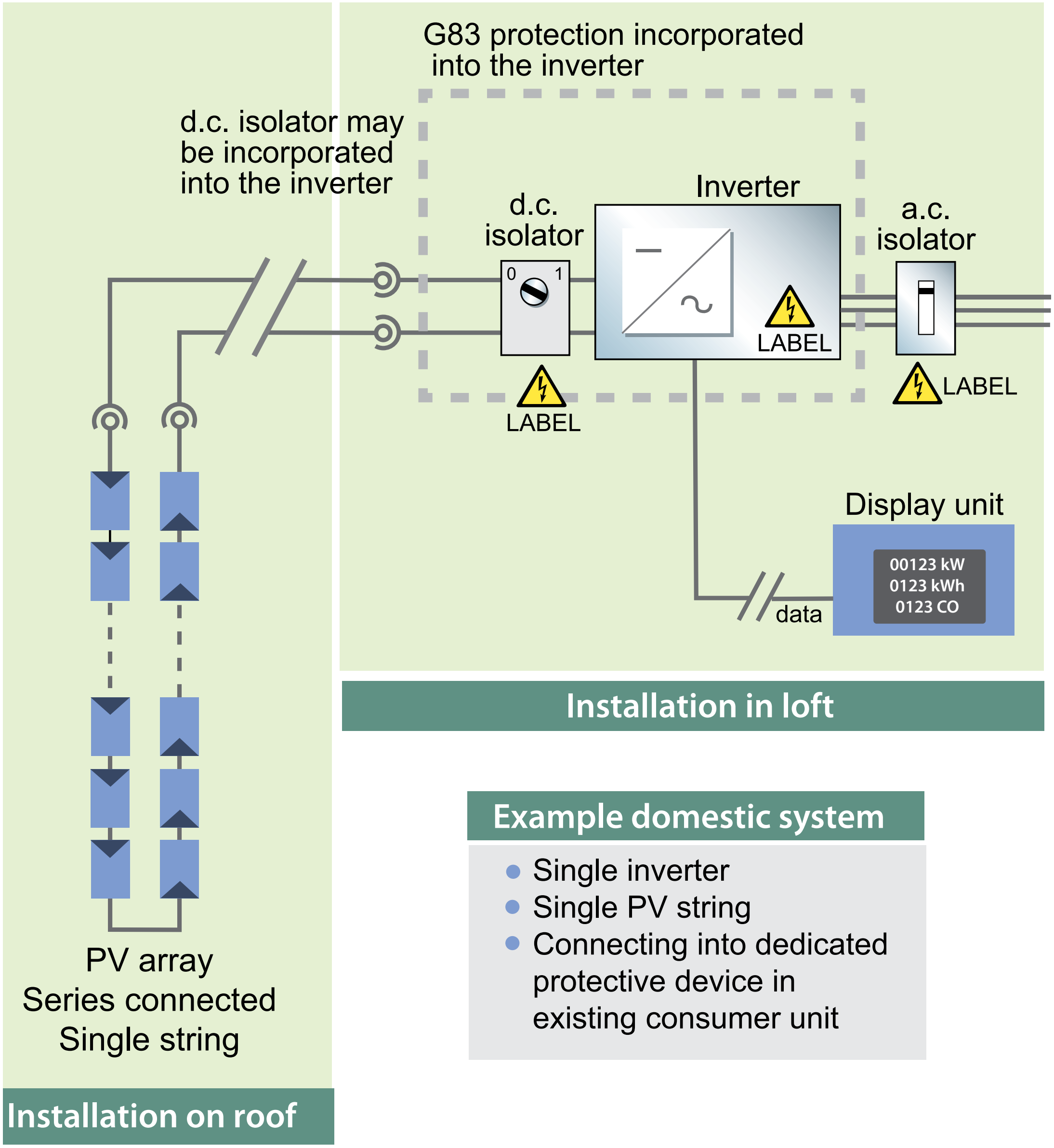
For more information see section 2.4.1

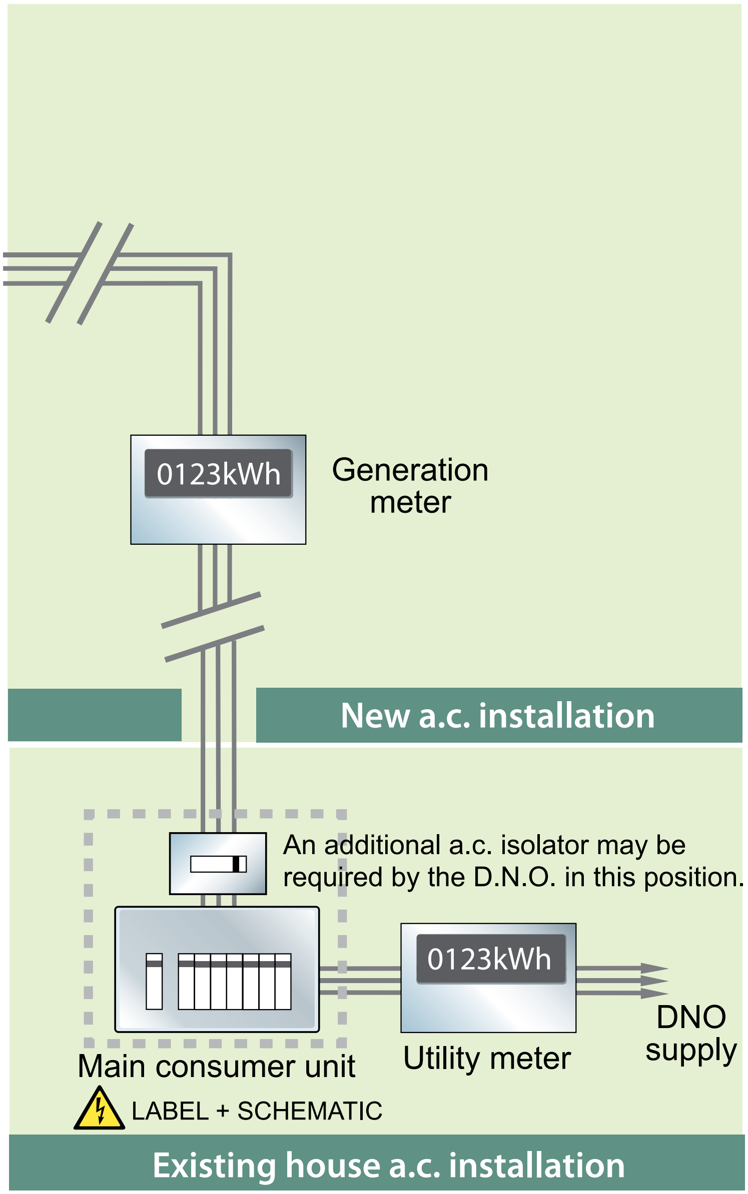
1.6 Ready Reference to the Guide

Example schematics for the two main types of system are shown in the following 2 figures to help when reading this Guide. They should not be used for a particular installation without taking into account the special circumstances of each individual installation.

Example Single Phase Layout:

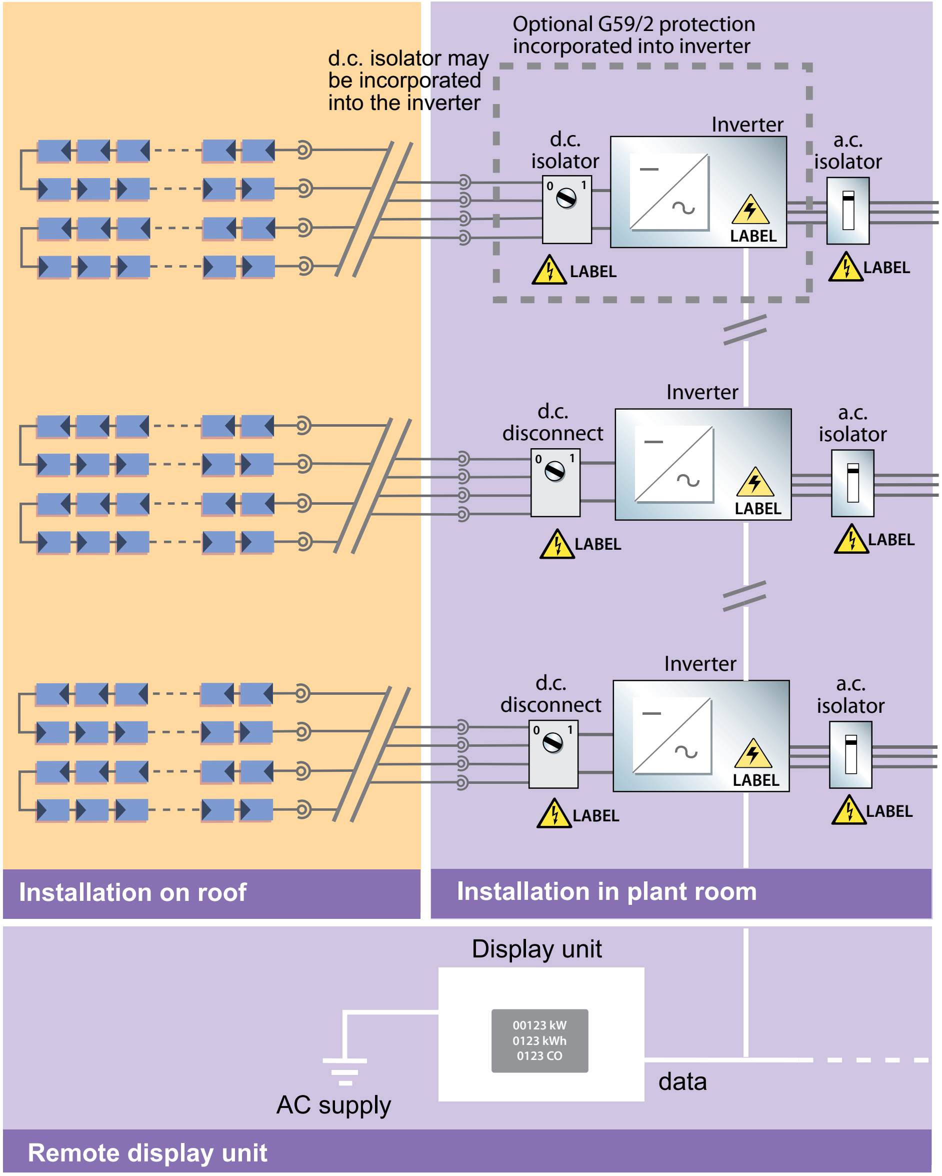
Fig 1




0123kWh
Generation meter
New a.c. installation
An additional a.c. isolator may be required by the D.N.O. in this position.
0123kWh
DNO supply
Main consumer unit
Utility meter
LABEL + SCHEMATIC
Existing house a.c. installation

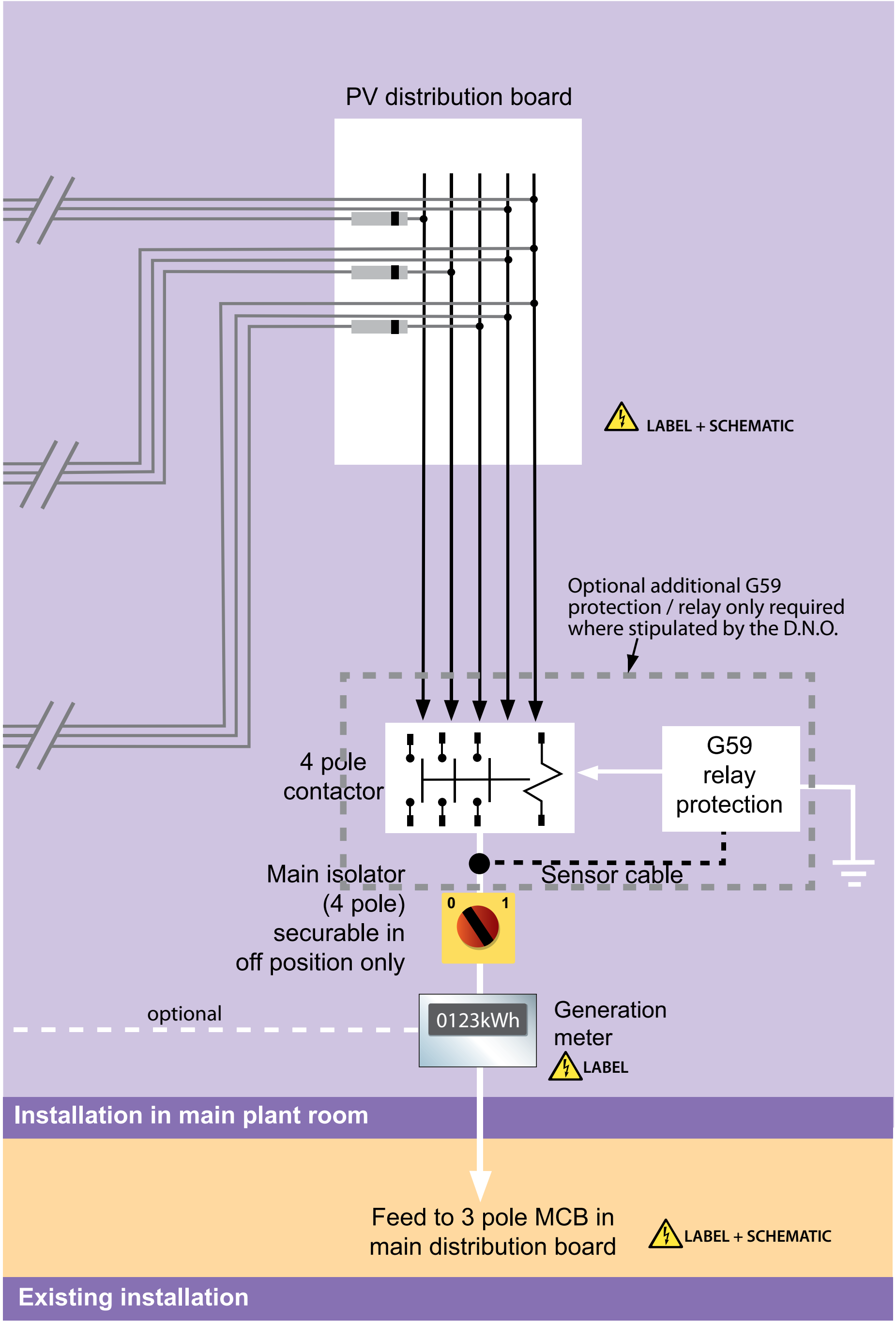
Example Three Phase Layout:

Fig 2



Example larger system

- Two PV strings for each inverter
- Three inverters (split across three-phase supply)
- Connected via G59/1 relay protection to 3 phase MCB in main distribution unit


PV distribution board
LABEL + SCHEMATIC
Optional additional G59 protection / relay only required where stipulated by the D.N.O.
4 pole contactor
G59 relay protection
Main isolator (4 pole) securable in off position only
Sensor cable
0
1
optional
0123kWh
Generation meter
LABEL
Installation in main plant room
Feed to 3 pole MCB in main distribution board
LABEL + SCHEMATIC
Existing installation

1.7 Definitions

a.c. Side

Part of a PV installation from the a.c. terminals of the PV inverter to the point of connection of the PV supply cable to the electrical installation

d.c. Side

Part of a PV installation from a PV cell to the d.c. terminals of the PV inverter

Distribution Network Operator (DNO)

The organisation that owns or operates a Distribution Network and is responsible for confirming requirements for the connection of generating units to that Network

Earthing

Connection of the exposed-conductive-parts of an installation to the main earthing terminal of that installation

Electricity Network

An electrical system supplied by one or more sources of voltage and comprising all the conductors and other electrical and associated equipment used to conduct electricity for the purposes of conveying energy to one or more Customer's installations, street electrical fixtures, or other Networks

Equipotential Zone

Where exposed-conductive parts and extraneous-conductive parts are maintained at substantially the same voltage

Exposed-Conductive-Part

Conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails

Extraneous-Conductive-Part

A conductive part liable to introduce a potential, generally Earth potential, and not forming part of the electrical system

Isc (stc) Short-Circuit Current

Short-circuit current of a PV module, PV string, PV array or PV generator under standard test conditions

Islanding

Any situation where a section of electricity Network, containing generation, becomes physically disconnected from the DNOs distribution Network or User's distribution Network; and one or more generators maintains a supply of electrical energy to that isolated Network

Isolating Transformer

Transformer where the input & output windings are electrically separated by double or reinforced insulation

Isolation

A function intended to cut off for reasons of safety the supply from all, or a discrete section, of the installation by separating the installation or section from every source of electrical energy

Isolator

A mechanical switching device which, in the open position, complies with the requirements specified for the isolating function. An isolator is otherwise known as a disconnector

Lightning Protection

A means of applying protective measures to afford protection to persons, property and livestock against the effects of a lightning strike

PME – Protective Multiple Earthing

An earthing arrangement, found in TN-C-S systems, in which the supply neutral conductor is used to connect the earthing conductor of an installation with Earth, in accordance with the Electrical Safety, Quality and Continuity Regulations 2002

Protective Equipotential Bonding - (also referred to as Equipotential Bonding)

Electrical connection maintaining various exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential

PV a.c. Module

Integrated module/convertor assembly where the electrical interface terminals are a.c. only. No access is provided to the d.c. side

PV Array

Mechanically and electrically integrated assembly of PV modules, and other necessary components, to form a d.c. power supply unit

PV Array Cable

Output cable of a PV array

PV Array Junction Box

Enclosure where all PV strings of any PV array are electrically connected and where protection devices can be located

PV String

A number of PV modules are connected in series to generate the required output voltage

PV Cell

Basic PV device which can generate electricity when exposed to light such as solar radiation

PV Charge Controller

A device that provides the interface between the PV array and a battery

PV d.c. Main Cable

Cable connecting the PV array junction box to the d.c. terminals of the PV convertor

PV Grid-Connected System

A PV generator operating in 'parallel' with the existing electricity network

PV Installation

Erected equipment of a PV power supply system

PV Inverter (also known a PV Convertor)

Device which converts d.c. voltage and d.c. current into a.c. voltage and a.c. current

PV Kilowatts Peak (kWp)

Unit for defining the rating of a PV module where kWp = watts generated at stc

PV Module Maximum Series Fuse

A value provided by the module manufacturer on the module nameplate & datasheet (a requirement of IEC61730-2)

PV Module

Smallest completely environmentally protected assembly of interconnected PV cells

PV MPP Tracker (MPPT)

A component of the d.c. input side of an inverter designed to maximise the input from the array by tracking voltage and current

PV Self-Cleaning

The cleaning effect from rain, hail etc. on PV arrays which are sufficiently steeply inclined

PV String Cable

Cable connecting PV modules to form a PV string

PV String Fuse

A fuse for an individual PV string

PV Supply Cable

Cable connecting the AC terminals of the PV convertor to a distribution circuit of the electrical installation

PV Standard Test Conditions (stc)

Test conditions specified for PV cells and modules (25°C, light intensity 1000W/m^2, air mass 1.5)

V_{oc} Open circuit d.c. voltage

2 DESIGN

2.1 Design Part 1 – d.c. System

2.1.1 PV Modules

2.1.1.1 Standard Modules

Modules must comply with the following international standards:

- **IEC 61215 in the case of crystalline types**
- **IEC 61646 in the case of thin film types**
- **IEC 61730 - Photovoltaic (PV) module safety qualification**
- **Modules must also carry a CE mark**

The use of Class II modules is generally recommended, and strongly recommended for array open-circuit voltages of greater than 120 V.

For an installation to comply with the requirements of MCS - modules must be certificated and listed on the MCS product database

2.1.1.2 Building Integrated Products / Modules

PV products shall be designed and constructed to meet the requirements within the relevant Building Regulations for the particular application that the PV product is intended. The PV installer must be able to demonstrate such compliance for all relevant projects. MCS012 or MCS017 (as relevant) may assist in demonstrating such compliance.

For an installation to comply with the requirements of MCS - PV systems mounted above or integrated into a pitched roof shall utilise products that have been tested and approved to MCS012 (test procedures used to demonstrate the performance of solar systems under the action of wind loads, fire, rainfall and wind driven rain).

Note: Under the MCS scheme, MCS012 becomes compulsory in September 2013 and MCS 017 in May 2013

PV systems utilising bespoke building integrated PV modules should utilise products that have been tested and approved to MCS017 Product Certification Scheme Requirements: Bespoke Building Integrated Photovoltaic Products. The use of products listed to MCS012 or MCS017 is still recommended, even if MCS compliance is not required

Details of MCS approved system components can be found at:
www.microgenerationcertification.org

2.1.2 d.c. System – Voltage and Current Ratings (Minimum)

All d.c. component ratings (cables, isolators / disconnectors, switches, connectors, etc.) of the system must be derived from the maximum voltage and current of the relevant part of the PV array adjusted in accordance with the safety factors as below. This must take into account system voltage/currents of the series/parallel connected modules making up the array. It must also take into account the maximum output of the individual modules.

When considering the voltage and current requirements of the d.c. system, the maximum values that could occur need to be assessed. The maximum values originate from two PV module ratings – the open-circuit voltage (V_{oc}) and the short-circuit current (I_{sc}) which are obtained from the module manufacturer. The values of V_{oc} and I_{sc} provided by the module manufacturer are those at standard test conditions (stc) – irradiance of 1000 W/m2, air mass 1.5 and cell temperature of 25°C. Operation of a module outside of standard test conditions can considerably affect the values of V_{oc}(stc), I_{sc}(stc). In the field, irradiance and particularly temperature can vary considerably from stc values. The following multiplication factors allow for the maximum values that may be experienced under UK conditions.

Mono- and multi-crystalline silicon modules - All d.c. components must be rated, as a minimum, at:

- Voltage: V_{oc}(stc) x 1.15
- Current: I_{sc}(stc) x 1.25

All other module types - All d.c. components must be rated, as a minimum, from:

- Specific calculations of worst case V_{oc} and I_{sc}, calculated from manufacturer's data for a temperature range of -15°C to 80°C and irradiance up to 1,250 W/m^2
- A calculation of any increase in V_{oc} or I_{sc} over the initial period of operation. This increase is to be applied in addition to that calculated above.

Note: Some types of PV modules have temperature coefficients considerably different to those of standard mono- and multi-crystalline modules. The effects of increased irradiance may also be more pronounced. In such cases the multiplication factors used for crystalline silicon modules may not cover the possible increase in voltage/current. In addition, some thin film modules have an electrical output that is considerably higher during the first weeks of exposure to sunlight.

This increase is on top of that produced by temperature/irradiance variation. Typically, operation during this period will take V_{oc}, I_{sc} (and nominal power output) well above any value calculated using a standard multiplication factor. To avoid oversizing the inverter for this eventuality the array could be left disconnected for that initial period, refer to the manufacturer for this information.

2.1.3 PV String & Array Voltages

It is always desirable to keep voltages low to minimise associated risks, however in many systems, the d.c. voltage will exceed levels that are considered to reduce the risk to a minimum (usually around 120V d.c.)

Where this is the case, double insulation is usually applied as the method of shock protection. In this instance the use of suitably rated cables, connectors and enclosures along with controlled installation techniques becomes fundamentally important to providing this protective measure as defined in BS 7671- Section 412. Similarly, double insulation of the d.c. circuit greatly minimises the risk of creating accidental shock current paths and the risk of fire.

Where the PV array voltage exceeds 120V:

Double insulation (insulation comprising both basic & supplementary insulation) or reinforced insulation, appropriate barriers and separation of parts must be applied to all parts of the d.c. circuit to facilitate a level of protection equivalent to the protective measure “double or reinforced insulation” as defined in BS 7671- Section 412.

Where the PV array open circuit voltage exceeds 1000V:

Due to the added complexities and dangers associated with systems of a higher voltage than normal, the PV array should not be installed on a building. In addition, access should be restricted to only competent, skilled or instructed persons.

2.1.4 d.c. Cables – General

2.1.4.1 Cable Sizing

Cables should be sized in accordance with BS 7671. These calculations shall also take into account the multiplication factors in 2.1.2 of this guide. Guidance on a method of cable sizing including any de-rating factor requiring to be applied and typical current carrying capacities for common cable types are provided in Appendix 4 of BS 7671.

Cables should be sized such that the overall voltage drop, at array maximum operating power (stc), between the array and the inverter is <3%.

2.1.4.2 Cable Type and Installation Method

To minimise the risk of faults, PV d.c. cable runs should be kept as short as practicable.
Note: See also section 2.1.12 (additional d.c. switches for long cable runs).

The cables used for wiring the d.c. section of a grid-connected PV system need to be selected to ensure that they can withstand the extremes of the environmental, voltage and current conditions, under which they may be expected to operate. This will include heating effects of both the current and solar gain, especially where installed in close proximity to the PV modules.

Purpose designed "PV cables" are readily available and it is expected that all installations would use such cables. An IEC PV cable standard is under development and it is expected cables in compliance with this standard will be required once it is issued. In the interim, it is recommended that cables should comply with UL 4703, or TUV 2 Pfg 1169 08.2007.

Cables routed behind a PV array must be rated for a temperature range of at least of -15°C to 80°C.

Cables must be selected and installed so as to minimise the risk of earth faults and short-circuits. This can be achieved by reinforcing the protection of the wiring either through:

a) Single conductor "double insulated" cable

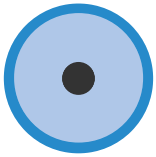


Fig 3a

b) Single conductor cable suitably mechanically protected conduit/trunking. Alternatively a single core SWA cable may be a suitable mechanically robust solution.

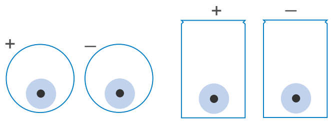


Fig 3b

c) Multi core Steel Wire Armoured SWA. Typically only suitable for main d.c. cable between a PV array junction box and inverter position, due to termination difficulties between SWA and the plug and socket arrangements pre-fitted to modules.

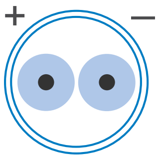


Fig 3c

External cables should be UV stable and water resistant. Where cables are likely to be subjected external movement, i.e. those mounted immediately behind the array, it is recommended that they be flexible (multi-stranded) to allow for thermal/wind movement of arrays/modules.

Because PV array cables almost exclusively rely on double or reinforced insulation as their means of shock protection they should not be buried in walls or otherwise hidden in the building structure as mechanical damage would be very difficult to detect and may lead to increase instances of shock and fire risk.

Where this cannot be avoided conductors should be suitably protected from mechanical damage, suitable methods may include the use of metallic trunking or conduit or the use of steel wire armoured cable in accordance with BS 7671.

Exterior cable colour coding is not required for PV systems. Consideration must be given to the UV resistance of all cables installed outside or in a location that may be subject to UV exposure, PV cables are therefore commonly black in colour to assist in UV resistance.

Where long cable runs are necessary (e.g. over 20m), labels should be fixed along the d.c. cables as follows:

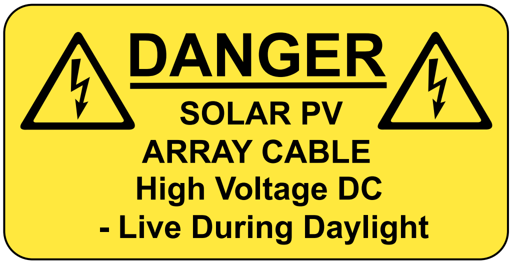


Fig 4

Labelling fixed every 5 to 10m is considered sufficient to identify the cable on straight runs where a clear view is possible between labels.

Where multiple PV sub-arrays and or string conductors enter a junction box they should be grouped or identified in pairs so that positive and negative conductors of the same circuit may easily be clearly distinguished from other pairs.

2.1.5 String Cables

In a PV array formed from a number of strings, fault conditions can give rise to fault currents flowing though parts of the d.c. system. Two key problems need addressing – overloaded string cables and excessive module reverse currents, both of which can present a considerable fire risk.

For small systems where it is determined that string fuses are not required for module protection (maximum reverse currents less than module reverse current rating), a common approach is to ensure that the string cables are suitably rated such that they may safely carry the maximum possible fault current.

This method relies on oversizing the string cables such that any fault current can be safely accommodated. Such a method does not clear the fault but simply prevents a fire risk from

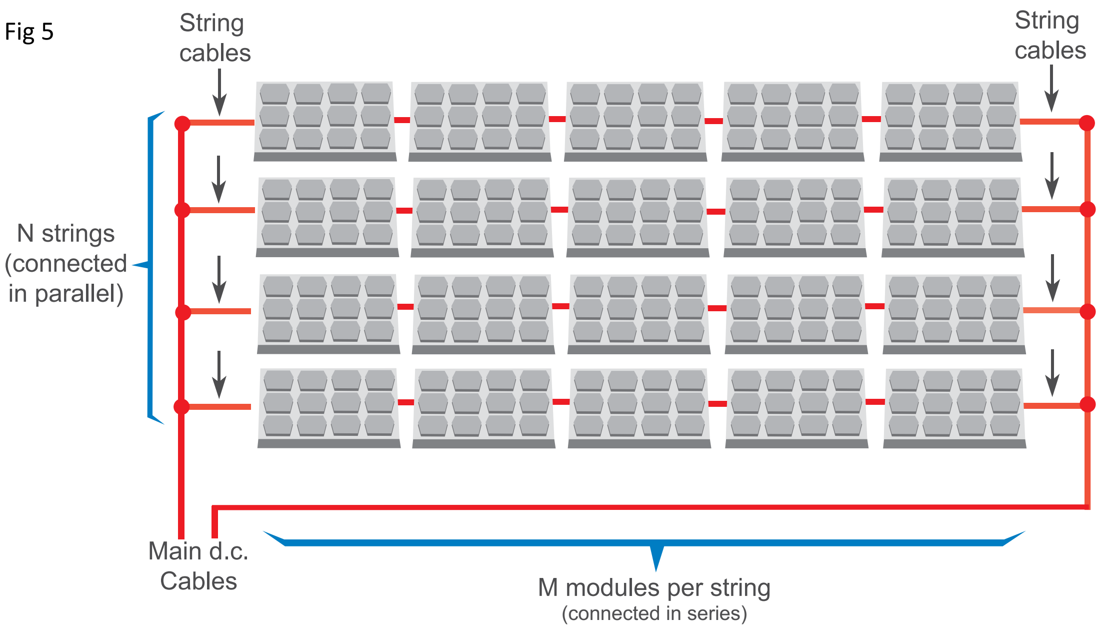
overloaded cables. See also section 2.1.10 - string fuses.
For an array of N parallel connected strings, with each string formed of M series connected modules:

String cables must be rated as a minimum as follows:

- Voltage > V_{oc}(stc) x M x 1.15
- Current > I_{sc}(stc) x (N-1) x 1.25
- The cable Current Carrying Capacity (I_z) must be calculated according to the requirements of BS 7671. This shall include factors taking into account installation conditions such as cable installation method, solar gains and grouping etc.

Where a system includes string fuses, the cable size may be reduced, but in all cases the I_z after de-rating factors have been applied must exceed the string fuse rating and must exceed the I_{sc}(stc) x 1.25.

Fig 5



2.1.6 Main d.c. Cable

For a system of N parallel connected strings, with each formed of M series connected modules:

d.c. main cables must be rated as a minimum as follows:

- Voltage: V_{oc}(stc) x M x 1.15
- Current: I_{sc}(stc) x N x 1.25

The cable Current Carrying Capacity (I_z) must be calculated according to the requirements of BS 7671 to include cable de-rating factors to take into account factors such as cable installation method and grouping

2.1.7 d.c. Plug and Socket Connectors

PV specific plug and socket connectors are commonly fitted to module cables by the manufacturer. Such connectors provide a secure, durable and effective electrical contact. They also simplify and increase the safety of installation works.

Plugs and socket connectors mated together in a PV system shall be of the same type from the same manufacturer and shall comply with the requirements of BS EN 50521. Different brands may only be interconnected where a test report has been provided confirming compatibility of the two types to the requirements of BS EN 50521.

Fig 6a

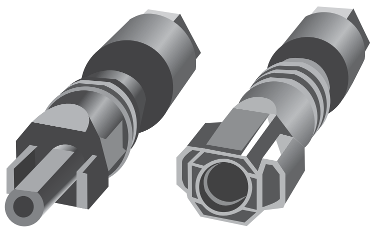
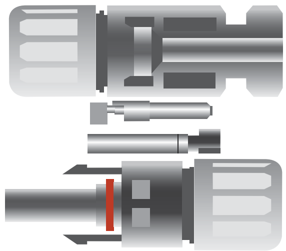


Fig 6b



Connectors used in a PV string circuit must comply with the minimum voltage and current ratings as detailed in string cable section above (section 2.1.5). Connectors used in a d.c. main cable circuit must comply with the minimum voltage and current ratings as detailed in the main d.c. cable section above (section 2.1.6)

Connectors should have a UV, IP and temperature rating suitable for their intended location and should be compatible with the cable to which they are connected.

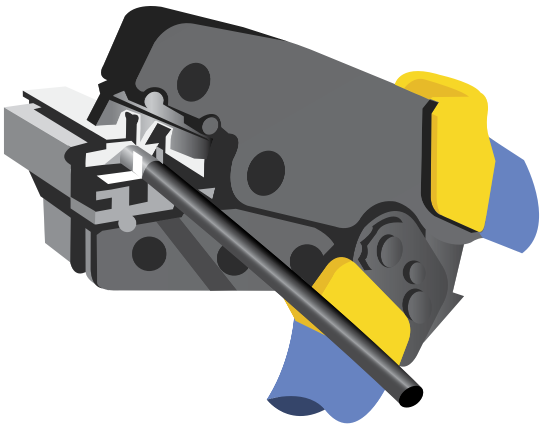
Connectors readily accessible to ordinary persons shall be of the locking type, requiring a tool or two separate actions to separate and shall have sign attached that reads: ‘Do not disconnect d.c. plugs and sockets under load'

Cable connectors must not be used as the means for d.c. switching or isolation under load (see 2.1.12) as d.c. arcing can cause permanent damage to some connectors.

Plug and socket "Y" connectors can also be used to replace a junction box. It is good practice to keep "Y" connectors in accessible locations and where possible note their location on layout drawings, to ease troubleshooting in future.

Where required by the connectors special tooling shall be used to ensure that connections are adequately made off and secure. Failure to use the correct tooling will result in connections that are not mechanically or electrically sound and can lead to overheating and fires.

Fig 7



Example tooling required for correct termination of connectors

2.1.8 Other Inline Cable Junctions

In general cable junctions shall either be by an approved plug and socket connector or contained within a d.c. Junction Box (see below). However in certain limited circumstances it may be necessary for an in-line cable junction to be made (e.g. soldered extension to a module flying lead) although this should be avoided if at all possible.

Note: Great care needs to be applied in the design and installation of in-line junctions. Where unavoidable, such junctions need to maintain the 'double or reinforced insulated' nature of the cables as described in section 2.1.4 (e.g. by the use of two layers of appropriately rated adhesive lined heat shrink sleeving), and be provided with appropriate strain relief. Such junctions would typically be completed off-site, prior to works, using fittings and tools appropriate to the cable to be jointed.

2.1.9 PV Array d.c. Junction Box

If there is more than one string, the d.c. junction box (sometimes called a combiner box) is normally the point at which they are connected together in parallel. The box may also contain string fuses and test points.

The d.c. junction box must be labelled with - 'PV array d.c. junction box, Danger contains live parts during daylight'.

All labels must be clear, legible, located so as to be easily visible, durably constructed and affixed to last lifetime of the installation.

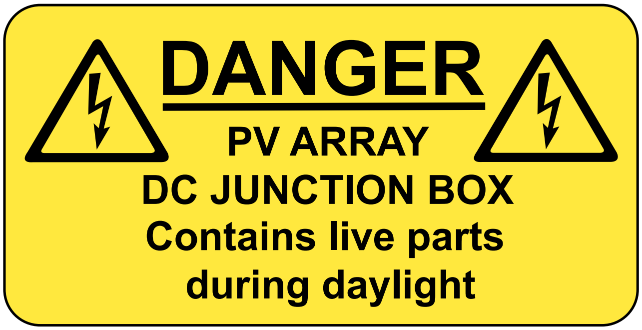


Fig 8

Note: A PV system cannot be turned off – terminals will remain live at all times during daylight hours. It is important to ensure that anyone opening an enclosure is fully aware of this.

The short-circuit protection afforded by the cable installation throughout the rest of the d.c. circuit needs to be maintained in the construction and makeup of the d.c. junction box. (See IEC 60536 and IEC 61140).

It is recommended that short-circuit protection shall be achieved by:

- Fabrication of the enclosure from non-conductive material
- Positive and negative busbars and terminals adequately separated and segregated within the enclosure and/or by a suitably sized insulating plate, or separate positive and negative junction boxes.
- Cable and terminal layout such that short-circuits during installation and subsequent maintenance are extremely unlikely.

2.1.10 String Fuses

The short circuit current of a module is little more than the operating current, so in a single string system, a circuit fuse would simply not detect or operate to clear a short circuit fault.

In systems with multiple strings some fault scenarios can result in the current from several adjacent strings flowing through a single string and the prospective fault current may be such that overcurrent protective devices are required. Hence, the selection of overcurrent protective measures depends upon the system design and the number of strings.

While string cable sizes can be increased as the number of parallel connected strings (and the potential fault current) increases, the ability of a module to withstand the reverse current must also be considered.

Where currents exceed the modules' maximum reverse current rating, there is the potential for damage to the affected modules' and also a fire risk. IEC61730-2 Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing [5], includes a reverse current overload test. This reverse current test is part of the process that enables the manufacturer to provide the maximum overcurrent protection rating or maximum series fuse. Fault currents above the maximum series fuse rating present a safety risk and must be addressed within the system design.

For a system of N parallel connected strings, the maximum module reverse current (I_R) to be experienced under fault conditions is:

$$\mathbf{I_R = (N - 1) \times I_{sc}}$$

Hence, overcurrent protection is required where $(N - 1) \times I_{sc}$ is greater than the module maximum series fuse rating. While some fault combinations are less likely than others, in order to provide full protection of all cables and modules – string fuses are required in both the positive and negative legs of the string cabling.

Note: For small systems where it is determined that fault currents do not present a risk to the modules, only the string cables & connectors need to be considered. A common approach in this case relies on oversizing string cables & connectors - such that they may safely carry the maximum possible fault current. Such a method does not clear the fault but simply prevents a fire risk from overloaded cables. See also section 2.1.5 - string cables

Where the inverter is of such a design that it has multiple MPPT inputs and the design does not allow fault currents to flow between these inputs, each MPPT input may be treated as a wholly separate sub-array for the purposes of deciding whether string fuses are required.

Fuses should not be mounted in such a position where their rating may be compromised by the build-up of heat from solar gains. The use of MCBs (miniature circuit breakers) is permissible provided they meet the string fuse criteria and are rated for use in an inductive circuit and will operate for currents flowing in either direction through the device. A system fitted with suitable removable string fuses provides a means to achieve the requirements for string isolation (section 2.1.12.1)

2.1.10.1 String Fuse Selection

The following requirements apply where the PV array provides the only source of fault current, such as in a typical grid connected system with no battery. For a system with a battery or other source of fault current see also Section 2.5.

For a system of N parallel connected strings, with each formed of M series connected modules:

- String fuses must be provided for all arrays where: $(N - 1) \times I_{sc}$ > module maximum series fuse rating
- Where fitted, fuses must be installed in both positive and negative string cables for all strings.
- The string fuse must be of a type gPV - according to IEC60269-6
- The string fuse must be rated for operation at V_{oc}(stc) x M x 1.15
- The string fuse must be selected with an operating current In such that:
    - $I_n > 1.5 \times I_{sc}$ stc
    - $I_n \leq 2.4 \times I_{sc}$ stc
    - $I_n \leq$ Maximum series fuse value

2.1.11 Blocking Diodes

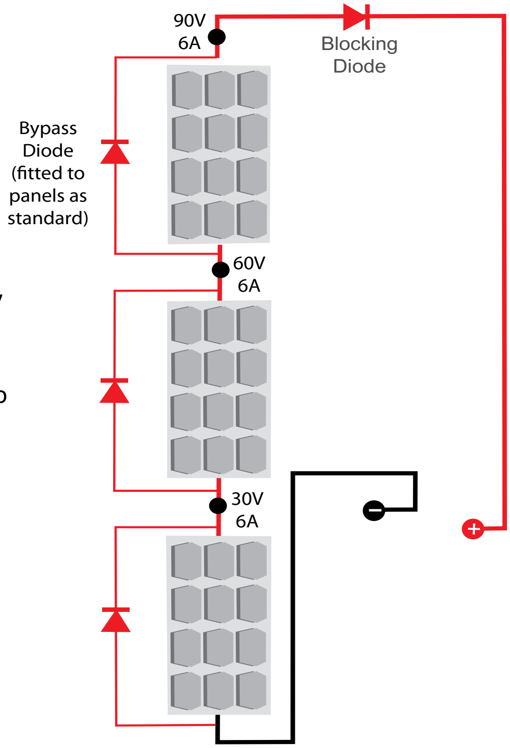
Blocking diodes are not commonly used in a grid-connect system as their function is better served by the installation of a string fuse. However, for multi-string arrays with some types of PV module, particularly thin-film types, it may not be possible to provide adequate overcurrent / reverse current protection with string fuses or MCBs alone.

This is due to the fact it may not be possible to specify a fuse/MCB which is greater than Isc x 1.25 but less than the reverse current rating of the module. In this situation blocking diodes should be used in addition to string fuses.

It is to be noted that:

- The installation of a blocking diode results in a small voltage drop across the diode
- Blocking diodes may fail as a short-circuit and therefore require regular testing.

Fig 9



In most cases the specification of string fuses can provide sufficient reverse current protection without the problems and power losses associated with a blocking diode. If blocking diodes are used, they should be supplemented by string fuses.

If specified, a blocking diode must have:

- A reverse voltage rating > 2 x maximum system voltage (as calculated in section 2.1.2)
- A current rating > 1.4 x Isc (where Isc is the relevant short circuit current for the string / sub array / array)
- Have adequate cooling (heatsinks) if required

Note that blocking diodes should not be confused with bypass diodes. Bypass diodes are normally encapsulated into the module junction box at the back of the PV module and are intended to allow current(s) to bypass cells and / or modules that have a high resistance (usually caused by shading).

2.1.12 d.c. Isolation and Switching

The following table describes the requirements for both isolation and switching in the d.c. side of the PV array circuit:

d.c. Circuit	Switching	Isolation
String	Not required	Readily accessible means of string isolation
Sub array	Optional	Readily accessible means of Sub Array isolation
Array	Readily accessible load break switch disconnector on d.c. side of inverter	

An additional d.c. switch or isolating device may be specified for systems with long d.c. cable runs (typically at the point of cable entry into the building) – so as to provide a means of isolating the cable for safety reasons or maintenance works.

2.1.12.1 Isolation

Isolation is defined as a function intended to cut off for reasons of safety the supply from all, or a discrete section, of the installation by separating the installation or section from every source of electrical energy (from BS 7671).

Isolation shall be provided in both positive and negative cables and all isolation measures shall be readily accessible

String isolation – This can be achieved by any suitable means such as appropriately located plug and socket connectors or removable string fuses.

Sub array isolation – This can be achieved by any suitable means such as a removable sub array fuse or by the use of a switch disconnector.

Array isolation – This shall be provided by the **Array Switch Disconnector** (see next page)

2.1.12.2 Switch Disconnector – General Requirements

A switch disconnector installed on the d.c. side shall have the following features:

- The switch must isolate all live conductors (typically double pole to isolate PV array positive and negative conductors)
- The switch must be rated for d.c. operation at the system voltage maximum as calculated
- The switch must be rated for d.c. operation at the system current maximum as calculated
- The switch must be labelled as 'PV array d.c. isolator', with the ON and OFF positions clearly marked. Switch enclosures should also be labelled with 'Danger - contains live parts during daylight'. All labels must be clear, easily visible, constructed and affixed to last and remain legible for as long as the enclosure.

NOTE: A circuit breaker may also be used provided it meets all the above requirements

2.1.12.3 Array Switch Disconnector

As noted in section 2.1.12, a readily accessible load break switch disconnector on d.c. side of inverter must be provided. This array switch disconnector shall be one of the following:

- A physically separate switch-disconnector mounted adjacent to the inverter; or
- A switch-disconnector that is mechanically connected to the inverter – that allows the inverter to be removed from the section containing the switch-disconnector without risk of electrical hazards; or
- A switch-disconnector integral to the inverter, if the inverter includes a means of isolation only operable when the switch-disconnector is in the open position (e.g. plugs only accessible once the switch disconnector handle is removed); or
- A switch-disconnector integral to the inverter, if the inverter includes a means of isolation (e.g. plugs) which can only be operated with a tool and is labelled with a readily visible warning sign or text indicating ("Do not disconnect under load").

2.1.12.4 a.c. Module Systems

Where inverters are of the type that mounts directly or adjacent to PV modules, BS 7671 regulation 712.537.2.2.5 would still require the fitting of a switch disconnector.

However it is considered that from a practical perspective a d.c. isolator may not always be necessary where the system fulfils all of the following requirements:

- Connects only one module per inverter
- Does not require the extension of the PV module d.c. cables beyond the length of the original factory fitted cables
- Does not exceed the voltages within the band of ELV (Not exceeding 50 V a.c. or 120 V ripple-free d.c. whether between conductors or to Earth.)
- Has a plug and socket type connector arrangement for the d.c. cables

In this case, the designer of the installation must carefully consider the layout of such a system and if it is decided to omit the switch disconnector this shall be recorded as a departure on the Electrical installation certificate.

NOTE: At the time of going to press comments have been submitted to the relevant UK panel to review the requirements of 712.537.2.2.5 in relation to such inverters.

2.2 Design Part 2 – Earthing, Protective Equipotential Bonding and Lightning Protection

2.2.1 Lightning Protection

Whilst this installation guide does not cover specific guidance on selection, or application of lightning protection, it was felt that a brief overview was required as given below. Where further information is required, this can be referenced from BS EN 62305.

In most cases the ceraunic value (number of thunderstorm days per year for a given installation location in the UK) does not reach a level at which particular protective measures need to be applied. However where buildings or structures are considered to be at greater risk, for example very tall, or in an exposed location, the designer of the a.c. electrical system may have chosen to design or apply protective measures such as installation of conductive air rods or tapes.

If the building or dwelling is fitted with a lightning protection system (LPS), a suitably qualified person should be consulted as to whether, in this particular case, the array frame should be connected to the LPS, and if so what size conductor should be used.

Where an LPS is fitted, PV system components should be mounted away from lightning rods and associated conductors (see BS EN 62305). For example, an inverter should not be mounted on an inside wall that has a lightning protection system down conductor running just the other side of the brickwork on the outside of the building.

Where there is a perceived increase in risk of direct lightning strike as a consequence of the installation of the PV system, specialists in lightning protection should be consulted with a view to installing a separate lightning protection system in accordance with BS EN 62305.

Note: It is generally accepted that the installation of a typical roof-mounted PV system presents a very small increased risk of a direct lightning strike. However, this may not necessarily be the case where the PV system is particularly large, where the PV system is installed on the top of a tall building, where the PV system becomes the tallest structure in the vicinity, or where the PV system is installed in an open area such as a field.

2.2.2 Earthing

Earthing is a means of connecting the exposed conductive parts to the main earthing terminal, typically this definition means the connection of metallic casings of fixtures and fittings to the main earthing terminal via a circuit protective conductor (cpc).

Importantly, it must be noted that we only make this connection when the accessory or appliance requires it. This connection is required when it is considered to be a class I appliance or accessory and is reliant on a connection with earth for safety using ‘automatic disconnection of supply’ (ADS) as the fault protective measure.

As the d.c. side of PV systems is a current limiting generating set, the protective measure ADS is almost never used and is outside of the scope of this guidance. In these circumstances, where the d.c. side of the installation is constructed to meet the requirements of an installation using double or reinforced insulation, no connection to earth between the PV Modules or frame and main earthing terminal would be required.

Earthing of the inverter at the a.c. terminations will still be necessary where the inverter is a Class I piece of equipment and must be applied where necessary. Where class I inverters are used externally (ie field mount systems) careful consideration must be given to the requirements for earthing.

2.2.3 Protective Equipotential Bonding

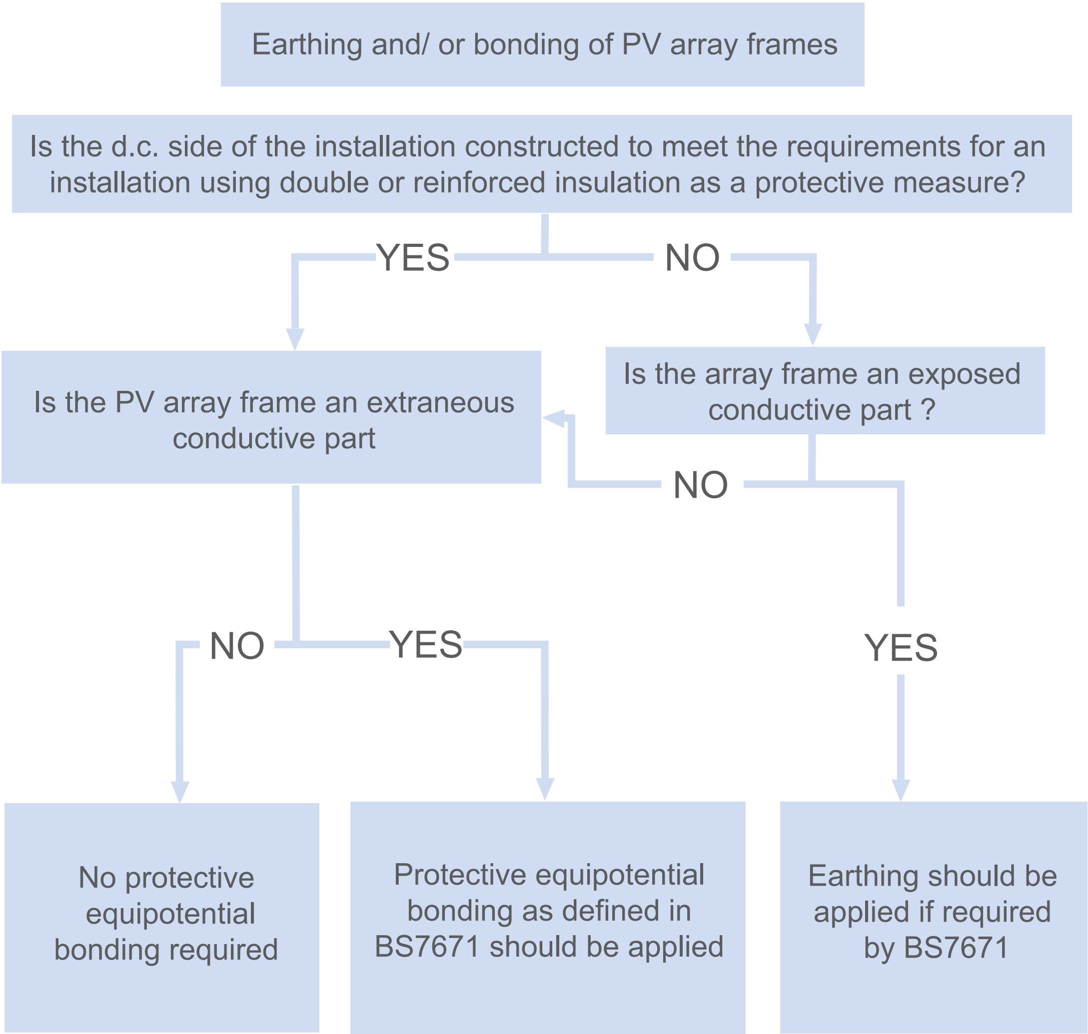
Protective equipotential bonding is a measure applied to parts of the electrical installation which, under fault conditions may otherwise have a different potential to earth. By applying this measure the risk of electric shock is limited as there should be little or no difference in voltages (potential difference) between the parts that may otherwise become live. These parts are categorised as either Exposed-Conductive-Parts or Extraneous-Conductive-Parts

In most PV systems there are no parts that are considered to be an exposed-conductive-part or extraneous-conductive-part, therefore protective equipotential bonding is not usually required. For guidance on when to consider protective equipotential bonding please see the decision tree on the next page.

On the d.c. side of the PV installation the designer will have usually already selected double or reinforced insulation as the protective measure and therefore the component parts of the installation will be isolated and will not require protective equipotential bonding.

Earthing and or Bonding Decision Tree:

Fig 10



2.2.4 Determining an Extraneous-Conductive-Part

The frame of the array has to be assessed as to whether it is likely to introduce a potential into the installation. This aim of this assessment is to find out if the frame has any direct contact with ground that would make it introduce a potential.

The details on carrying out these tests are best given in the IET BS 7671 Guidance Note 8 Earthing & Bonding and this should be referred to before undertaking a test. The principle behind the test is to ascertain whether or not there is a low enough conductivity between the part under test and the Main earthing terminal (MET) to say that it could introduce an earth potential.

To find this out a resistance test should be carried out between the part in question (the array frame) and the MET of the building. Where the value recorded is greater than 22kΩ (most cases) the part can be considered to be isolated from earth and NOT an extraneous conductive part. If however the reading is less than 22kΩ, then the part is considered to be extraneous and protective equipotential bonding, as required by BS 7671, should be applied.

Where the array frame is mounted on a domestic roof or similar, the likelihood of the frame being an extraneous-conductive-part is very low - due to the type and amount of material used between the ground and the roof structure (which will mainly be non-conductive). Even in the case of an array frame being mounted on a commercial building where mostly steelwork is used, it is likely that the frame will be either isolated, and therefore not required to be bonded, or will be bolted to the framework or steelwork of the building which will often be sufficient to maintain bonding continuity and a sufficiently low enough resistance to consider it to be bonded through the structure itself.

Careful consideration needs to be given to systems that are ground mounted as they may initially appear to be an extraneous-conductive-part. However, as they are usually a good distance away from the earthed equipotential zone, by bonding them you may well be introducing a shock risk that wasn't there initially, and in the case of an installation supplied by a TN-C-S (PME) supply you may be contravening the supply authority's regulations (ESCQR 2002). In most cases these installations wouldn't require bonding – in such cases the designer must make an informed decision based on the electrical design of the entire installation, not just the PV system in isolation.

2.2.5 System Earthing (d.c. Conductor Earthing)

There are a variety of possible PV array system d.c. earthing scenarios which can be broadly summarised as follows:

- No earth connection
- Hardwired connection of positive or negative conductor to earth
- Centre tapped array – with / without earth connection
- High impedance connection of positive or negative conductor to earth (for functional reasons)

The manufacturer's instructions for both the PV modules and the equipment to which the PV array is connected must be taken into account in determining the most appropriate earthing arrangement.

A connection to earth of any of the current carrying d.c. conductors is not recommended. However, earthing of one of the live conductors of the d.c. side is permitted, if there is at least simple separation between the a.c. and the d.c. side. Where a functional earth is required, it is preferable that where possible this be done through high impedance (rather than directly).

The designer must confirm whether the inverter is suitable for earthing of a d.c. conductor. Transformerless inverters will not be suitable, and an earthed conductor may interfere with the inverter's built-in d.c. insulation monitoring. Hence, if an earthed d.c. conductor is required, this is ideally done in the inverter in accordance with guidance from the inverter manufacturer.

NOTE: In the case of PV systems connected to an inverter, IEC62109-2 (Safety of Power convertors for use in photovoltaic power systems – Part 2: Particular requirements for inverters), includes requirements according to the type of earthing arrangement (and inverter topology). These include minimum inverter isolation requirements, array ground insulation resistance measurement requirements and array residual current detection and earth fault alarm requirements.

2.2.5.1 Systems with High Impedance Connection to Earth

A high impedance connection to earth of one of the current carrying conductors may be specified where the earth connection is required for functional reasons. The high impedance connection fulfils the functional requirements while limiting fault currents.

Where a functional earth is required, it is preferred practice that systems be functionally earthed through high impedance rather than a direct low impedance connection (where possible).

2.2.5.2 Systems with Direct Connection to Earth

Where there is a hardwired connection to earth, there is the potential for significant fault currents to flow if an earth fault occurs somewhere in the system. A ground fault (earth fault) interrupter and alarm system can interrupt the fault current and signal that there has been a problem. The interrupter (such as a fuse) is installed in series with the ground connection and selected according to array size. It is important that the alarm is sufficient to initiate action, as any such earth fault needs to be immediately investigated and action taken to correct the cause.

An earth fault interrupter shall be installed in series with the earth connection of the PV array such that if an earth fault occurs the fault current is interrupted. When the earth fault interrupter operates, an alarm shall be initiated. The nominal overcurrent rating of the interrupter shall be as follows:

Array size	Overcurrent rating
≤3kWp	≤1A
3- 100KWp	≤3A
>100kWp	≤5A

The earth fault alarm shall be of a form that ensures that the system operator or owner of the system becomes immediately aware of the fault. For example, the alarm system may be a visible or audible signal placed in an area where operational staff or system owners will be aware of the signal or another form of fault communication like Email, SMS or similar

NOTE: In grid connected systems, an earth fault alarm may be a feature of the inverter. In such systems and where the inverter is located in a remote location, the system should be configured so that a secondary alarm is triggered that will be immediately seen by the system operator. For systems in accordance with BS 7671 conductors used for earth fault detection are usually cream in colour.

2.2.6 Surge Protection Measures

All d.c. cables should be installed to provide as short runs as possible and positive and negative cables of the same string or main d.c. supply should be installed together, avoiding the creation of loops in the system. This requirement includes any associated earth/bonding conductors.

Long cables (e.g. PV main d.c. cables over about 50 m) should be installed in earthed metal conduit or trunking, or be screened cables such as armoured.

Note: These measures will act to both shield the cables from inductive surges and, by increasing inductance, attenuate surge transmission. Be aware of the need to allow any water or condensation that may accumulate in the conduit or trunking to escape through properly designed and installed vents.

Most grid connect inverters have some form of in-built surge suppression; however discrete devices may also be specified.

Note: Surge protection devices built into an inverter may only be type D and a designer may wish to add additional (type B or C) devices on the d.c. or a.c. side. To protect the a.c. system, surge suppression devices may be fitted at the main incoming point of a.c. supply (at the consumer's cut-out). To protect the d.c. system, surge suppression devices can be fitted at the inverter end of the d.c. cabling and at the array. To protect specific equipment, surge suppression devices may be fitted as close as is practical to the device.

2.3 Design Part 3 – a.c. System

2.3.1 a.c. Cabling

The PV system inverter(s) should be installed on a dedicated final circuit to the requirements of BS 7671 in which:

- No current-using equipment is connected, and
- No provision is made for the connection of current-using equipment, and
- No socket-outlets are permitted.

Note: For the purposes of this guide a datalogger is not considered current-using equipment and can be connected into the same final circuit as the PV system.

Where a single circuit feeds more than one inverter, the protective device for that circuit shall be less than the maximum MCB rating recommended by the inverter manufacturer(s). An inverter must not be connected by means of a plug with contacts which may be live when exposed and a.c. cables are to be specified and installed in accordance with BS 7671.

The a.c. cable connecting the inverter(s) to the consumer unit should be sized to minimise voltage drop. A 1% drop or less is recommended. However in larger installations this may not be practicable or economic due to the very large size of cable resulting. In this case the designer should minimise voltage drop as far as possible and must remain within voltage drop limits as prescribed by BS 7671.

Note: The recommendation for a 1% voltage drop is due to two reasons: firstly when generating, the voltage at the inverter terminals is higher than the voltage at the supplier's cutout – during periods of high power output this voltage drop must be kept to a minimum in order to prevent the inverter nuisance tripping on over voltage ; secondly the requirement ensures losses from the PV system are minimised.

2.3.2 RCD Protection

Where an electrical installation includes a PV power supply system that cannot prevent d.c. fault currents from entering the a.c. side of the installation, and where an RCD is needed to satisfy the general requirements of the electrical installation in accordance with BS 7671, then the selected RCD should be a Type B RCCB as defined in IEC 62423. Where any doubt exists about the capability of the inverter to prevent d.c. fault currents entering the a.c. side of the system then the manufacturer shall be consulted.

Types of RCD

The selection of RCD's in respect of load d.c. components is an issue that is often overlooked by designers. RCD's are classified according to their response to d.c.signals as follows:

- **Type A.C.** This class of device generally only detect sinusoidal alternating residual currents. They may not detect non-sinusoidal, non-alternating residual components. These non-sinusoidal currents are present in many items of equipment – for example, virtually all equipment with a switched mode power supply will have a d.c. component.
- **Type A** This class of device will detect residual current of both a.c. and pulsating d.c. and are known as a d.c. sensitive RCD's. They cannot be used on steady d.c. loads.
- **Type B** This type will detect a.c., pulsating d.c. and steady d.c. residual currents.

RCD's are required to be marked with their type and the following table shows the markings and provides selection criteria.

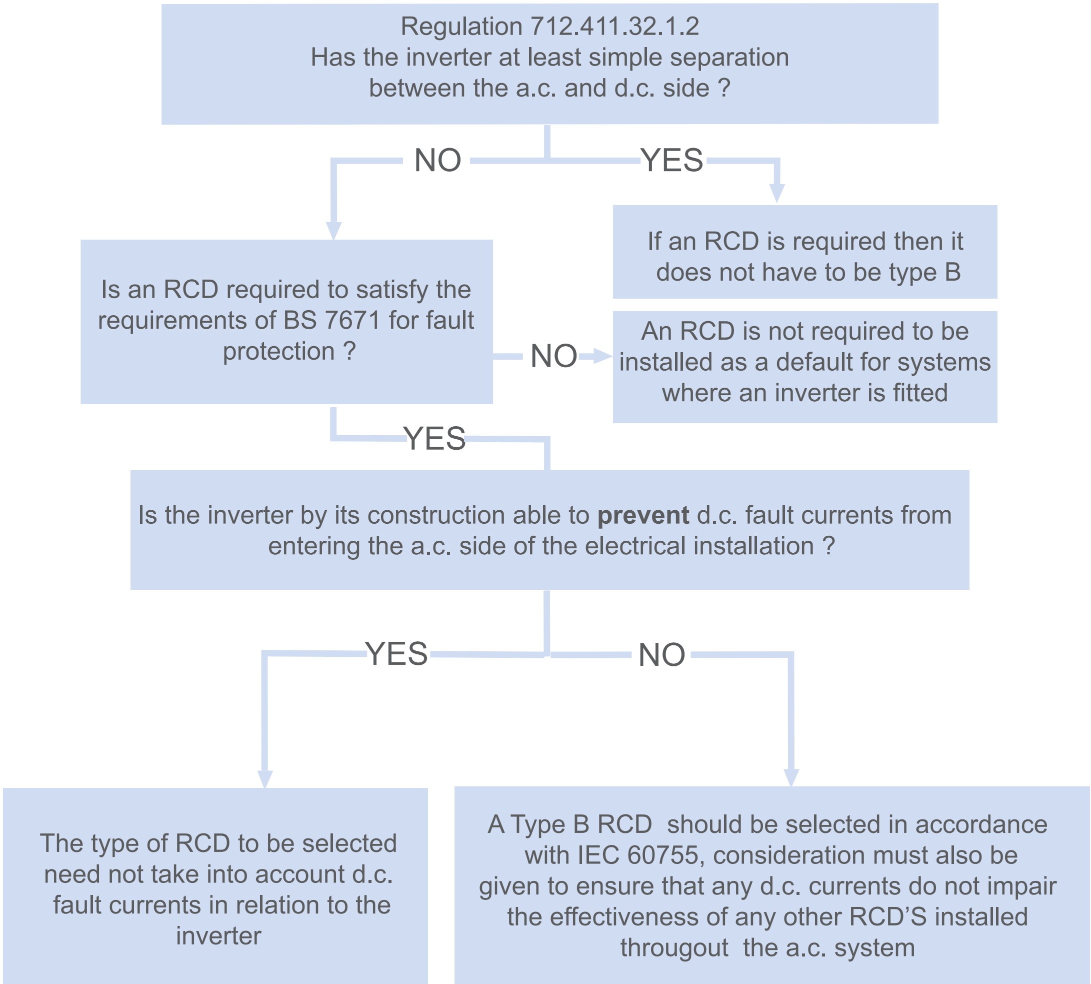
Fig 11

Supply	Form of Residual Current	Recommended type of symbol AC	A	B
Sinusoidal A. C.	Suddenly applied Slowly rising	✓	✓	✓
Pulsating D.C.	Suddenly applied Slowly rising		✓	✓
Smooth D.C.				✓

The following decision tree can be used to determine the correct selection of the type of RCD in accordance with Regulation 712.411.3.2.1.2 of BS 7671.

RCD Decision Tree:

Fig 12



2.3.3 a.c. Isolation and Switching

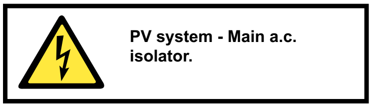
To comply with the requirements of Engineering Recommendations G83 / G59:

The PV system shall be connected to an isolation switch that fulfils the following conditions:

- Isolates line and neutral conductors
- Be securable in the OFF position
- Located in an accessible location

This switch shall clearly show the ON and OFF positions and be labelled as 'PV system – main a.c. isolator'

Fig 13



Isolation and Switching of the a.c. side of the installation shall also comply with the requirements of BS 7671.   This is to include the provision of an isolator adjacent to the inverter to disconnect the inverter from the source of supply (AC).

In its simplest form, for a single phase inverter, an unswitched fused connection unit mounted adjacent to the inverter may be used to fulfil this requirement, see figures 1 and 2 for a typical layout. It is however suggested that for the purposes of routine maintenance a switched fused connection unit offers a better degree of control and therefore should be used as a minimum.

Note: At the point of installation of any a.c. switch-disconnector, the public supply should be considered the source and the PV installation the load.

2.3.4 Inverters

Inverters must carry a Type Test certificate to the requirements of Engineering Recommendation G83 or G59 (as applicable – see section 2.4.1) unless specifically agreed by an engineer employed by or appointed by the DNO for this purpose, and in writing.

Note: A key safety consideration is that the PV system will disconnect 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. Engineering recommendations G83 and G59 ensure that a PV system is properly prevented from such islanding operation. Other considerations addressed by these Engineering Recommendations include the prevention of harmonics, EMC compatibility and d.c. injection.

Fig 14

2.3.4.1 Inverter Sizing

The sizing of an inverter for a grid connected PV system is influenced by a number of factors, including:

- The inverters available for use in the UK (not all manufacturers have G83 / G59)
- Array voltage fluctuations due to operating temperature
- The maximum permissible d.c. input voltage of the inverter
- The MPP (maximum power point) voltage range of the inverter
- The desired inverter – array power ratio

Inverter matching is to be done using the guidance from the inverter manufacturer – typically using the manufacturer's system sizing software.

Where a system features multiple strings/arrays with significantly different orientation or inclination, the strings or arrays should be connected to an inverter with a multiple MPPT function or separate inverters should be utilised. This is only required where the variations in orientation or inclination are such that connecting the strings/arrays to a single MPPT input may significantly reduce the overall performance of the system.

The inverter must be selected to safely withstand the maximum array voltage and current (as highlighted in section 2.1.2). This must include any initial overvoltage period which is a feature of some module types. This is to include verifying that the inverter can safely withstand the array open circuit voltage maximum at -15°C.

Temperature range - While an inverter must be able to safely withstand array operation between -15°C to 80°C (see section 2.1.2), it is permissible for a narrower temperature band (e.g. -10°c to 70°c) to be used when looking at the operational mpp range of the inverter. In such cases, an assessment should be made as to the temperature range acceptable and appropriate for that particular site and array mounting method (eg some building integrated systems will operate at higher temperatures than "on-top" systems)

Power ratio - It is common practice for an inverter power to be less than the PV array rating. In the UK, inverters are typically sized in the range of 100 - 80% of array capacity. However, in certain circumstances and depending on the inverter used, ratios outside this are sometimes utilised (NB: Inverter power is taken to be maximum steady state a.c. power output).

Inverter ventilation – Inverters generate heat and should be provided with sufficient ventilation. Clearance distances as

Fig 15

specified by the manufacturer (e.g to a heatsink) should also be observed. Inverter locations such as Plant or Boiler rooms, or roof spaces prone to high temperatures, should be carefully considered to avoid overheating.

Failure to follow this can cause a loss in system performance as the inverter will de-rate when it reaches its maximum operating temperature. This should be highlighted within the operation and use manual, left with the customer and ideally with a label – “not to block ventilation” – placed next to the inverter.

NOTE: It is recommended that Inverters carry a sign ‘Inverter - isolate a.c. and d.c. before carrying out work’.

2.3.5 a.c. Cable Protection

Protection for the cable from the inverter(s) must be provided at the distribution board. This protective measure shall be specified and installed in accordance with the requirements of BS 7671.

In very many cases the current limiting nature of the PV array and inverter(s) omits the requirements for overload protection and therefore the designer only need to consider fault current protection.

The protection afforded at the origin of the circuit (the distribution board) in accordance with BS 7671, means there is no requirement for additional overcurrent protection to be installed at the inverter end of the a.c. installation.

2.3.6 Metering

Inverter output meter: As a minimum, metering at the inverter output should be installed to display/record energy delivered by the PV system (kWh). In addition it is highly recommended for instantaneous power output (kW) to be displayed.

This will not only add to customer satisfaction it should lead to more effective fault detection. An approved kWh meter as detailed in the “Metering Guidance” document issued by MCS, connected to measure generation, will be required to facilitate payments of any financial incentives (e.g. Feed in Tariff payments).

The meter should be located where the consumer can readily observe it.

Building Export meter: Although not directly part of the PV system, where required in order to enable payment on exported electricity, an approved kWh export meter with appropriate reading capabilities may be required.

The appropriate Energy Supplier should be contacted to find out any particular requirements and to arrange for its fitting.

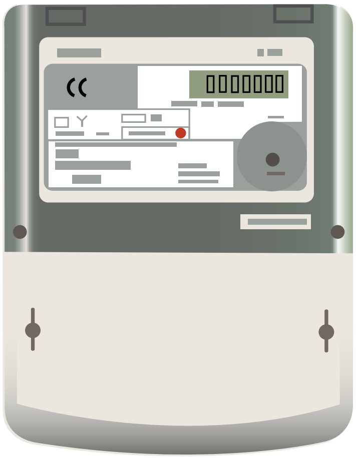


Fig 16

2.4 Design Part 4 – Design Approval

2.4.1 DNO Approval (Grid Connected Systems)

Engineering Recommendations issued by the Electricity Network Association, govern key aspects concerning the grid interface of a solar PV system. Systems up to 16A, AC output per phase, come under Engineering Recommendation G83. This would correspond to 3.68kW single phase (230v Nominal) and 11.04kW three phase (400v nominal). Systems over 16A per phase come under Engineering Recommendation G59.

Installers are required to gain approval and inform the relevant distribution Network Operator (DNO) of the installation of a grid connected PV system in the following manner:

a) Single installation ≤ 16A/phase using G83 type tested inverter(s)

- Notification using G83 commissioning form within 28 days following commissioning of the installation, to the DNO's designated contact details.

b) Multiple installations in close geographical proximity less than 16A/phase using G83 type tested inverter(s)

- Application to connect submitted to DNO - using G83 multiple system application form
- Approval for connection to be received prior to installation.
- Notification within 28 days of commissioning using G83 commissioning form

c) Systems up to 50kW (AC) 3-phase or 17kW single phase using G59 type approved inverters(s)

- Application to connect submitted to DNO using G59 application form
- Approval for connection to be received prior to installation
- Commissioning to be performed to the requirements of the DNO (witness testing not typically required)
- Notification within 28 days of commissioning using G59 Appendix A13.2 commissioning form

d) All other systems

- Application to connect submitted to DNO using G59 application form
- Approval for connection to be received prior to installation.
- Additional interface protection measures to be approved by DNO
- Commissioning to be performed to the requirements of the DNO
- Notification within 28 days of commissioning using G59 Appendix A13.3 commissioning form

2.4.2 Planning Permission

The relevant planning authority should be consulted at an early stage to determine if planning permissions are required.

Under most circumstances for domestic dwellings, the PV array can be installed under the amendments made in the General Permitted Development Order (GPDO), or the Town and Country Planning (General Permitted Development) (Domestic Microgeneration) (Scotland) Amendment Order 2009.

These grant rights to carry out certain limited forms of development on the home, without the need to apply for planning permission. However this may not be the case in areas of outstanding natural beauty (AONB), national parks conservation areas etc. Recent changes to planning regulations now also allow for similar provisions for commercial installations. Further information can be obtained from consult the planning portal at www.planningportal.gov.uk/planning.

2.4.3 Building Regulations

All installation work in or around occupied structures will be covered by the building regulations. Different sets of regulations apply depending on the geographical area within the UK. Whilst all of the regulations are set out and worded slightly differently, they all have the same aims and objectives of ensuring that the buildings that they cover are built and maintained in safe, reliable and most energy efficient way. It should be noted that by adding additional equipment to an electrical installation, it may be necessary to provide appropriate fire detection measures.

2.4.3.1 England & Wales

These regulations are segregated into parts A-P which individually cover key aspects of the buildings safety and performance. When installing a Photovoltaic system the work has to comply with all parts of the building regulations, these parts of the regulations cover the following aspects of work;

Those which are most immediately relevant to the installation of a PV system have been highlighted below (✓), however it must be noted that other parts may also apply, and where they do compliance must be achieved.

- A. Structure ✓
- B. Fire Safety ✓
- C. Resistance to contaminants and moisture ✓
- D. Toxic Substances
- E. Resistance to sound
- F. Ventilation
- G. Sanitation, Hot water safety and water efficiency
- H. Drainage and waste disposal
- J. Heat Producing Appliances
- K. Protection from falling
- L. Conservation of fuel and power
- M. Access to and use of buildings
- N. Glazing safety
- P. Electrical safety ✓

In all cases notification has to be made to the local area building control (LABC) that the work has taken place. Notification can take place several ways but the two principle methods are:

1. Submitting a building notice to the LABC (has to be prior to work commencing)
2. Notifying the work through a competent persons scheme – this can be done after the work has been completed

Note: Where it is determined that structural work is required to alter or strengthen a roof prior to the installation of the PV system – such works will always require a building notice to be submitted. Where it has been determined that the structure can accept the loads concerned, either a building notice or notification via a competent persons scheme is deemed to meet the requirements of the building regulations.

Generally those involved with PV installation work will want to use method 2 or employ contractors who use method 2 as method 1 can be expensive and time consuming.
When registering with a competent person's scheme, an installer can register for one or more categories of work. PV system installers will typically register under a scheme that offers notification of Microgeneration and part P work categories (to cover both of the key aspects). Successful registration will mean that an installer will be able to install and then notify the work after completion (within 30 days).

It is important to note that although registered under a "key" category of work the registrant is also responsible for ensuring compliance with all other categories of work. The registrant should also be aware that these other categories are also covered by the certificate of compliance that the householder receives from the competent person's scheme. This is especially important factor to PV installers as it means that not only are they specifically notifying that the electrical and microgeneration work is compliant, but it also covers all other applicable aspects of the building regulations including part A (structure).

The following table summarises the routes for registering an installation:

Installer status			Activities that require notification	
			PV array notification Row 17 of schedule 3 of the building regulations (microgeneration)	New a.c. circuit / installation of a generator notification Row 12 of schedule 3 of the building regulations (electrical)
MCS Only	MCS and CPS for renewables only	MCS, CPS for renewables & Part P		
✓			Notification must be done direct to LABC	Notification done direct to LABC unless installer uses a Part P registered subcontractor
	✓		Notification made through competent persons scheme for row 17 (microgeneration)	Notification done direct to LABC unless installer uses a Part P registered subcontractor
		✓	Notification made through competent persons scheme for row 17 (microgeneration)	Notification made through competent persons scheme for row 12

Notes:
1. A full list of Competent Person Scheme (CPS) providers can be found on the CLG website at:
http://www.communities.gov.uk/planningandbuilding/buildingregulations/competentpersonsschemes/existingcompetentperson/

2.4.3.2 Scotland

All solar PV systems installed on a building must comply with the requirements of the Building (Scotland) Regulations 2004 as amended. Guidance on complying with the Building (Scotland) Regulations 2004 as amended is given in the two Scottish Building Standards (SBS) Technical handbooks (Domestic and Non-domestic)

Each handbook has seven sections:

Section1 – Structure	(Mechanical resistance and stability)
Section 2 – Fire	(Safety in fire)
Section 3 – Environment	(Hygiene, health and the environment)
Section 4 – Safety	(Safety in use)
Section 5 – Noise	(Protection against noise)
Section 6 – Energy	(Energy, economy and heat retention)
Section 7 – Sustainability	(Sustainable use of natural resources)

Each of the seven sections consists of an introduction and guidance on the individual standards within each Section. Where any building contains both domestic and non-domestic use, it is a general principle that the more stringent of the two sets of recommendations should be used.

New Buildings - For a new building (domestic or non-domestic) which includes the installation of a solar PV system the installation of the system will be covered by a building warrant and therefore must comply with the relevant functional standards.

Existing Buildings - For an existing one or two storey dwelling which is capable of supporting the solar PV equipment without structural alterations a building warrant is not required, however if the existing structure of the dwelling requires strengthening a building warrant will be necessary. For an existing building, guidance issued by the Scottish Governments Building Standards Division states that before installing PV panels on an existing roof, a structural appraisal should be undertaken by a competent person.(see section 4.4.2). Further information on this can be found at:

http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubverletts/lettdommicrogen

Further advice on specific projects can also be obtained by contacting the relevant local authority's Building Standards office. Information on which is the relevant local authority for any given location can be obtained from the website of the Scottish Association of building Standards Managers (SABSM)

http://www.sabsm.co.uk/ system performance

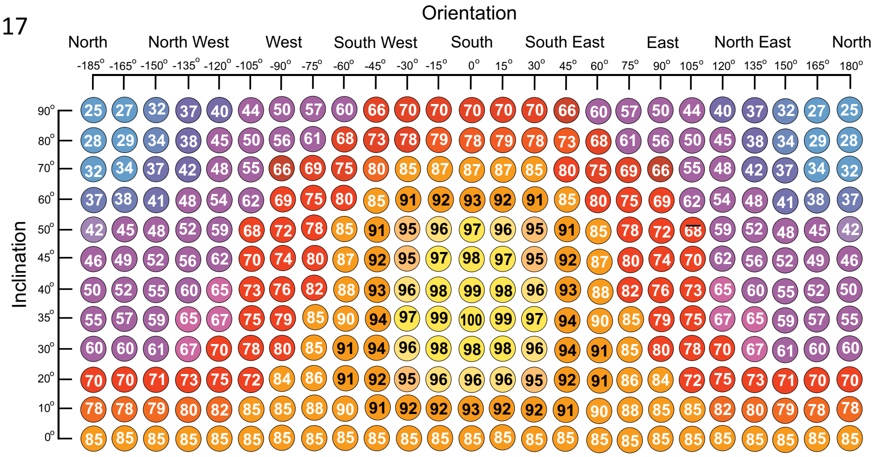
3 System Performance

3.1 Array Orientation and Inclination

The effect of variations in array orientation and inclination on system performance is shown in the chart below. The example shown is for a location in the middle of the UK and represents the percentage of maximum yield you may expect to get for different angles and orientations.

<u>This chart is indicative only and should not be used for the calculation of performance estimates</u>

Fig 17



3.2 Shade Effects

Shade makes a big impact on the performance of a PV system. Even a small degree of shading on part of an array can have a very significant impact on the overall array output. Shade is one element of system performance that can be specifically addressed during system design – by careful selection of array location, equipment selection and layout and in the electrical design (string design to minimise shade effects).

Shading from objects adjacent to the array (for example: vent pipes, chimneys, and satellite dishes) can have a very significant impact on the system performance. Where such shading is apparent, either the array should be repositioned out of the shade zone, or where possible the object casting the shade should be relocated.

3.3 Geographical Location

The amount of irradiance that falls onto the earth's surface alters across the UK according to several factors. The most significant factor is the location in respect of latitude (distance from the equator).

Generally speaking the further the array is from the equator the less irradiation there will be; subsequently the further North the installation is the less output can be expected from a PV system. This does not preclude systems in the north as there are other factors to consider.

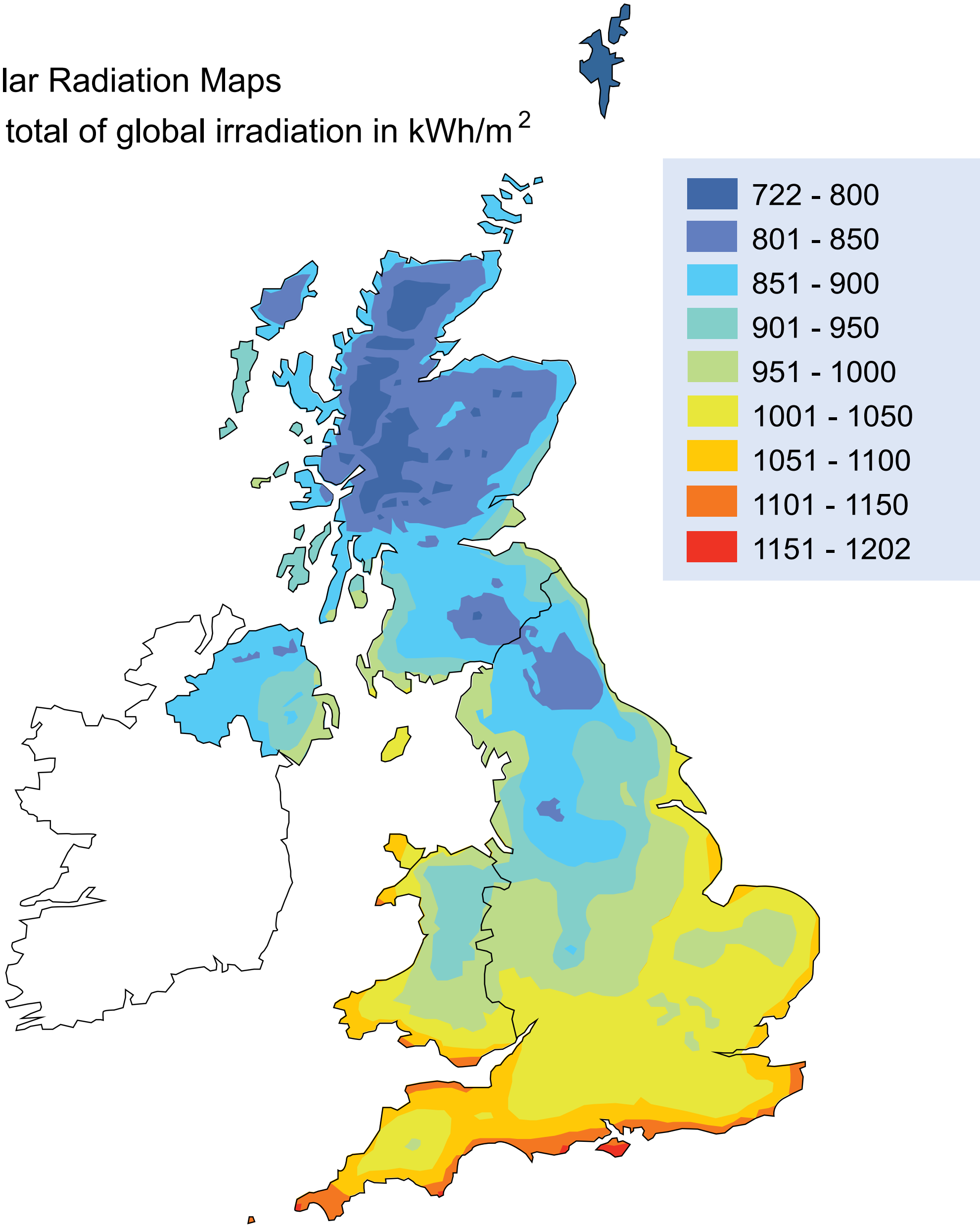
In order to assess these differences the performance estimate in section 3.7 shall be used to make any comparisons.

The variation in irradiance across the UK is shown on the following map:

UK Solar Radiation Maps

Yearly total of global irradiation in kWh/m^2

Fig 18



Average period: 1993 - 2007

Picture courtesy of the Met Office

3.4 Temperature Effects

Module temperature – An increase in module temperature results in a decrease in performance (eg 0.5% per 1°C above stc for a crystalline module). Sufficient ventilation must be provided behind an array for cooling (typically a minimum 25mm vented air gap to the rear). For building integrated systems, this is usually addressed by the provision of a vented air space behind the modules. On a conventional pitched roof, batten cavity ventilation is typically achieved by the use of counterbattens over the roof membrane and by the installation of eaves and ridge ventilation.

Note: It may be possible to omit counterbattens with some integrated PV roofing products / roof construction. This is acceptable where there is test data showing that a specific integrated PV product and associated roof construction provide a similar PV cell temperature performance to a roof with a ventilated counterbatten space.

3.5 Other Factors

A variety of other factors will also affect system performance, including:

- Panel characteristics & manufacturing tolerances
- Inverter efficiency
- Inverter – array matching
- Cable losses
- Soiling of the array (more relevant in certain locations)
- Grid availability
- Equipment availability (system down-time due to equipment failures)

3.6 Daily and Annual Variation

Typical daily and annual insolation curves, together with the monthly and seasonal trend in system performance are shown in the charts below.

Fig 19

Daily W/m2 per hour

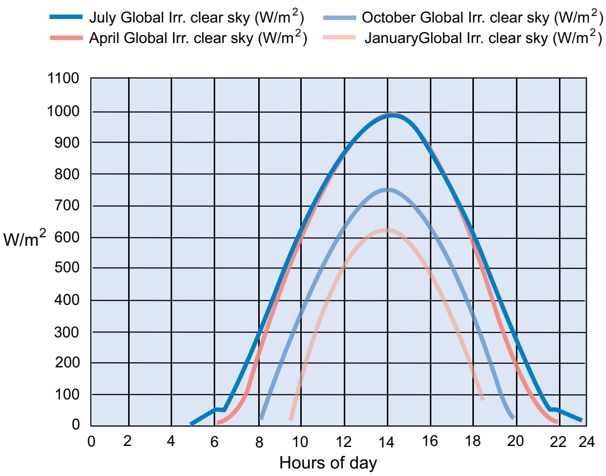
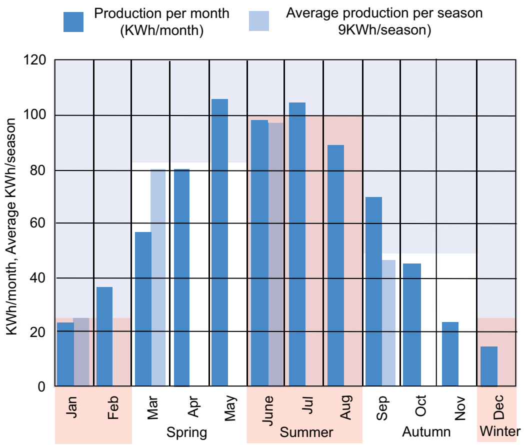


Fig 20

Yearly kWh per Month and season



3.7 Photovoltaic Performance Estimation

As can be seen above, the annual performance of a grid connected PV system depends on a large number of factors. Against this background, the methodology described below is necessarily simplified in order to create a standard method that can be used to achieve a reasonable estimation of performance without it being an unduly complex procedure.

The purpose of a standardised procedure is intended to prevent miss-selling and overestimation of PV systems – such that all customers will receive a system performance estimation completed to a standardised procedure.

3.7.1 Site Evaluation

Inclination, orientation and shading are the three main site factors that influence the performance of a PV system. While drawings, maps or photos are a suitable means to determine inclination and orientation, an accurate estimation of any shade effects will typically require a site visit.

In some circumstances however, data may need to be estimated or taken remotely. In such circumstances, any performance estimate provided to a customer should include the following statement:

“This system performance calculation has been undertaken using estimated values for array orientation, inclination or shading. Actual performance may be significantly lower or higher if the characteristics of the installed system vary from the estimated values.”

In all cases where inclination, orientation or shade has been estimated at quotation stage, e.g. for a new build development, a site survey shall be undertaken before installation commences.

Following the detailed site survey, where any factors do not match those given in the original performance estimate, the installation company shall recalculate the performance estimate and supply this in writing to the client.

If the adjusted performance estimate is worse than originally predicted, the client shall be given the same cooling off period and cancellation rights (to include any right to cancel without financial penalties) that applied to the original quote. This shall apply from the date of issue of the updated performance estimate.

3.7.2 Standard Estimation Method

The approach is as follows:

1. Establish the electrical rating of the PV array in kilowatts peak (kWp)
2. Determine the postcode region
3. Determine the array pitch
4. Determine the array orientation
5. Look up kWh/kWp (Kk) from the appropriate location specific table
6. Determine the shading factor of the array (SF) according to any objects blocking the horizon - using shade factor procedure set out in 3.7.7

The estimated annual electricity generated (AC) in kWh/year of installed system shall then be determined using the following formula:

Annual AC output (kWh) = kWp x Kk x SF

3.7.3 kWp of Array (kWp)

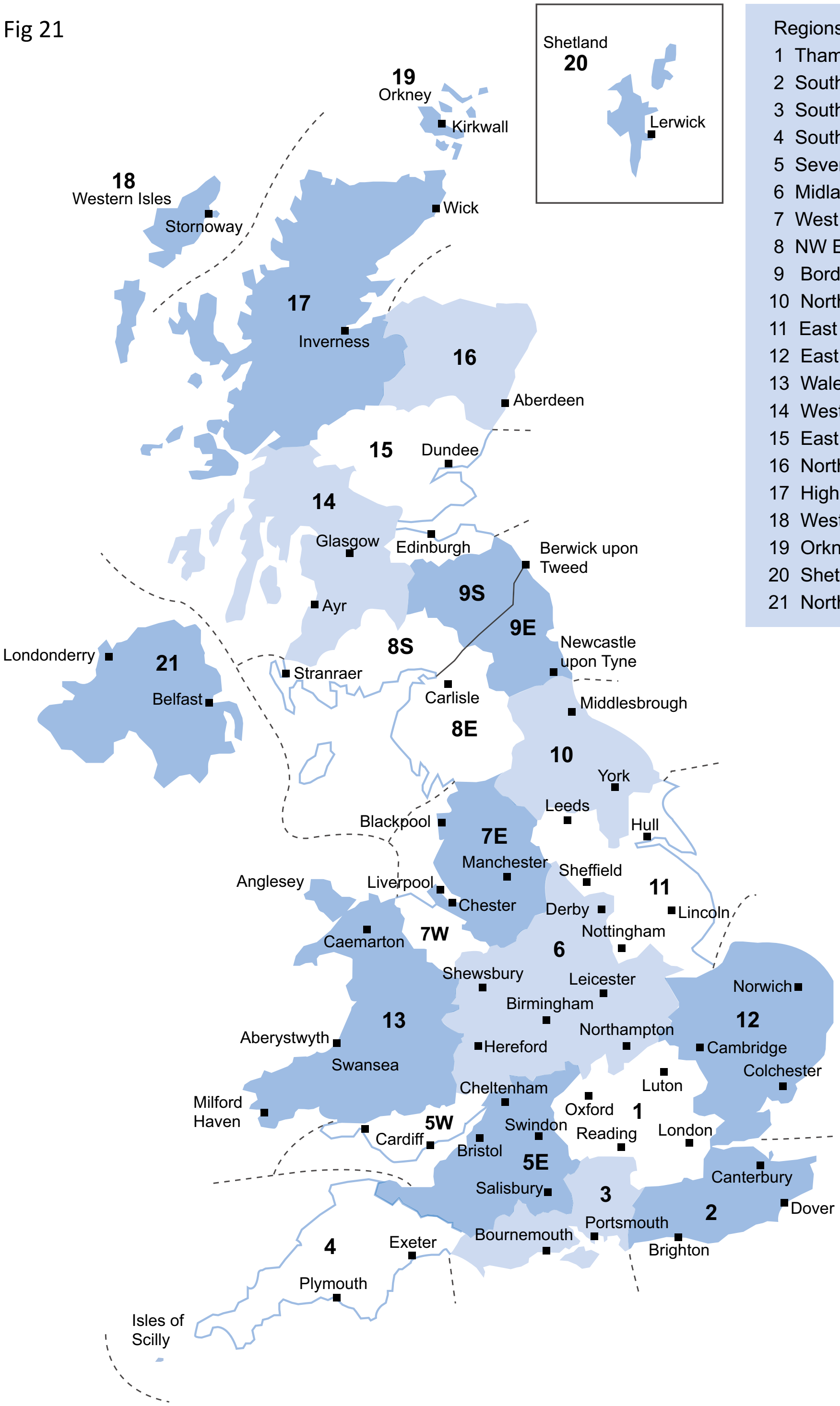
The kWp value used shall be the sum of the data plate value (Wp at STC) of all modules installed (the value printed on the module label).

3.7.4 Postcode Zone

Determine the postcode zone of the site from the map and the table on the following pages. Once this has been obtained, you will be able to select the correct table for the kWh/kWp (Kk) values to be selected.

Note: These zones are the same as the SAP postcode zones

Fig 21



Regions

1 Thames
2 South East England
3 Southern England
4 South West England
5 Severn
6 Midlands
7 West Pennines
8 NW England/ SW Scotland
9 Borders
10 North East England
11 East Pennines
12 East Anglia
13 Wales
14 West Scotland
15 East Scotland
16 North East Scotland
17 Highland
18 Western Isles
19 Orkney
20 Shetland
21 Northern Ireland

Postcode	Zone	Postcode	Zone	Postcode	Zone	Postcode	Zone
AB	16	G	14	N	1	SK	7E
AL	1	GL	5E	NE	9E	SK13	6
B	6	GU	1	NG	11	SK17	6
BA	5E	GU11-12	3	NN	6	SK22-23	6
BB	7E	GU14	3	NP	5W	SL	1
BD	11	GU28-29	2	NPS	13	SM	1
BD23-24	10	GU30-35	3	NR	12	SN	5E
BH	3	GU46	3	NW	1	SN7	1
BL	7E	GU51-52	3	OL	7E	SO	3
BN	2	HA	1	OX	1	SP	5E
BR	2	HD	11	PA	14	SP6-11	3
BS	5E	HG	10	PE	12	SR	9E
BT	21	HP	1	PE9-12	11	SR7-8	10
CA	8E	HR	6	PE20-25	11	SS	12
CB	12	HS	18	PH	15	ST	6
CF	5W	HU	11	PH19-25	17	SW	1
CH	7E	HX	11	PH26	16	SY	6
CH5-8	7W	IG	12	PH30-44	17	SY14	7E
CM	12	IP	12	PH49	14	SY15-25	13
CM21-23	1	IV	17	PH50	14	TA	5E
CO	12	IV30-32	16	PL	4	TD	9S
CR	1	IV36	16	PO	3	TD12	9E
CT	2	KA	14	PO18-22	2	TD15	9E
CV	6	KT	1	PR	7E	TF	6
CW	7E	KW	17	RG	1	TN	2
DA	2	KW15-17	19	RG21-29	3	TQ	4
DD	15	KY	15	RH	1	TR	4
DE	6	L	7E	RH10-20	2	TS	10
DG	8S	LA	7E	RH77	2	TW	1
DH	10	LA7-23	8E	RM	12	UB	1
DH4-5	9E	LD	13	S	11	W	1
DL	10	LE	6	S18	6	WA	7E
DN	11	LL	7W	S32-33	6	WC	1
DT	3	LL23-27	13	S40-45	6	WD	1
DY	6	LL30-78	13	S49	6	WF	11
E	1	LN	11	SA	5W	WN	7E
EC	1	LS	11	SA14-20	13	WR	6
EH	15	LS24	10	SA31-48	13	WS	6
EH43-46	9S	LU	1	SA61-73	13	WV	6
EN	1	M	7E	SE	1	YO	10
EN9	12	ME	2	SG	1	YO15-16	11
EX	4	MK	1			YO25	11
FK	14	ML	14			ZE	20
FY	7E						

3.7.5 Orientation

The orientation of the array is to be measured or determined from plan. The required value is the azimuth angle of the PV modules relative to due South. Hence, an array facing due south has an azimuth value of 0°; an array facing either SW or SE has an azimuth value of 45°; and an array facing either East or West has an azimuth value of 90°.

The azimuth value is to be rounded to the nearest 5°.

3.7.6 Inclination

The Inclination (or pitch) of the array is to be measured or determined from plan. The required value is the degrees from horizontal. Hence, an inclination of 0° represents a horizontal array; 90° represents a vertical array.

The inclination value is to be rounded to the nearest 1°.

3.7.6.1 kWh/kWp Value (Kk)

Tables of kWh/kWp (Kk) values are provided for each postcode zone. Abbreviated tables are contained in Annex D of this document. Full tables are available to download from the MCS website.

The tables provide kWh/kWp values for the zone in question for 1° variations of inclination (p[itch) and 5° variations of orientation.

Note: This data has been provided by the European Commission, Joint Research Centre. The data is drawn from the Climate-SAF-PVGIS dataset and multiplied by 0.8

3.7.7 Shade Factor (SF)

Where there is a potential for shading from objects further than 10m away from the centre midpoint of the array then the procedure given in 3.7.7.1 shall be applied, where there are objects at or less than 10m away from the centre midpoint of the array then the procedure stated in clause 3.7.7.2 shall be used **<u>in addition</u>** to the method in clause 3.7.7.1.

3.7.7.1 Determining shading factor as a result of objects further than 10m from the centre and midpoint of the array

Where there is an obvious clear horizon and no near or far shading, the assessment of SF can be omitted and an SF value of 1 used in all related calculations.

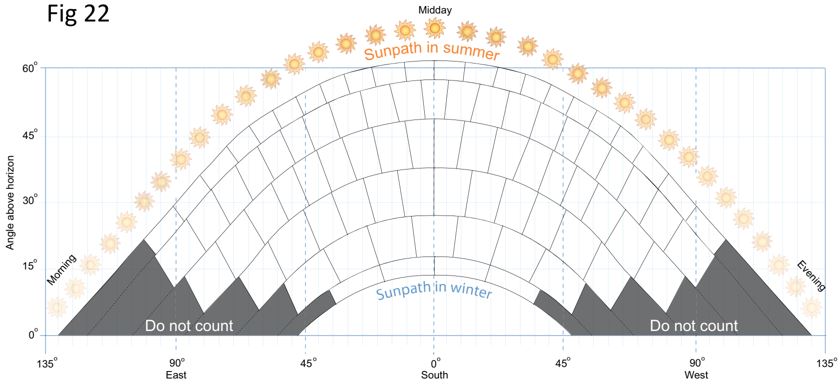
Where there is potential for shading, it shall always be analysed and the reading shall be taken from a location that represents the section of the potential array that is most affected by any shade. For systems with near shading this will typically be just to the North of the near shading object.

It is intended that this assessment provides an indicative estimate of the potential shading on the solar array. This is done by indicating how much of the potential irradiance could be blocked by objects on the horizon at differing times of the day and of the year (as indicated by the different arcs).

The sunpath diagram below shall be used to produce a shading analysis for all estimates produced.

Fig 22

The diagram shown has a total of 84 segments, each segment has a value of 0.01



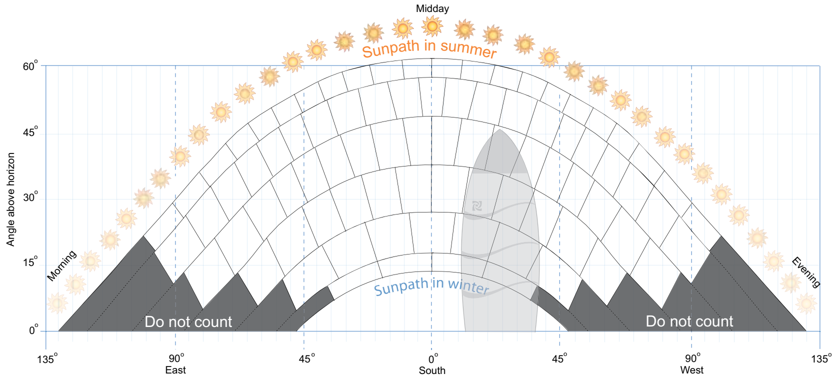
The potential shading is analysed as follows:

Stand as near as possible to the base and centre of the proposed array, e.g. through an upstairs window, unless there is shading from objects within 10m (e.g. aerials, chimneys, etc.), in which case the assessment of shading must be taken from a position more representative of the centre and base of the potentially affected array position.

Looking due south (irrespective of the orientation of the array), draw a line showing the uppermost edge of any objects that are visible on the horizon (either near or far) onto the sunpath diagram

Fig 23

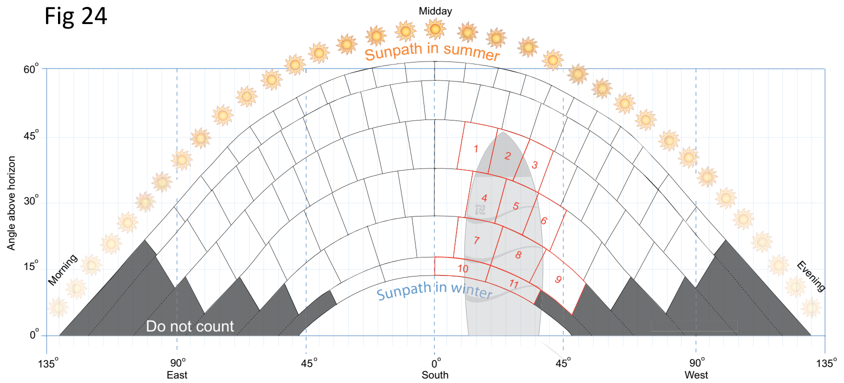
This line is called the *horizon line*, an example of which is shown here:



Note: There are purpose made instruments for undertaking sunpath assessments; the use of such instruments is optional

Once the horizon line has been drawn, the number of segments that have been touched by the line, or that fall **under** the horizon line shall be counted, in the following example you can see there are 11 segments covered or touched by the horizon line.

Fig 24



The total number of segments are multiplied by their value (0.01) and the total value shall be deducted from 1 to arrive at the shading factor.

The result will be the shading factor for the proposed installation, in our example the shading factor is calculated as follows:

1 - (11*0.01) = 1 – 0.11 = <u>0.89</u>

For systems connected to multiple inverters, or a single inverter with more than one MPP, it is acceptable to do a separate calculation of SF for each sub array (each array connected to a dedicated MPP tracker.

Note: installing a system will any significant near shading will have a considerable effect on array performance. Where possible any near shading on the array should be avoided.

IMPORTANT NOTE

This shade assessment procedure has been designed to provide a simplified and standardised approach for MCS installers to use when estimating the impact of shade on system performance. It is not intended to be as accurate as more sophisticated methods such as, for example, those included in proprietary software packages. It is estimated that this shade assessment method will yield results within 10% of the actual annual energy yield for most systems. Unusual systems or environments may produce different results.

Where the shading factor is less than 1 (i.e. any shading is present) the following disclaimer shall accompany the quotation:

“This shade assessment has been undertaken using the standard MCS procedure - it is estimated that this method will yield results within 10% of the actual annual energy yield for most systems.”

3.7.7.2 Determining shading factor as a result of objects at, or less than, 10m from the centre midpoint of the array

As noted previously, shading from objects adjacent to the array (for example: vent pipes, chimneys, and satellite dishes) can have a very significant impact on the system performance. Where such shading is apparent, either the array should be repositioned out of the shade zone, or where possible the object casting the shade should be relocated. Where some near shade remains, the following additional shade analysis procedure shall be undertaken in addition to the method described in 3.7.7.1:

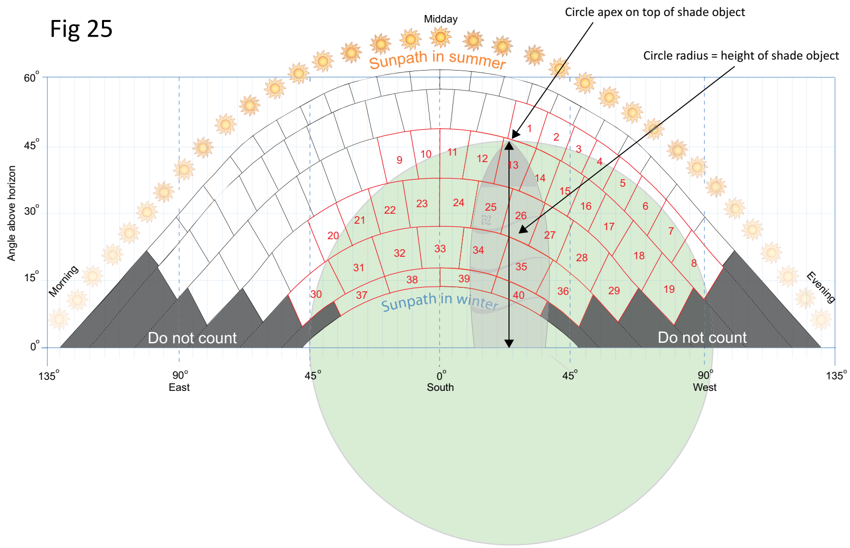
a. A standard horizon line, as described previously, shall be drawn - to represent the worst case (drawn from the array location most affected by shade)

b. In addition, any objects on the horizon diagram that are 10m or closer to any part of the array, shall have a shade circle added to the diagram to reflect the severe impact that these items may have on the array performance. Where there are multiple objects within 10m, then multiple circles shall be drawn – one for each object.

The shade circle shall have a radius equal to the height of the object. The shade circle should be located so that the apex of the circle sits on the highest point of the shade object.

All segments touched by or within the shade circle should be counted as part of the overall shade analysis.

Fig 25



Note: The above diagram uses the same shade object as the worked example in section 3.7.7. Assuming the object is near shade results in a shade factor of 0.6 (compared with 0.89 in the previous calculation).

3.7.8 Documentation

For systems under the MCS scheme, a performance estimate that determines the total annual a.c. energy output of a given system shall be communicated with the client before the point that the contract is awarded.

Along with the performance estimate, the client shall be provided with the sun path diagram and the information used to calculate the performance estimate as illustrated in the following table.

A. Installation data	
Installed capacity of PV system - kWp (stc)	kWp
Orientation of the PV system – degrees from South	°
Inclination of system – degrees from horizontal	°
Postcode region	
B. Calculations	
kWh/kWp (Kk) from table	kWh/kWp
Shade factor (SF)	
Estimated annual output (kWp x Kk x SF)	kWh

All quotations and / or estimates to customers shall be accompanied by one or more of the following disclaimers where applicable:

<u>For all quotations and / or estimates:</u>

"The performance of solar PV systems is impossible to predict with certainty due to the variability in the amount of solar radiation (sunlight) from location to location and from year to year. This estimate is based upon the standard MCS procedure is given as guidance only. It should not be considered as a guarantee of performance."

Additionally where data has been estimated or taken remotely (clause 3.7.1):

"This system performance calculation has been undertaken using estimated values for array orientation, inclination or shading. Actual performance may be significantly lower or higher if the characteristics of the installed system vary from the estimated values."

Additionally where the shade factor is less than 1 (clause 3.7.7):

"This shade assessment has been undertaken using the standard MCS procedure - it is estimated that this method will yield results within 10% of the actual annual energy yield for most systems."

3.7.9 Additional Estimates

Additional estimates may be provided using an alternative methodology, including proprietary software packages, but any such estimates must clearly describe and justify the approach taken and factors used and must not be given greater prominence than the standard MCS estimate. In addition, it must be accompanied by a warning stating that it should be treated with caution if it is significantly greater than the result given by the standard method.

4 INSTALLATION/SITEWORK

4.1 General

Standard health and safety practice and conventional electrical installation practice must apply to the installation of a PV system. Issues such as working on roofs or standard domestic a.c. wiring are covered thoroughly in other publications and are not detailed in this guide. Attention shall be paid to the location of accessories and equipment to ensure that any future service and maintenance can be carried out.

4.2 PV Specific Hazards

When compiling a method statement and risk assessment for the installation of a PV system, there are a number of PV specific hazards that need to be addressed. These will be in addition to standard considerations such as PPE (Personal Protective Equipment), working at height, manual handling, handling glass and the application of the construction design and management (CDM) regulations.

- PV modules produce electricity when exposed to daylight and individual modules cannot be switched off. Therefore unlike most other electrical installation work, the installation of a PV system typically involves working on a live system. See requirements of Regulation 14 of Electricity at Work Regulations 1989.
- As current limiting devices, PV module string circuits cannot rely on fuse protection for automatic disconnection of supply under fault conditions, as the short-circuit current is little more than the operating current. Once established, a fault may remain a hazard, perhaps undetected, for a considerable time.
- Good wiring design and installation practice will serve to protect both the system installers and any persons subsequently coming into contact with the system from an electric shock hazard (operator, owner, cleaner, service engineers, etc).
- Undetected, fault currents can also develop into a fire hazard. Without fuse protection to clear such faults, protection from this fire hazard can be achieved only by both a good d.c. system design and a careful installation.
- PV presents a unique combination of hazards – due to risk of shock, falling, and simultaneous manual handling difficulty. 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 will not be used to handling large objects at heights.

4.3 d.c. Circuits - Installation

4.3.1 Personnel

All persons working on the live d.c. cabling of a Photovoltaic (PV) system must be experienced / trained in working with such systems and fully acquainted with the voltages present on that system in particular.

Plug and socket connectors simplify and increase the safety of installation works – see section 2.1.7. They are recommended in particular for any installation being performed by a non-PV specialist – e.g. a PV array being installed by a roofer.

4.3.2 Sequence of Works

All d.c. wiring should if possible be completed prior to installing a PV array. This will allow effective electrical isolation of the d.c. system (via the d.c. switch-disconnector and PV module cable connectors) while the array is installed; and effective electrical isolation of the PV array while the inverter is installed.

Typically this would require an installation sequence of:

- d.c. switch-disconnector and d.c. junction box(es)
- String/array positive and negative cables - from the d.c. disconnect/junction box to either end of the PV string/array;
- PV array main cables from d.c. switch to inverter.

This should be carried out in such a way that it should never be necessary for an installer to work in any enclosure or situation featuring simultaneously accessible live PV string positive and negative parts.

Note: While the installer will be handling live cables during the subsequent module installation, because the circuit is broken at the d.c. switch-disconnector, there is no possibility of an electric shock current flowing from the partially completed PV string. The maximum electric shock voltage that should ever be encountered is that of one individual PV module.

Where it is not possible to pre-install a d.c. isolator (eg a new-build project where a PV array is installed prior to the plant room being completed), cable ends/ connectors should be put temporarily into an isolation box and suitably labelled (as per d.c. junction box – section 2.1.9).

Cables are to be well supported, especially those cables exposed to the wind. Cables must be routed in prescribed zones or within mechanical protection, fully supported / cable tied (using UV stabilised ties) and they must also be protected from sharp edges.

4.3.3 Live Working

Due to the nature of PV installation work live working is almost unavoidable. However, given the nature of the system design and so long as the system is designed to fully meet the requirements set out for shock protection by the use of double or reinforced insulation, working on one conductor only represents only a small risk which is usually mitigated by the use of appropriate tooling and operative care.

If it is unavoidable to work in any enclosure containing both positive and negative connections that are simultaneously live, work must be performed either by utilising insulating gloves & tools, insulating materials for shrouding purposes and appropriate personal protective equipment.

These situations are only likely to arise whilst working on larger systems and wherever possible these situations should be avoided by following the advice given in section 4.3.2.

A temporary warning sign and barrier must be posted for any period while live PV array cables or other d.c. cables are being installed.

A means to prevent the need for live working may be to work at night (with appropriate task lighting). Covering an array is also sometimes suggested as an alternative method. However, covering a PV array is not generally recommended due to the practical problems of keeping the array covered as the installation proceeds and protecting the covering from the effects of the weather.

4.3.4 Shock Hazard (Safe Working Practices)

It is important to note that, despite all the above precautions, an installer or service engineer may still encounter an electric shock hazard, therefore:

Always test for the presence of voltage of parts before touching any part of the system.

An electric shock may be experienced from a capacitive discharge – a charge may build up in the PV system due to its distributed capacitance to ground. Such effects are more prevalent in certain types of modules and systems, namely amorphous (thin film) modules with metal frames or steel backing. In such circumstances, appropriate and safe live working practices must be adopted.

An example of where such hazards may be encountered is the case where an installer is seated on earthed metal roof whilst wiring a large PV array. In such circumstances the installer could touch the PV cabling and might get an electric shock to earth. The electric shock voltage will increase with the number of series connected modules. The use of insulated tools and gloves, together with insulating matting to stand or sit on, can mitigate this hazard.

An electric shock may also be experienced due to the PV array developing a ground (earth) leakage path. Good wiring practice, double insulation and modules of double or reinforced insulation (class II) construction can significantly reduce this problem, but in any installed systems, leakage paths may still occur. Any person working on a PV system must be aware of this and take the necessary precautions.

4.3.5 Array Mounting

The manufacturer's instructions should always be observed when designing a PV array mounting structure. In particular, attention shall be paid to the clamping zones as prescribed by each manufacturer as these will often vary.

4.3.6 Load Calculations

The design and specification of the PV array mounting system should take into account the wind and snow loads to be expected. Wind loads vary considerably across the UK and are influenced by factors such as site altitude, building height and local topography.

Even where an approved mounting system kit is utilised, site specific calculations will be required to ensure that the system proposed is sufficient to withstand the imposed loads.

For each site the imposed wind and snow loads should be derived using the procedures within Eurocode- 1 (BS EN 1991-1).

The pressure coefficients (C_p) used to calculate wind loads shall be derived as follows:

- For PV arrays that are mounted above, and parallel to, an inclined roof where there is a clear gap between the array and the roof - the pressure coefficients shall be taken from BRE digest 489 or from recognised test data commissioned for the specific purpose of determining the wind loads on solar systems.
- For flat roof systems - the pressure coefficients shall be taken from BRE digest 489 or from recognised test data commissioned for the specific purpose of determining the wind loads on solar systems.
- For roof integrated, nominally airtight systems - the pressure coefficients shall be taken from Eurocode-1.
- For roof integrated, air permeable "PV tile" type systems - the pressure coefficients shall be taken from BS5534 and treating the PV array as roof tiles

In determining the appropriate pressure coefficient to use in calculations, the location of the PV array on the roof needs to be determined as some, or all, of the array may be in the "Edge Zone" as defined in BS EN 1991-1.

Pressure coefficients for the Edge Zone will be higher than those in the Central Zone of the roof. BRE digest 489 and the other sources listed above include pressure coefficient values for both Edge and Central zones.

Note: A simplified method to derive wind loads is described in annex B

Calculating a safety factor for the derived load

As described within Eurocode-1 tables A1.1 and A1.2, safety factors need to be applied to the calculated loads. Taken in isolation, a safety factor of 1.5 should be applied to the derived wind and snow loads and a factor of 1.0 to the dead load (self-weight).

However, in normal use solar panels may be designated with a lower consequence of failure than for the supporting building structure, in accordance with Table B1 of EN 1990: 2002 + A1:2005 Consequence Class CC1. As a result the partial factor for design wind and snow loads may be multiplied by 0.9 (Factor KFI for Reliability Class RC1 from Table B3 of EN 1990: 2002 +A1 : 2005). Hence a safety factor of 1.35 should be applied to the derived wind and snow loads. Load calculations shall be undertaken by a suitably competent person.

4.3.7 Fixing Calculations

The PV array fixings (type and quantity) shall be checked to ensure that they can withstand the imposed (dead) load and wind uplift loads as calculated. Examples of how this can be achieved include:

- For systems approved to MCS012 - ensuring that the imposed loads are within the range specified by the product manufacturer (and then installing according to the manufacturer's instructions)
- Using fixing data from Eurocode 5 - design of timber structures
- Using fixing bracket test data

Note: Many standard above roof systems for pitched roofs suggest a screw layout that conflicts with the requirements of Eurocode 5 to keep fixings a certain number of screw diameters away from the rafter edge and each other. In such cases one solution is to fix the mounting bracket to a timber noggin fitted between the rafters. Alternatively, the fixing resilience can be determined from test data.

In all cases it is expected an appropriate safety factor to have been applied to the fixing withstand capacity

Note: for systems listed to MCS012, a safety factor will have been applied as a part of the certification process and will be shown in the MCS012 certification.

Fixing calculations shall be carried out by a suitably competent person.

4.3.8 Building Structure Calculations

The roof structure shall be checked to ensure it can withstand the imposed loads as calculated. This is to include a site inspection by a suitably competent person.

The table below details some typical scenarios and possible calculation methodologies for pitched roofs. Where the roof is unusual in anyway, such as, for example:

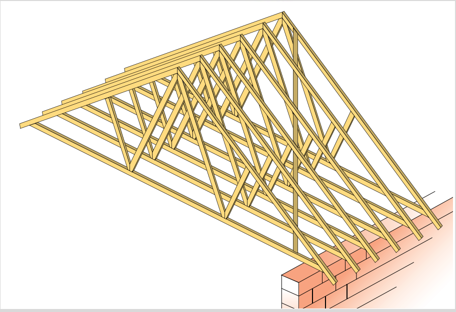
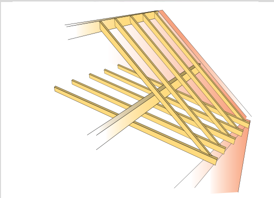
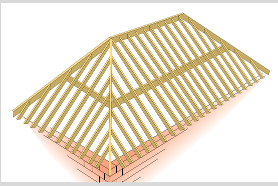
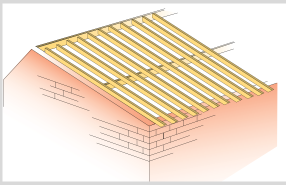
- Signs of structural distress
- Signs of post construction modification (e.g. removal of timbers, notching, change of roof covering),
- The roof pitch is particularly shallow (<30°)

- The roof design has increased potential for snow build-up (e.g. dormers, valleys, parapets etc)
- The type of construction is not detailed in the table

or if there is **any doubt whatsoever then a qualified structural engineer shall be consulted.**

For installations on flat roofs, special consideration shall be given to the load of the PV system and any associated ballast. Structural calculations shall be carried out by a suitably competent person.

Fig 26

Diagram	Construction Type of Roof	Typical Methodologies
Roof constructed from Timber Trussed Rafters 		Method 1: Assuming a typical design **dead load** of 0.785kN/m², deduct the load of the existing roof covering to give the maximum allowable residual load available for the solar array.
		Method 2 (not generally applicable where the roof pitch exceeds 60°): Assuming a typical **design imposed load** of 0.75kN/m2, deduct the likely snow load for the location taken from Eurocode-1 (BS EN 1991-1) to give the maximum allowable residual load available for the solar array.
	Traditional cut roofs constructed from timber rafters/purlins - gable ended	Calculate the maximum dead load for the rafters and purlins using the TRADA Span tables (2nd or 3rd Edition), deduct the load of the existing roof covering to give the maximum allowable residual load available for the solar array.
	Traditional cut roofs constructed from timber rafters/purlins – with hips and/or valleys	Consult a structural engineer.
	Asymmetric duo-pitched roofs constructed from rafters and purlins	Consult a structural engineer.

4.3.9 PV Roofing and Cladding Works

PV systems should not adversely affect the weather tightness of the structure to which they are fitted. The system should be designed and installed to ensure this is maintained for the life of the system.

For integrated systems, the weather tightness of the PV system should be the same or better than the roof or cladding systems they are replacing and should not adversely affect the weather tightness of the surrounding covering.

For above roof PV systems, the array fixing brackets should not affect the weather tightness of the roof they are fitted to. For example, systems attached to tile roofs should be designed and installed such that the fixing brackets do not displace the tiles and cause gaps more than naturally occurs between the tiles. Fixing methods must not subject roof coverings to imposed loads which may degrade their primary purpose of maintaining weather-tightness.

Fig 27

It is good practice to notch tiles when fixing a roof bracket

Tiles or slates removed for fixing a mounting bracket should be re-attached to include a means of mechanical fixing.

Historically, some mounting systems on slate or tile roofs have relied on a simple “through bolt” approach. However, this fixing method has the potential for the fixing bolts or sealing washer cracking the slates/tiles beneath them. It can also present difficulties with ensuring the long term weather tightness and durability of the roof penetration.

Through bolts shall only be used on tile or slate roofs where the following requirements are met:

1. The bolt or flashing shall not transfer any load on the slates / tiles beneath
2. The system shall not rely on silicone or other mastic sealant to provide a weather-tight seal
3. The system must durably seal every layer of roof covering that is perforated by the bolt system
4. The system shall not rely on a sealing washer or plate that presses down on the slate/tile to ensure a weather tight seal
5. The bolt fixings shall not be into battens

Fig 28

Using a standard roof hook on a slate roof

The roof underlay should be inspected for damage during installation works. Any damage should be repaired or the underlay replaced as necessary. Damaged underlay will not provide an effective weather and air barrier and can affect weather tightness and the wind loads imposed on the roof cladding.

Unless **specifically designed to do so**, systems should be kept away from the roof perimeter. For a domestic roof, a suitable minimum clearance zone is around 40-50cm.

The requirement to keep an arrays away from a the edge of a roof is suggested because: wind loads are higher in the edge zones; keeping edge zones clear facilitates better access for maintenance and fire services; taking arrays close to the roof edge may adversely affect rain drainage routes; and when retrofitting systems, there is the potential for damage to ridge, hip, valley or eaves details.

Note – on many roofs a 50cm gap from the edge will still mean that PV modules are fitted in the "Edge Zone" as defined in BS EN 1991-1 where higher pressure coefficients need to be implemented due to the higher imposed wind loads.

Cable penetrations through the roof should not affect the weather tightness of the roof and should be durably sealed to accommodate the movement and temperatures expected. The use of a purpose-made product is an example of a durable means to achieve this.

Cable penetrations through underlay should be achieved using purpose-made products or, if taken through a lap in the underlay, the cable should be carefully routed, clipped and tensioned so as to leave a minimal residual gap in the underlay lap joint.

Thermal expansion should be considered when installing larger arrays. The module and mounting system manufacturer should be consulted to determine the maximum array width and continuous rail length that can be permitted without the need for an expansion gap.

4.3.10 MCS Pitched Roof System Requirements

PV systems mounted above or integrated into a pitched roof should utilise products that have been tested and approved to MCS012 (test procedures used to demonstrate the performance of solar systems under the action of wind loads, fire, rainfall and wind driven rain).

Note: Under the MCS scheme, MCS012 becomes mandatory in September 2013

In roof products (eg PV tiles) – All fixing and flashing components used to mount and make weather-tight the solar roofing product must be packaged and listed as part of a complete kit that includes the PV module. *The MCS installer must ensure that the system is installed to comply with the manufacturer's instructions*.

In roof mounting system – All fixing and flashing components used to mount and make weather-tight the PV system must be specifically approved to work together (e.g. supplied and listed as a kit of parts) and listed to work with either the named PV module, or listed as a universal type where PV module type is immaterial to the performance of the system. *The MCS installer must ensure that the system is installed to comply with the manufacturer's instructions for both the mounting system and the PV module.*

Above roof mounting systems – All components used to mount the system must be specifically approved to work together or be listed as universal components. The mounting system must also be listed to work with either the named PV module, or listed as a universal type where PV module type is immaterial to the performance of the system. *The MCS installer must ensure that the system is installed to comply with the manufacturer's instructions for both the mounting system components and the PV module.*

In all cases it is expected that the manufacturers' fixing instructions are followed with respect to wind loading. Wind loads vary from site to site and the installer must ensure that the design wind load is within the range as specified by the manufacturer; and/or for high wind sites, any required additional fixings are correctly installed. Where an installer has chosen to utilise a mounting assembly comprised of "universal" components, the installer must ensure that all components are suitable for the wind load imposed on that component.

4.3.11 Standing Seam and Other Metal Roofs

Some PV array mounting systems rely on securing the array to the metal roof cladding. In such circumstances, the adequacy of the roof covering to transfer all additional loads back to the supporting structure should be verified. This should include consideration of all elements of the roof construction that could be affected by the additional loading. Calculations will include consideration of the array configuration (pitched or parallel to the roof) and the type, quantity and locations of PV array fixings.

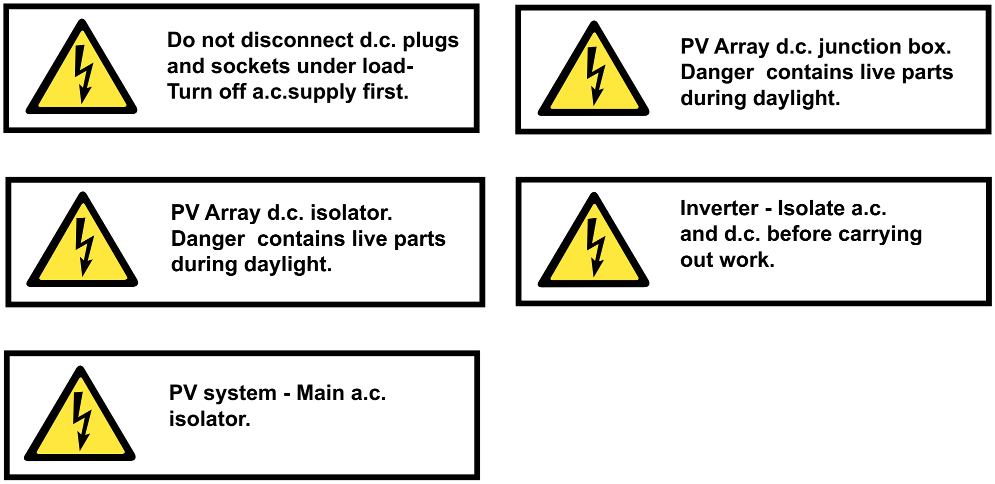
Sitework should include verification to confirm that all the design requirements have been satisfied and that the roof covering has not been adversely affected by the installation work

5 Signs and Labels

All labels must be clear, easily visible, constructed and affixed to last and remain legible for the lifetime of the system.

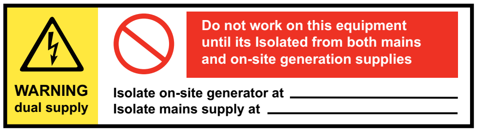
Requirements for labelling are contained within the relevant sections of this guide. Example labels can be seen below.

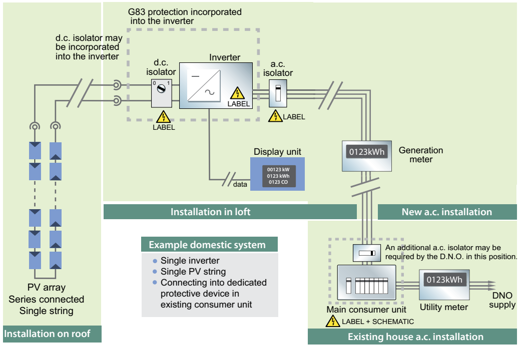
Fig 29

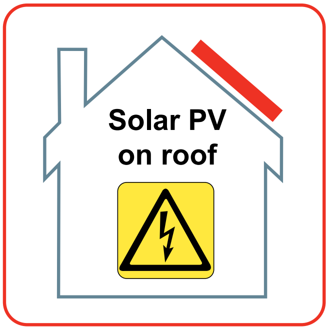


In addition to the labels described elsewhere in this document, the following labels are also to be to be fitted:

Fig 30

<table>
<tr><th colspan="2">Dual supply label</th></tr>
<tr><td>Dual supply labelling should be provided at the service termination, meter position and all points of isolation between the PV system and supplier terminals to indicate the presence of on-site generation and indicating the position of the main a.c. switch disconnector.</td><td>
</td></tr>
<tr><th colspan="2">Circuit diagram & system information</th></tr>
<tr><td>At the point of interconnection, the following information is to be displayed (typically all displayed on the circuit diagram):

• Circuit diagram showing the relationship between the inverter equipment and supply.
• A summary of the protection settings incorporated within the equipment.
• A contact telephone number for the supplier/installer/maintainer of the equipment.
• It is also good practice for shutdown and start-up procedures to be detailed on this diagram.</td><td>
</td></tr>
<tr><th colspan="2">Fire and Rescue Notification</th></tr>
<tr><td>To ensure the Fire and Rescue Service are aware that a PV system is installed on the roof, the following sign shall also be fitted

• Location: next to the suppliers' cut-out in the building
• Size: This label shall measure at least 100mm x 100mm
• Only required for PV systems fitted on roofs</td><td>
</td></tr>
</table>

6 Inspection, Testing and Commissioning Requirements

6.1 Inspection and Testing – a.c. Side

Inspection and testing of the completed system to the requirements of BS 7671 must be carried out and documented

The inspection and testing of a.c. circuits is comprehensively covered within BS 7671 and supporting technical guides, specifically Guidance Note 3. The forms required for the a.c. side (the BS 7671 model test certificates) are reproduced in annex C and are also available to download free of charge from the IET's website.

Inspection and testing documentation for the a.c. side typically comprises 3 documents:

- Electrical installation certificate,
- Schedule of items inspected
- Schedule of test results

6.2 Inspection and Testing – d.c. Side (PV Array)

The inspection and testing of the d.c. side of the PV system shall be in accordance with the requirements of BS 7671 and also BS EN 62446 *Grid connected photovoltaic systems — Minimum requirements for system documentation, commissioning tests and inspection*

The verification sequence contained within BS EN 62446 includes

- Inspection schedule
- Continuity test of protective earthing and/or equipotential bonding conductors (if fitted)
- Polarity test
- String open circuit voltage test
- String short circuit current test
- Functional tests
- Insulation resistance of the d.c. circuits

These tests shall be recorded on a PV array test report (see annex C) which shall be appended to the a.c. documents listed above.

Full details of the inspection schedule and guidance on test procedures is contained with BS EN 62446.

6.3 Engineering Recommendation (ER) G83 and G59 Requirements

Depending on the size of the PV installation, the requirements of either Engineering Recommendation G83 or G59 are to be followed when commissioning a grid connected PV system.

Systems up to 16A a.c. output per phase come under ER G83.This would correspond to 3.68kW single phase (230v Nominal) and 11.04kW three phase (400v nominal). These systems will not require any extra commissioning procedures (measures other than those described elsewhere in this document).

Systems over 16A per phase come under ER G59. These systems may require additional commissioning tests to verify the correct and safe operation of the grid interface protection circuits. Smaller systems using G59 type approved inverters may not require any additional tests.

However, for larger systems or systems where separate protection relays are fitted (a "G59 relay"), on site testing of the relay and protection system will often be required. For some systems, particularly those over 50kWp, the DNO may wish to witness the tests. In all cases, the DNO needs to be consulted over the test procedure required and whether the tests need to be witnessed by a DNO representative. Further information on testing procedures are contained within ER G59.

Standard forms are provided by the DNO's to document the commissioning of a PV system. See section 2.4.1 for more details on the process to be followed.

7 Handover & Documentation

The system user should be provided as a minimum with the information as described in of BS EN 62446 Grid connected photovoltaic systems — Minimum requirements for system documentation, commissioning tests and inspection. The following provides a summary of the information required:

- Basic system information (parts used, rated power, installation dates etc)
- System designer information
- System installer information
- Wiring diagram, to include information on:
  - ➢ Module type & quantities
  - ➢ String configurations
  - ➢ Cable specifications – size and type.
  - ➢ Over-current protective device specifications (where fitted) - type and ratings.
  - ➢ Array junction box locations (where applicable).
  - ➢ d.c. isolator type, location and rating
  - ➢ Array over-current protective devices (where applicable) – type, location and rating
  - ➢ Details of all earth / bonding conductors – size and connection points.
  - ➢ Details of any connections to an existing Lightning Protection System (LPS).
  - ➢ Details of any surge protection device installed (both on a.c. and d.c. lines) to include location, type and rating.
  - ➢ AC isolator location, type and rating.
  - ➢ AC overcurrent protective device location, type and rating.
  - ➢ Residual current device location, type and rating (where fitted).

- Module datasheets
- Inverter datasheets
- Mounting system datasheet
- Operation and maintenance information, to include:
  - ➢ Procedures for verifying correct system operation.
  - ➢ A checklist of what to do in case of a system failure.
  - ➢ Emergency shutdown / isolation procedures.
  - ➢ Maintenance and cleaning recommendations (if any).
  - ➢ Considerations for any future building works related to the PV array (e.g. roof works).

- Warranty documentation for PV modules and inverters - to include starting date of warranty and period of warranty.
- Documentation on any applicable workmanship or weather-tightness warranties.
- Test results and commissioning data

Annex A - Battery Systems

This section of the guide covers the additional requirements where a battery forms part of a PV installation – whether as part of a true stand-alone (off-grid) system or part of a hybrid (e.g. grid linked/ batteries) system.

Note: The design and requirements of any of the load circuits within such a system are outside the scope of this document.

A1 PV Array Charge Controller

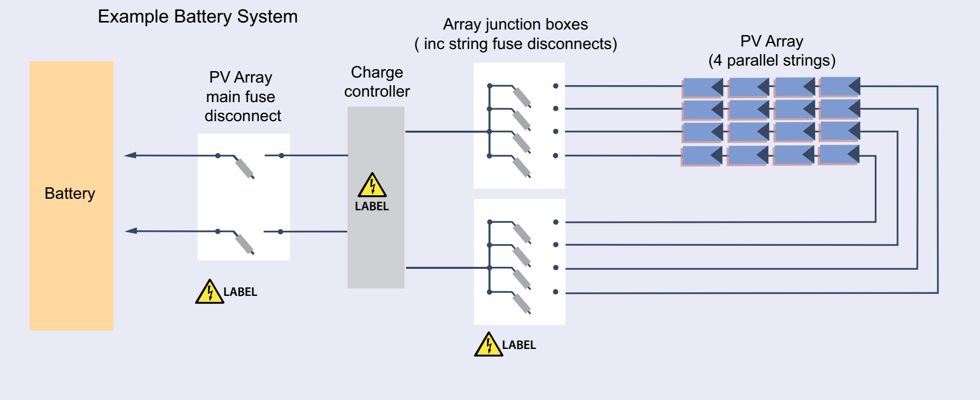
This provides the regulator/dump interface between the PV array and the battery so as to prevent overcharging of the battery. The unit may also provide other functions such as maximum power point tracking, voltage transformation, load control and metering.

- The charge controller must be rated for the current and voltage maxima (see Section 2.1.2, minimum voltage and current ratings)
- The charge controller must be labelled as per the d.c. junction box requirements in section 2.1.9.
- The charge controller must carry a CE Mark.

A full recharge is important for good battery health. A small size cable between the charge control unit and the battery – with an associated high voltage drop – may lead to the control system prematurely halting the charge cycle. These cables should therefore be sized for a maximum voltage drop of less than 1% at peak PV array output. For controllers with a separate battery sense function, a fused battery sense cable can be installed.

Example Battery System:

Fig 31



A2 Battery Over Current Protection

A battery stores significant energy and has the capacity to deliver large fault currents. Proper fault protection must be provided.

An over current device must be installed in all live (non-earthed) conductors between the battery and the charge controller.

The over current device (either a fuse or circuit-breaker) must:

- Have a trip value and response time as specified within the charge controller manual
- Be rated for operation at d.c., at 125% of the nominal battery voltage
- Have an interrupt rating greater than the potential battery short circuit current.

The length of cable between the over current device and battery terminal must be as short as practicable.

A3 Battery Disconnection

A means of manual isolation must be provided between the charge controller and the battery, either combined with the over current device or as a separate unit. The isolator must be double pole, d.c. rated and load break, and the length of the cable between it and the battery must be as short as practicable. In positioning this device, the requirements of section A7 of this guide are also to be observed.

Note: In order to keep the cable run as short as practicable and to keep the device away from battery gasses – isolation devices will typically be located immediately to the side of the battery bank (rather than directly above).

Isolation is to be installed and the system designed so that the PV array cannot directly feed the loads when the battery has been disconnected.

Combined fault protection and isolation:

- A circuit-breaker provided for battery fault current protection may be used to provide isolation, if it is rated as an isolation device.
- A fuse assembly provided for fault current protection may be used to provide isolation if it has readily removable fuses (e.g. fuse unit with disconnect mechanism)

A4 Cables in Battery Systems

The requirements set out in the main sections of this guide apply: *Note: In some circumstances, a voltage drop greater than that in section 2.1.4.1 may be justified on economic grounds.* In addition, all cables must have a current rating above that of the relevant over current device (nearest downstream fuse / circuit breaker). Cable current ratings are to be adjusted using standard correction factors for installation method, temperature, grouping and frequency to BS 7671.

A5 PV String Cable and Fuse Ratings

String cables (upstream of the charge controller) must be rated to the trip current of the nearest downstream device plus the rating as calculated in section 2.1.5.

A PV–battery system must be designed such that the string cable and string fuse design and specification reflects that fault currents may come either from the array itself, from the battery or from both. Again, cable current ratings are to be adjusted using standard correction factors for installation method, temperature, grouping to BS 7671.

Note: Specification & labelling for the PV cables/ junction boxes/ connectors/ etc. should be as in the main sections of the guide.

A6 Battery Selection and Sizing

The selection of a battery is generally out of the scope of this document. However, some key considerations are:

- Is the battery fit for purpose, i.e. appropriately rated for its duties? In the majority of cases a true ‘deep cycle’ battery will be required
- Does it have an adequate storage capacity (days of autonomy) and cycle life?
- Is a sealed or vented battery more appropriate for the particular installation?
- Will the battery be made up of series cells or parallel banks? While series cells will generally give better performance, practical considerations may influence the design. In general, though, banks with more than four parallel units are to be avoided.

The sizing of a battery is generally out of the scope of this document. However, for an effective charging regime where a PV array is the only charge source, the battery would normally be sized so that the output of the PV array falls between the manufacturer’s maximum and minimum recommended charge rates.

Charge/discharge rates (C) are commonly expressed as an hourly rate derived from the formula: Rate = Capacity (Ah) / Time (h) For example, a C10 charge rate for a 500Ah battery would take place at 50A.

Charge rates between C5 and C20 are often used in systems with vented lead acid batteries, for example.

A7 Battery installation / Labelling

In an enclosed location, ventilation must be provided to battery installations with an air inlet at low level and an outlet at the highest point in the room or enclosure.

Sufficient ventilation is needed to remove battery gases. It is particularly important in the case of vented lead acid units as hydrogen is given off during charging (which is lighter than air) – and a concentration of more than 4% creates an explosion hazard. Ventilation also prevents excessive heat build-up.

BS EN 50272-1 2010 'Safety requirements for secondary batteries and battery installations'. General safety information' gives a procedure for calculating ventilation requirements.

Battery banks must be housed in accordance with BS EN 50272-1 2010 and such that:

- Access can be restricted to authorised personnel
- Adequate containment is assured
- Appropriate temperature control can be maintained

Battery terminals are to be guarded so that accidental contact with persons or objects is prevented.

The ideal operating temperature for a lead acid battery is around 25ºC, temperatures significantly above or below this will lead to reduced lifetime and capacity. Indeed, at very low temperatures, discharged batteries may freeze and burst; at high temperatures, thermal runaway can occur in sealed batteries.

Items which could produce sparks (e.g. manual disconnects, fuses, relays) should not be positioned within a battery box or directly above one.

Battery gases are corrosive, so cables and other items inside a battery enclosure need to be corrosion resistant. Sensitive electronic devices should not be mounted in, or above, a battery box.

To ensure proper load/charge sharing in a battery bank made up of units connected in parallel, the units need to have the same thermal environment and the same electrical connection resistance.

In larger battery banks, fusing each parallel unit should be considered.

A typical connection configuration for a small series-parallel bank (take-offs are on opposite corners):

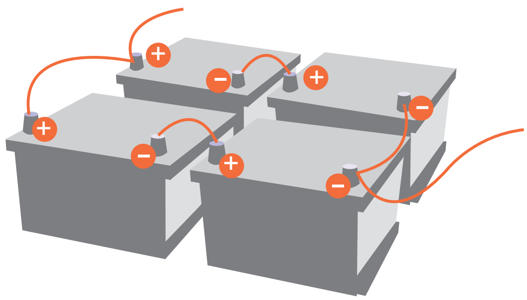


Fig 32

The following warning signs are to be displayed:

- No Smoking or Naked Flames
- Batteries contain acid – avoid contact with skin or eyes
- Electric shock risk – (xxx) V d.c.

Note: Circuit protection and all points of isolation should also be labelled with

"d.c. Supply – {insert voltage} V d.c."

All labels should be clear, easily visible and should be constructed and fixed so as to remain legible and in place throughout the design life of the system.

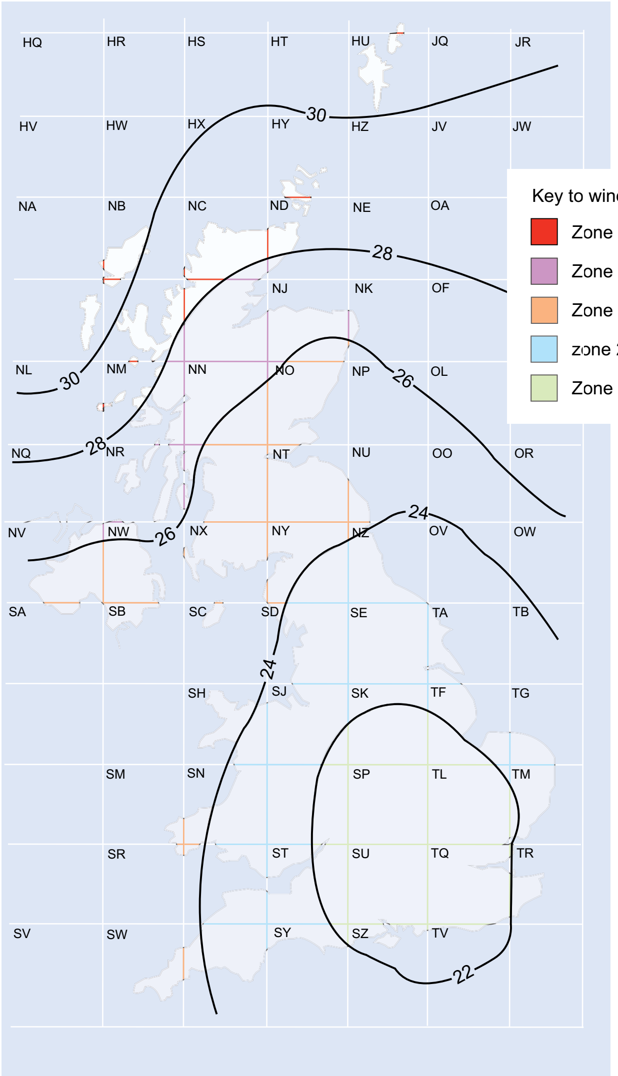
Protective equipment, including appropriate gloves and goggles – together with an eye wash and neutralising agent – should be stored adjacent to the battery installation.

Annex B - Simplified Method for Determining Peak Wind Loads

The following simplified procedure to calculate wind loads is based on the on the peak velocity pressures derived from Eurocode-1 (BS EN 1991-1-4). A more accurate, typically lower value can be determined using the methodology and tables within Eurocode-1.

This method is taken from work undertaken by the NHBC Foundation, their contribution is gratefully acknowledged.

Fig 33



a. With reference to the site wind zone, site type (rural / urban), the ridge height of the building and the distance of the site from the sea - derive the peak velocity pressure (q_p) from the following table:

Fig 34

Peak velocity pressures (q_p) in pascals							
Wind zone	Ridge height (m)	Country terrain Distance to sea			Urban terrain Distance to sea		
		<2km	2-20km	>20km	<2km	2-20km	>20km
1	5	869	783	718	688	620	569
1	10	1009	955	872	883	836	763
1	15	1094	1062	977	1012	982	904
1	20	1122	1108	1017	1066	1052	966
1	25	1166	1166	1072	1137	1137	1045
2	5	1034	931	854	819	738	677
2	10	1201	1136	1038	1050	994	908
2	15	1302	1264	1163	1204	1169	1075
2	20	1335	1318	1210	1268	1253	1149
2	25	1388	1388	1276	1353	1353	1244
3	5	1213	1093	1003	961	866	794
3	10	1409	1334	1218	1233	1167	1066
3	15	1527	1483	1364	1413	1372	1262
3	20	1567	1547	1420	1489	1470	1349
3	25	1629	1629	1498	1588	1588	1460
4	5	1407	1268	1163	1115	1004	921
4	10	1634	1547	1413	1430	1353	1236
4	15	1772	1720	1582	1639	1591	1464
4	20	1817	1795	1647	1726	1705	1565
4	25	1889	1889	1737	1842	1842	1694
5	5	1703	1534	1407	1349	1215	1115
5	10	1977	1872	1710	1730	1638	1496
5	15	2144	2081	1915	1983	1925	1771
5	20	2199	2171	1993	2089	2063	1893
5	25	2286	2286	2102	2229	2229	2049

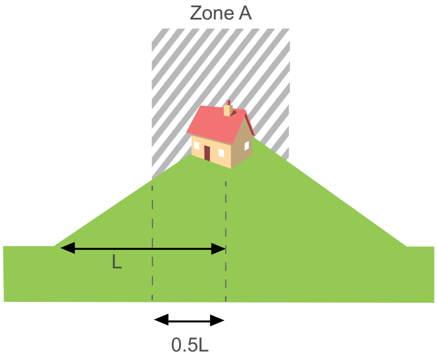
b) Apply correction factors for site altitude (h) in metres:

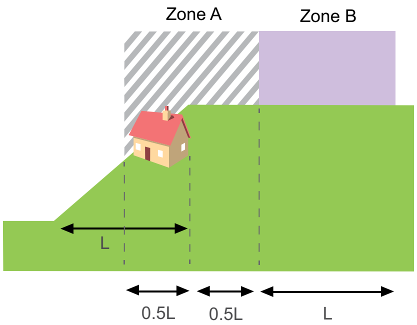
Height above sea level	Correction factor
0-100m	None
>100m	$1 + \left[\frac{h-100}{100} \times 0.2 \right]$

Note: the altitude correction formula for sites over 100m above sea level calculates a 20% increase for each 100m above the initial 100m. Hence a site at 180m above sea level would have a correction factor of 1.16.

c) Apply correction factor for topography

Fig 35

Sites more than half way up a hill		
Site classification	**Correction factor**	
Slope = 10%	1.2	
Slope = 20%	1.45	
Slope ≥ 30%	1.7	

Escarpments			
Site classification	**Zone A**	**Zone B**	
Slope = 10%	1.2	1.12	
Slope = 20%	1.45	1.25	
Slope ≥ 30%	1.7	1.4	

Where a site is selected that does not match exactly the slope % quoted, then factor can be derived by either rounding up to the next highest value, or by interpolation.

d) Calculate wind pressure using the following formula

$$w = q_p \times c_p$$

Where: w … is the wind pressure in Pascals
q_p … is the peak velocity pressure derived in steps a-c
c_p … is the pressure coefficient for the particular installation

Note: the pressure coefficient c_p will depend upon the type of system and the array location on the building. The procedure for selecting the appropriate pressure coefficient is covered in clause 4.3.6.

Note: A safety factor will also need to be applied to the derived load – see clause 4.3.6 for more details

Example Calculation #1

- Above roof PV array, mounted away from edges in central zone of roof (C_p uplift = -1.3)
- Site located in central London (more than 2km from edge of town)
- Site more than 20km from the sea
- Building height = 10m
- Site altitude = 20m
- Topography = not significant

a. Site in zone 1 (22 m/s) → Table gives value for q_p = 763Pa
b. Altitude correction factor = none
c. Topography correction factor = none
d. W_{uplift} = 763 x -1.3 = -992Pa *(value excludes safety factor)*

Example Calculation #2

- Above roof PV array, mounted away from edges in central zone of roof (C_p uplift = -1.3)
- Site located in rural Yorkshire near the top of a hill of 8% slope
- Site more than 20km from the sea
- Building height = 10m
- Site altitude = 150m

a. Site in zone 2 (24 m/s) → Table gives value for q_p = 1038P
b. Altitude correction factor = 1 + (150-100/100)*0.2 = 1.1
c. Topography correction factor = 1.2
d. W_{uplift} = 1038 x 1.1 x 1.2 x -1.3 = -1781Pa *(value excludes safety factor)*

Annex C – PV Array Test Report

Fig 36

PV Array Test Report		☐ Initial verification ☐ Periodic verification
Installation address		Reference Date
Description of work under test		Inspector Test instruments

String		1	2	3	4		n
Array	Module						
	Quantity						
Array parameters (as specified)	Voc (stc)						
	Isc (stc)						
String over-current protective device	Type						
	Rating (A)						
	DC Rating (V)						
	Capacity (kA)						
Wiring	Type						
	Phase (mm^2)						
	Earth(mm^2)						
String test							
	Voc (V)						
	Isc (A)						
	Irradiance						
Polarity check							
Array installation Resistance	Test voltage (V)						
	Pos - Earth (MΩ)						
	Neg - Earth (MΩ)						
Earth continuity (where fitted)							
Switchgear functioning correctly							
Inverter make/ model							
Inverter serial number							
Inverter function correctly							
Loss of mains test							

Comments

Annex C – Electrical Installation Certificate

Fig 37a **ELECTRICAL INSTALLATION CERTIFICATE BS 7671:2008**

THREE SIGNATURE Certificate number: ☐ Registration number: ☐ (optional) **Sheet** ☐ **of** ☐

DETAILS OF THE CLIENT

....

INSTALLATION ADDRESS

....

....

DESCRIPTION AND EXTENT OF THE INSTALLATION Tick boxes as appropriate

Description of installation: ....

....

Extent of installation covered by this Certificate: ....

....

(Use continuation sheet if necessary) See continuation sheet no. ....

New installation	☐
Addition to an existing installation	☐
Alteration to an existing installation	☐

FOR DESIGN

I/We being the person(s) responsible for the design of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the design, hereby CERTIFY that the design work of which I/we have been responsible is, to the best of my/our knowledge and belief, in accordance with BS 7671:2008 amended to .... (date) except for departures, if any, detailed as follows:

Details of departures from BS 7671 (regulation 120.3 and 133.5)

....

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.

For the DESIGN of the installation: ****Where there is mutual responsibility for the design**

Signature.. **Date**.......................... **Name (CAPITALS)** .... **Designer No. 1**

Signature.. **Date**.......................... **Name (CAPITALS)** .... **Designer No. 2****

FOR CONSTRUCTION

I/We being the person(s) responsible for the construction of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the construction, hereby CERTIFY that the construction work of which I/we have been responsible is, to the best of my/our knowledge and belief, in accordance with BS 7671:2008 amended to .... (date) except for departures, if any, detailed as follows:

Details of departures from BS 7671 (regulation 120.3 and 133.5)

....

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.

For the CONSTRUCTION of the installation:

Signature.. **Date**.......................... **Name (CAPITALS)** .... **Constructor**

FOR INSPECTION & TESTING

I/We being the person(s) responsible for the inspection & testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the inspection & testing, hereby CERTIFY that the work of which I/we have been responsible is, to the best of my/our knowledge and belief, in accordance with BS 7671:2008 amended to .... (date) except for departures, if any, detailed as follows:

Details of departures from BS 7671 (regulation 120.3 and 133.5)

....

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.

For the INSPECTION & TESTING of the installation:

Signature.. **Date**.......................... **Name (CAPITALS)** .... **Constructor**

NEXT INSPECTION

I/We the designer(s), recommend that this installation is further inspected and tested after an interval of not more than .... years / months

Annex C – Electrical Installation Certificate

Sheet ☐ of ☐

Fig 37b

PARTICULARS OF SIGNATORIES TO THE ELECTRICAL INSTALLATION CERTIFICATE

Designer (No. 1)

Name .... Company ....

Address ....

.... Postcode .... Tel: ....

Designer (No. 2)

Name .... Company ....

Address ....

.... Postcode .... Tel: ....

Constructor

Name .... Company ....

Address ....

.... Postcode .... Tel: ....

Inspector

Name .... Company ....

Address ....

.... Postcode .... Tel: ....

SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS

Tick boxes and enter details as appropriate

Earthing arrangements	Number and type of live conductors	Nature and type of supply parameters	Supply protective device
TN-S ☐	a.c. ☐ d.c. ☐	Nominal voltage, U / U_o[1] V	BS (EN) ....
TN-C-S ☐	1-phase, 2-wire ☐ 2-wire ☐	Nominal frequency, f[1] .... Hz	
TT ☐	2-phase, 3-wire ☐ 3-wire ☐	Prospective fault current, I_{pf}[2] .... kA	Type ....
TN-C ☐	3-phase, 4-wire ☐	External loop impedance, Ze[2] .... Ω	
IT ☐	Confirmation of supply polarity ☐	Note: (1) by enquiry. (2) by enquiry or measurement	Rated current .... A

Alternative source of supply (as detailed on attached schedule) ☐

PARTICULARS OF INSTALLATION REFERRED TO IN THE CERTIFICATE

Tick boxes and enter details as appropriate

Means of earthing	Maximum demand		
	Maximum demand (load) .... kVA / Amps (delete as appropriate)		
Distributor's facility ☐	**Details of installation earth electrode** *(where applicable)*		
Installation earth electrode ☐	Type (e.g. rod(s), tape, etc.)	Location	Electrode resistance to earth .... Ω

Main protective conductors

Earthing conductor material .... csa .... mm² Continuity and connection verified ☐

Main protective bonding conductors material .... csa .... mm² Continuity and connection verified ☐

To incoming water and/or gas service ☐ To other elements: ....

Main switch or circuit-breaker

BS, type and no. of poles .... Current rating .... A Voltage rating .... A

Location .... Fuse rating or setting .... A

Rated residual operating current $I_{\Delta n}$ .... mA, and operating time of .... ms (at $I_{\Delta n}$) (Applicable only where an RCD is suitable and is used as a main circuit-breaker)

COMMENTS ON EXISTING INSTALLATION (in the case of an addition or alteration see Section 633)

....

....

....

....

....

SCHEDULES

The attached Schedules are part of this document and this Certificate is valid only when they are attached to it.

.... Schedules of Inspections and .... Schedules of Test Results are attached.

(Enter quantities of Schedules attached.)

Annex C – Schedule of Inspections

Fig 38

For new installations only

Sheet ☐ **of** ☐

Methods of protection against electric shock

Both basic and fault protection:

- ☐ (i) SELV
- ☐ (ii) PELV
- ☐ (iii) Double insulation
- ☐ (iv) Reinforced insulation

Basic protection:

- ☐ (i) Insulation of live parts
- ☐ (ii) Barriers or enclosures
- ☐ (iii) Obstacles
- ☐ (iv) Placing out of reach

Fault protection:

(i) Automatic disconnection of supply:

- ☐ Presence of earthing conductor
- ☐ Presence of circuit protective conductors
- ☐ Presence of protective bonding conductors
- ☐ Presence of supplementary bonding conductors
- ☐ Presence of earthing arrangements for combined protective and functional purposes
- ☐ Presence of adequate arrangements for other sources, where applicable
- ☐ FELV
- ☐ Choice and setting of protective and monitoring devices (for fault and/or overcurrent protection)

(ii) Non-conducting location:

- ☐ Absence of protective conductors

(iii) Earth-free local equipotential bonding:

- ☐ Presence of earth-free local equipotential bonding

(iv) Electrical separation:

- ☐ Provided for **one item** of current-using equipment
- ☐ Provided for **more than one item** of current-using equipment

Additional protection:

- ☐ Presence of residual current device(s)
- ☐ Presence of supplementary bonding conductors

Prevention of mutual detrimental influence

- ☐ (a) Proximity of non-electrical services and other influences
- ☐ (b) Segregation of Band I and Band II circuits or use of Band II insulation
- ☐ (c) Segregation of safety circuits

Identification

- ☐ (a) Presence of diagrams, instructions, circuit charts and similar information
- ☐ (b) Presence of danger notices and other warning notices
- ☐ (c) Labelling of protective devices, switches and terminals
- ☐ (d) Identification of conductors

Cable and conductors

- ☐ Selection of conductors for current-carrying capacity and voltage drop
- ☐ Erection methods
- ☐ Routing of cables in prescribed zones
- ☐ Cables incorporating earthed armour or sheath, or run within an earthed wiring system, or otherwise adequately protected against nails, screws and the like
- ☐ Additional protection provided by 30 mA RCD for cables concealed in walls (where required in premises not under the supervision of a skilled or instructed person)
- ☐ Connection of conductors
- ☐ Presence of fire barriers, suitable seals and protection against thermal effects

General

- ☐ Presence and correct location of appropriate devices for isolation and switching
- ☐ Adequacy of access to switchgear and other equipment
- ☐ Particular protective measures for special installations and locations
- ☐ Connection of single-pole devices for protection or switching in line conductors only
- ☐ Correct connection of accessories and equipment
- ☐ Presence of undervoltage protective devices
- ☐ Selection of equipment and protective measures appropriate to external influences
- ☐ Selection of appropriate functional switching devices

Inspected by .... **Date** ....

NOTES

✓ to indicate an inspection has been carried out and the result is satisfactory

NA to indicate that the inspection is not applicable to a particular item

An entry must be made in every box.

Annex C – Schedule of Test Results

Fig 39

Sheet ☐ of ☐

DB Reference no.	Details of circuits and/or installed equipment vulnerable to damage when testing	Details of test instruments used (state serial and/or asset numbers)
Location	....	Continuity ....
Zs at DB (Ω)	....	Insulation resistance ....
I_{pf} at DB (kA)	....	Earth fault loop impedance ....
Correct polarity of supply confirmed YES / NO	....	RCD ....
Phase sequence confirmed (where appropriate)	....	Earth electrode resistance ....

Tested by:
Name (CAPITALS)....................
Signature.................... **Date** ....

Circuit details									Test results												
		Overcurrent device				Conductor details			Ring final circuit continuity (Ω)			Continuity (Ω) $(R_1 + R_2)$ or R_2		Insulation resistance (MΩ)		Polarity	Z_s (Ω)	RCD (ms)			Remarks (continue on a separate sheet if necessary)
Circuit number	Circuit description	BS (EN)	Type	Rating (A)	Breaking capacity (kA)	Reference method	Live (mm²)	cpc (mm²)	r_1 (line)	r_n (neutral)	r_2 (cpc)	$(R_1 + R_2)$ *	R_2	Live – Live	Live – E	✓	Ω	@$I_{\Delta}n$	@5$I_{\Delta}n$	Test button operation	
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V

* Where there are no spurs connected to a ring final circuit this value is also the $(R_1 + R_2)$ of the circuit.

Annex D – Abbreviated KWh/kWp (Kk) Tables

Due to space restrictions, these tables do not show the full range of orientation and inclination options within each of the postcode zones. The complete data tables are available on the MCS website to download.

Each table shows annual kWh / kWp output per annum for each zone. The table is divided into 5° increments for orientation, and 1° increments for inclination (pitch).

When surveying a site the survey results shall be rounded up or down according to standard convention.

For orientation the number shall be rounded up or down to the nearest 5° as defined in the examples below:

Measured orientation –	13° = requires rounding up to 15°
	12° = requires rounding down to 10°
	12.5 = requires rounding up to 15°
	12.4 = requires rounding down to 10°

For inclination (pitch) the number shall be rounded up or down to the nearest 1° as defined in the examples below:

Measured inclination –	35.5° = requires rounding up to 36°
	35.4° = requires rounding down to 35°

For ease of reference the tables have been shaded to indicate optimum and minimum potential outputs

Dark Green	= Optimum
Dark Red	= Minimum

Zone 1

Inclination (variation from horizontal)	Orientation (variation from south)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	828	828	828	828	828	828	828	828	828	828
1	835	835	835	835	835	835	834	834	833	833
2	843	843	843	842	842	841	841	840	839	838
3	850	850	850	849	849	848	847	846	845	843
4	857	857	857	856	855	854	853	852	850	848
5	864	864	864	863	862	861	859	857	855	853
6	871	871	870	869	868	867	865	863	861	858
7	878	877	877	876	874	873	871	868	866	862
8	884	884	883	882	880	879	876	873	870	867
9	890	890	889	888	886	884	882	878	875	871
10	896	896	895	894	892	890	887	883	880	875
11	902	902	901	900	898	895	892	888	884	879
12	908	908	907	905	903	900	897	893	888	883
13	914	913	912	910	908	905	901	897	892	887
14	919	919	917	916	913	910	906	901	896	890
15	924	924	922	920	918	914	910	905	900	894
16	929	929	927	925	922	919	914	909	903	897
17	934	933	932	930	927	923	918	913	907	900
18	938	938	936	934	931	927	922	917	910	903
19	943	942	941	938	935	931	926	920	913	906
20	947	946	945	942	939	935	929	923	916	908
21	951	950	949	946	943	938	933	926	919	911
22	954	954	952	950	946	941	936	929	922	913
23	958	957	956	953	949	944	939	932	924	915
24	961	961	959	956	952	947	941	934	926	917
25	964	964	962	959	955	950	944	937	928	919
26	967	967	965	962	958	953	946	939	930	921
27	970	969	968	965	960	955	948	941	932	922
28	972	972	970	967	962	957	950	942	933	923
29	975	974	972	969	964	959	952	944	935	924
30	977	976	974	971	966	960	953	945	936	925
31	979	978	976	973	968	962	955	946	937	926
32	980	979	977	974	969	963	956	947	937	926
33	982	981	979	975	970	964	957	948	938	927
34	983	982	980	976	971	965	957	948	938	927
35	984	983	981	977	972	966	958	949	938	927
36	984	984	981	978	973	966	958	949	938	927
37	985	984	982	978	973	966	958	949	938	926
38	985	984	982	978	973	966	958	949	938	925
39	985	984	982	978	973	966	958	948	937	925
40	985	984	982	978	973	966	957	947	936	924
41	984	984	981	977	972	965	956	946	935	922
42	984	983	981	977	971	964	955	945	934	921
43	983	982	980	976	970	963	954	944	932	919
44	982	981	979	975	969	962	953	943	931	918
45	980	980	977	973	967	960	951	941	929	916

Zone 2

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	938	938	938	938	938	938	938	938	938	938
1	947	947	947	946	946	946	945	945	944	944
2	956	956	956	955	955	954	953	952	951	950
3	965	965	964	964	963	962	961	960	958	957
4	974	973	973	972	971	970	969	967	965	963
5	982	982	981	981	979	978	976	974	971	969
6	990	990	990	989	987	985	983	980	978	974
7	999	998	998	996	995	993	990	987	984	980
8	1006	1006	1005	1004	1002	1000	997	993	989	985
9	1014	1014	1013	1011	1009	1007	1003	1000	995	990
10	1022	1021	1020	1019	1016	1013	1010	1006	1001	996
11	1029	1029	1027	1026	1023	1020	1016	1011	1006	1000
12	1036	1035	1034	1032	1030	1026	1022	1017	1011	1005
13	1043	1042	1041	1039	1036	1032	1028	1022	1016	1010
14	1049	1049	1047	1045	1042	1038	1033	1028	1021	1014
15	1056	1055	1054	1051	1048	1044	1039	1033	1026	1018
16	1062	1061	1060	1057	1054	1049	1044	1037	1030	1022
17	1068	1067	1065	1063	1059	1054	1049	1042	1035	1026
18	1073	1073	1071	1068	1064	1059	1053	1046	1038	1030
19	1078	1078	1076	1073	1069	1064	1058	1051	1042	1033
20	1084	1083	1081	1078	1074	1069	1062	1055	1046	1036
21	1088	1088	1086	1083	1079	1073	1066	1058	1049	1039
22	1093	1092	1090	1087	1083	1077	1070	1062	1053	1042
23	1097	1097	1095	1091	1087	1081	1074	1065	1056	1045
24	1102	1101	1099	1095	1091	1084	1077	1068	1058	1047
25	1105	1105	1103	1099	1094	1088	1080	1071	1061	1050
26	1109	1108	1106	1103	1097	1091	1083	1074	1063	1052
27	1112	1112	1109	1106	1101	1094	1086	1076	1066	1053
28	1115	1115	1112	1109	1103	1096	1088	1078	1067	1055
29	1118	1118	1115	1111	1106	1099	1090	1081	1069	1057
30	1121	1120	1118	1114	1108	1101	1092	1082	1071	1058
31	1123	1122	1120	1116	1110	1103	1094	1084	1072	1059
32	1125	1124	1122	1118	1112	1105	1096	1085	1073	1060
33	1127	1126	1124	1119	1114	1106	1097	1086	1074	1060
34	1128	1128	1125	1121	1115	1107	1098	1087	1074	1060
35	1130	1129	1126	1122	1116	1108	1098	1087	1075	1060
36	1131	1130	1127	1123	1117	1109	1099	1088	1075	1061
37	1131	1130	1128	1123	1117	1109	1099	1088	1075	1060
38	1132	1131	1128	1124	1117	1109	1099	1088	1074	1059
39	1132	1131	1128	1124	1117	1109	1099	1087	1074	1059
40	1132	1131	1128	1123	1117	1109	1099	1087	1073	1058
41	1131	1130	1128	1123	1116	1108	1098	1086	1072	1057
42	1131	1130	1127	1122	1116	1107	1097	1085	1070	1055
43	1130	1129	1126	1121	1114	1106	1095	1083	1069	1053
44	1128	1127	1125	1120	1113	1104	1094	1081	1067	1051
45	1127	1126	1123	1118	1111	1103	1092	1080	1065	1049

Zone 3

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	857	857	857	857	857	857	857	857	857	857
1	865	865	864	864	864	864	864	863	863	862
2	872	872	872	872	872	871	870	870	869	868
3	880	880	880	879	879	878	877	876	875	873
4	888	888	887	887	886	885	883	882	880	878
5	895	895	894	894	893	891	890	888	886	884
6	902	902	901	901	899	898	896	894	891	888
7	909	909	908	907	906	904	902	899	897	893
8	916	916	915	914	912	910	908	905	902	898
9	923	922	922	920	918	916	913	910	907	902
10	929	929	928	926	924	922	919	915	911	907
11	935	935	934	932	930	928	924	920	916	911
12	941	941	940	938	936	933	929	925	920	915
13	947	947	946	944	941	938	934	930	925	919
14	953	952	951	949	947	943	939	934	929	923
15	958	958	956	954	952	948	944	939	933	926
16	963	963	962	959	956	953	948	943	937	930
17	968	968	967	964	961	957	952	947	940	933
18	973	973	971	969	966	961	956	950	944	936
19	978	977	976	973	970	966	960	954	947	939
20	982	982	980	977	974	969	964	957	950	942
21	986	986	984	981	978	973	967	961	953	944
22	990	990	988	985	981	977	971	964	956	947
23	994	993	992	989	985	980	974	966	958	949
24	997	997	995	992	988	983	977	969	961	951
25	1001	1000	998	995	991	986	979	972	963	953
26	1004	1003	1001	998	994	988	982	974	965	955
27	1007	1006	1004	1001	996	991	984	976	967	956
28	1009	1009	1007	1003	999	993	986	978	968	958
29	1012	1011	1009	1006	1001	995	988	979	970	959
30	1014	1013	1011	1008	1003	997	989	981	971	960
31	1016	1015	1013	1009	1005	998	991	982	972	961
32	1017	1017	1015	1011	1006	1000	992	983	973	961
33	1019	1018	1016	1012	1007	1001	993	984	973	961
34	1020	1019	1017	1013	1008	1002	994	984	974	962
35	1021	1020	1018	1014	1009	1002	994	985	974	962
36	1022	1021	1019	1015	1010	1003	995	985	974	962
37	1022	1022	1019	1015	1010	1003	995	985	974	961
38	1023	1022	1019	1016	1010	1003	995	985	973	960
39	1023	1022	1020	1016	1010	1003	994	984	973	960
40	1023	1022	1019	1015	1010	1002	994	983	972	959
41	1022	1021	1019	1015	1009	1002	993	983	971	957
42	1021	1021	1018	1014	1008	1001	992	981	969	956
43	1020	1020	1017	1013	1007	1000	991	980	968	954
44	1019	1018	1016	1012	1006	998	989	979	966	953
45	1018	1017	1015	1010	1004	997	988	977	964	951

Zone 4

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	907	907	907	907	907	907	907	907	907	907
1	916	916	916	915	915	915	914	914	914	913
2	924	924	924	924	923	923	922	921	920	919
3	933	933	933	932	931	930	929	928	927	925
4	941	941	941	940	939	938	937	935	933	931
5	949	949	949	948	947	945	944	942	939	937
6	957	957	957	956	954	953	950	948	945	942
7	965	965	964	963	962	960	957	954	951	948
8	973	972	972	970	969	966	964	961	957	953
9	980	980	979	977	976	973	970	966	962	958
10	987	987	986	984	982	979	976	972	968	963
11	994	994	993	991	989	986	982	978	973	968
12	1001	1000	999	998	995	992	988	983	978	972
13	1007	1007	1006	1004	1001	998	993	988	983	977
14	1014	1013	1012	1010	1007	1003	999	994	988	981
15	1020	1019	1018	1016	1013	1009	1004	998	992	985
16	1025	1025	1024	1021	1018	1014	1009	1003	996	989
17	1031	1031	1029	1027	1023	1019	1014	1007	1001	993
18	1036	1036	1034	1032	1028	1024	1018	1012	1004	996
19	1041	1041	1039	1037	1033	1028	1023	1016	1008	1000
20	1046	1046	1044	1041	1038	1033	1027	1020	1012	1003
21	1051	1050	1049	1046	1042	1037	1031	1023	1015	1006
22	1055	1055	1053	1050	1046	1041	1034	1027	1018	1009
23	1060	1059	1057	1054	1050	1044	1038	1030	1021	1011
24	1064	1063	1061	1058	1054	1048	1041	1033	1024	1014
25	1067	1067	1065	1062	1057	1051	1044	1036	1027	1016
26	1071	1070	1068	1065	1060	1054	1047	1039	1029	1018
27	1074	1073	1071	1068	1063	1057	1050	1041	1031	1020
28	1077	1076	1074	1071	1066	1060	1052	1043	1033	1022
29	1080	1079	1077	1073	1068	1062	1054	1045	1035	1023
30	1082	1081	1079	1076	1071	1064	1056	1047	1036	1025
31	1084	1084	1081	1078	1073	1066	1058	1048	1038	1026
32	1086	1086	1083	1080	1074	1068	1059	1050	1039	1027
33	1088	1087	1085	1081	1076	1069	1061	1051	1040	1027
34	1089	1089	1086	1082	1077	1070	1062	1052	1040	1027
35	1091	1090	1087	1084	1078	1071	1062	1052	1041	1028
36	1091	1091	1088	1084	1079	1072	1063	1053	1041	1028
37	1092	1091	1089	1085	1079	1072	1063	1053	1041	1027
38	1093	1092	1089	1085	1080	1072	1063	1053	1041	1027
39	1093	1092	1089	1085	1080	1072	1063	1052	1040	1026
40	1093	1092	1089	1085	1079	1072	1063	1052	1039	1025
41	1092	1091	1089	1085	1079	1071	1062	1051	1038	1024
42	1092	1091	1088	1084	1078	1070	1061	1050	1037	1023
43	1091	1090	1087	1083	1077	1069	1060	1049	1036	1021
44	1089	1089	1086	1082	1076	1068	1058	1047	1034	1020
45	1088	1087	1085	1080	1074	1066	1057	1045	1032	1018

Zone 5W

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	803	803	803	803	803	803	803	803	803	803
1	809	809	809	809	809	809	808	808	808	807
2	816	816	816	816	816	815	814	814	813	812
3	823	823	823	823	822	821	820	819	818	817
4	830	830	830	829	828	827	826	825	823	822
5	837	837	836	835	835	833	832	830	828	826
6	843	843	842	842	841	839	838	836	833	831
7	849	849	849	848	846	845	843	841	838	835
8	855	855	855	854	852	850	848	846	843	839
9	861	861	860	859	858	856	853	850	847	843
10	867	867	866	865	863	861	858	855	851	847
11	873	872	872	870	868	866	863	859	856	851
12	878	878	877	875	873	871	868	864	860	855
13	883	883	882	880	878	875	872	868	863	858
14	888	888	887	885	883	880	876	872	867	862
15	893	893	892	890	887	884	880	876	871	865
16	898	898	896	894	892	888	884	880	874	868
17	902	902	901	899	896	892	888	883	877	871
18	907	906	905	903	900	896	892	886	880	874
19	911	910	909	907	904	900	895	890	883	876
20	915	914	913	910	907	903	898	893	886	879
21	918	918	916	914	911	907	901	895	889	881
22	922	921	920	917	914	910	904	898	891	883
23	925	925	923	921	917	913	907	901	893	885
24	928	928	926	923	920	915	910	903	896	887
25	931	931	929	926	923	918	912	905	897	889
26	934	933	932	929	925	920	914	907	899	890
27	936	936	934	931	927	922	916	909	901	892
28	939	938	936	933	929	924	918	910	902	893
29	941	940	938	935	931	926	919	912	903	894
30	943	942	940	937	933	927	921	913	904	895
31	944	944	942	939	934	929	922	914	905	895
32	946	945	943	940	936	930	923	915	906	896
33	947	946	944	941	937	931	924	916	906	896
34	948	947	945	942	937	932	924	916	907	896
35	949	948	946	943	938	932	925	916	907	896
36	949	949	947	943	938	932	925	916	907	896
37	950	949	947	943	939	933	925	916	906	895
38	950	949	947	944	939	932	925	916	906	895
39	950	949	947	943	939	932	925	916	905	894
40	949	949	947	943	938	932	924	915	904	893
41	949	948	946	942	937	931	923	914	903	892
42	948	948	945	942	937	930	922	913	902	890
43	947	947	944	941	936	929	921	912	901	889
44	946	945	943	940	934	928	920	910	899	887
45	945	944	942	938	933	926	918	908	897	885

Zone 5E

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	820	820	820	820	820	820	820	820	820	820
1	827	827	826	826	826	826	826	825	825	824
2	834	834	834	833	833	832	832	831	830	830
3	841	841	841	840	840	839	838	837	836	835
4	848	848	848	847	846	845	844	843	841	839
5	855	855	854	854	853	851	850	848	846	844
6	861	861	861	860	859	857	856	854	851	849
7	868	868	867	866	865	863	861	859	856	853
8	874	874	873	872	871	869	867	864	861	857
9	880	880	879	878	877	874	872	869	865	862
10	886	886	885	884	882	880	877	874	870	866
11	892	892	891	889	888	885	882	878	874	870
12	898	897	896	895	893	890	887	883	878	873
13	903	903	902	900	898	895	891	887	882	877
14	908	908	907	905	903	899	896	891	886	880
15	913	913	912	910	907	904	900	895	890	884
16	918	918	916	915	912	908	904	899	893	887
17	923	922	921	919	916	912	908	903	897	890
18	927	927	925	923	920	916	912	906	900	893
19	931	931	930	927	924	920	915	909	903	896
20	935	935	933	931	928	924	918	912	906	898
21	939	939	937	935	931	927	922	915	908	900
22	943	942	941	938	935	930	925	918	911	903
23	946	946	944	941	938	933	927	921	913	905
24	949	949	947	944	941	936	930	923	915	907
25	952	952	950	947	943	939	932	925	917	908
26	955	955	953	950	946	941	935	927	919	910
27	958	957	955	952	948	943	937	929	921	911
28	960	959	958	955	950	945	939	931	922	912
29	962	962	960	957	952	947	940	932	923	914
30	964	964	962	959	954	948	942	934	924	914
31	966	965	963	960	956	950	943	935	925	915
32	967	967	965	961	957	951	944	936	926	915
33	969	968	966	963	958	952	945	936	927	916
34	970	969	967	964	959	953	945	937	927	916
35	971	970	968	964	959	953	946	937	927	916
36	971	970	968	965	960	954	946	937	927	915
37	972	971	969	965	960	954	946	937	927	915
38	972	971	969	965	960	954	946	937	926	914
39	972	971	969	965	960	954	945	936	926	913
40	971	971	968	965	960	953	945	935	925	912
41	971	970	968	964	959	952	944	934	923	911
42	970	969	967	963	958	951	943	933	922	910
43	969	968	966	962	957	950	942	932	921	908
44	968	967	965	961	956	949	940	930	919	906
45	967	966	964	960	954	947	939	929	917	905

Zone 6

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	789	789	789	789	789	789	789	789	789	789
1	796	796	796	795	795	795	795	794	794	794
2	803	803	802	802	802	801	801	800	799	799
3	810	809	809	809	808	808	807	806	805	803
4	816	816	816	815	815	814	812	811	810	808
5	823	823	822	822	821	819	818	816	815	813
6	829	829	828	828	827	825	824	822	819	817
7	835	835	835	834	832	831	829	827	824	821
8	841	841	841	840	838	836	834	832	829	825
9	847	847	846	845	844	842	839	836	833	830
10	853	853	852	851	849	847	844	841	837	833
11	859	858	857	856	854	852	849	845	842	837
12	864	864	863	861	859	857	853	850	846	841
13	869	869	868	866	864	861	858	854	849	844
14	874	874	873	871	869	866	862	858	853	848
15	879	879	878	876	873	870	866	862	857	851
16	884	883	882	880	878	874	870	866	860	854
17	888	888	887	885	882	878	874	869	863	857
18	892	892	891	889	886	882	878	872	866	860
19	897	896	895	893	890	886	881	876	869	862
20	901	900	899	896	893	889	884	879	872	865
21	904	904	902	900	897	893	887	881	875	867
22	908	907	906	903	900	896	890	884	877	869
23	911	911	909	907	903	899	893	887	880	872
24	914	914	912	910	906	901	896	889	882	873
25	917	917	915	912	909	904	898	891	884	875
26	920	919	918	915	911	906	900	893	885	877
27	922	922	920	917	913	908	902	895	887	878
28	925	924	922	920	916	910	904	897	888	879
29	927	926	925	922	917	912	906	898	890	880
30	929	928	926	923	919	914	907	900	891	881
31	931	930	928	925	921	915	908	901	892	882
32	932	931	930	926	922	916	910	902	892	882
33	933	933	931	928	923	917	910	902	893	883
34	935	934	932	929	924	918	911	903	893	883
35	935	935	933	929	925	919	912	903	894	883
36	936	935	933	930	925	919	912	903	894	883
37	937	936	934	930	926	919	912	903	893	882
38	937	936	934	931	926	919	912	903	893	882
39	937	936	934	931	926	919	912	903	892	881
40	937	936	934	930	925	919	911	902	892	880
41	936	936	933	930	925	918	911	901	891	879
42	936	935	933	929	924	918	910	900	890	878
43	935	934	932	928	923	917	909	899	888	876
44	934	933	931	927	922	915	907	898	887	875
45	933	932	930	926	921	914	906	896	885	873

Zone 7W

Inclination (variation from horizontal)	Orientation (variation from south)									
	0	5	10	15	20	25	30	35	40	45
0	779	779	779	779	779	779	779	779	779	779
1	786	786	786	786	786	785	785	785	784	784
2	793	793	793	793	792	792	791	791	790	789
3	800	800	800	799	799	798	797	796	795	794
4	807	807	807	806	805	804	803	802	800	799
5	814	814	813	812	812	810	809	807	805	803
6	820	820	820	819	818	816	815	813	810	808
7	827	826	826	825	824	822	820	818	815	812
8	833	833	832	831	829	828	825	823	820	817
9	839	839	838	837	835	833	831	828	824	821
10	845	844	844	842	841	838	836	832	829	825
11	850	850	849	848	846	843	841	837	833	829
12	856	856	855	853	851	848	845	842	837	833
13	861	861	860	858	856	853	850	846	841	836
14	866	866	865	863	861	858	854	850	845	840
15	871	871	870	868	866	862	858	854	849	843
16	876	876	875	873	870	867	863	858	852	846
17	881	881	879	877	874	871	867	861	856	849
18	885	885	884	882	879	875	870	865	859	852
19	890	889	888	886	882	879	874	868	862	855
20	894	893	892	889	886	882	877	872	865	858
21	898	897	896	893	890	886	881	875	868	860
22	901	901	899	897	893	889	884	877	870	862
23	905	904	903	900	897	892	887	880	873	865
24	908	907	906	903	900	895	889	883	875	867
25	911	911	909	906	902	898	892	885	877	869
26	914	913	912	909	905	900	894	887	879	870
27	917	916	914	912	908	902	896	889	881	872
28	919	919	917	914	910	905	898	891	883	873
29	921	921	919	916	912	907	900	893	884	874
30	924	923	921	918	914	908	902	894	885	875
31	925	925	923	920	915	910	903	895	886	876
32	927	926	925	921	917	911	904	896	887	877
33	929	928	926	923	918	912	905	897	888	877
34	930	929	927	924	919	913	906	898	888	878
35	931	930	928	925	920	914	907	898	889	878
36	932	931	929	926	921	915	907	899	889	878
37	932	932	930	926	921	915	908	899	889	878
38	933	932	930	926	922	915	908	899	888	877
39	933	932	930	927	922	915	907	898	888	877
40	933	932	930	926	921	915	907	898	888	876
41	933	932	930	926	921	915	907	897	887	875
42	932	932	929	926	920	914	906	896	886	874
43	932	931	929	925	920	913	905	895	885	872
44	931	930	928	924	919	912	904	894	883	871
45	930	929	927	923	918	911	902	893	882	869

Zone 7E

	Orientation (variation East or West from South)									
Inclination (variation from horizontal)	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	735	735	735	735	735	735	735	735	735	735
1	741	741	741	741	741	740	740	740	740	739
2	747	747	747	747	746	746	746	745	744	744
3	753	753	753	753	752	752	751	750	749	748
4	759	759	759	759	758	757	756	755	753	752
5	765	765	765	764	763	762	761	760	758	756
6	771	771	770	770	769	767	766	764	762	760
7	776	776	776	775	774	772	771	769	766	764
8	782	782	781	780	779	777	775	773	771	768
9	787	787	786	785	784	782	780	777	774	771
10	792	792	791	790	789	787	784	781	778	775
11	797	797	796	795	793	791	789	785	782	778
12	802	802	801	800	798	795	793	789	786	781
13	807	806	806	804	802	800	797	793	789	785
14	811	811	810	808	806	804	800	797	792	787
15	816	815	814	813	810	808	804	800	795	790
16	820	819	818	817	814	811	808	803	798	793
17	824	823	822	820	818	815	811	806	801	796
18	827	827	826	824	821	818	814	809	804	798
19	831	831	829	828	825	821	817	812	807	800
20	835	834	833	831	828	824	820	815	809	803
21	838	837	836	834	831	827	823	818	812	805
22	841	841	839	837	834	830	825	820	814	807
23	844	843	842	840	837	833	828	822	816	809
24	847	846	845	842	839	835	830	824	818	810
25	849	849	847	845	842	837	832	826	819	812
26	852	851	850	847	844	839	834	828	821	813
27	854	853	852	849	846	841	836	830	822	814
28	856	855	854	851	848	843	837	831	823	815
29	858	857	856	853	849	845	839	832	825	816
30	859	859	857	855	851	846	840	833	825	817
31	861	860	859	856	852	847	841	834	826	817
32	862	862	860	857	853	848	842	835	827	818
33	863	863	861	858	854	849	843	835	827	818
34	864	864	862	859	855	850	843	836	827	818
35	865	864	863	860	855	850	844	836	827	818
36	865	865	863	860	856	850	844	836	827	818
37	866	865	863	860	856	850	844	836	827	817
38	866	865	863	860	856	850	844	836	827	817
39	866	865	863	860	856	850	843	835	826	816
40	866	865	863	860	855	850	843	835	825	815
41	865	865	863	859	855	849	842	834	824	814
42	865	864	862	859	854	848	841	833	823	813
43	864	863	861	858	853	847	840	832	822	811
44	863	862	860	857	852	846	839	830	821	810
45	862	861	859	855	851	845	837	829	819	808

Zone 8S

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	722	722	722	722	722	722	722	722	722	722
1	728	728	728	728	728	728	727	727	727	726
2	735	735	735	734	734	734	733	732	732	731
3	741	741	741	741	740	739	739	738	737	735
4	748	748	747	747	746	745	744	743	742	740
5	754	754	753	753	752	751	750	748	746	744
6	760	760	760	759	758	756	755	753	751	749
7	766	766	765	765	763	762	760	758	755	753
8	772	772	771	770	769	767	765	763	760	757
9	778	777	777	776	774	772	770	767	764	761
10	783	783	782	781	779	777	775	772	768	765
11	788	788	787	786	784	782	779	776	772	768
12	794	793	793	791	789	787	784	780	776	772
13	799	798	798	796	794	791	788	784	780	775
14	804	803	802	801	799	796	792	788	784	779
15	808	808	807	805	803	800	796	792	787	782
16	813	813	812	810	807	804	800	796	791	785
17	817	817	816	814	811	808	804	799	794	788
18	822	821	820	818	815	812	807	802	797	791
19	826	825	824	822	819	815	811	806	800	793
20	829	829	828	826	823	819	814	809	803	796
21	833	833	831	829	826	822	817	812	805	798
22	837	836	835	833	829	825	820	814	808	800
23	840	840	838	836	832	828	823	817	810	802
24	843	843	841	839	835	831	826	819	812	805
25	846	846	844	842	838	834	828	822	814	806
26	849	848	847	844	841	836	830	824	816	808
27	852	851	849	847	843	838	833	826	818	809
28	854	854	852	849	845	840	834	827	820	811
29	856	856	854	851	847	842	836	829	821	812
30	858	858	856	853	849	844	838	831	822	813
31	860	860	858	855	851	846	839	832	823	814
32	862	861	859	856	852	847	840	833	824	814
33	863	863	861	858	854	848	841	834	825	815
34	865	864	862	859	855	849	842	834	825	815
35	866	865	863	860	856	850	843	835	826	816
36	867	866	864	861	856	851	844	835	826	816
37	867	867	865	861	857	851	844	836	826	816
38	868	867	865	862	857	851	844	836	826	815
39	868	867	865	862	857	851	844	835	826	815
40	868	868	866	862	857	851	844	835	825	814
41	868	868	865	862	857	851	843	835	825	813
42	868	867	865	862	857	850	843	834	824	812
43	867	867	865	861	856	850	842	833	823	811
44	867	866	864	860	855	849	841	832	822	810
45	866	865	863	859	854	848	840	831	820	809

Zone 8E

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	731	731	731	731	731	731	731	731	731	731
1	737	737	737	737	737	737	736	736	736	735
2	744	744	744	744	743	743	742	742	741	740
3	751	751	750	750	750	749	748	747	746	745
4	757	757	757	756	756	755	754	752	751	749
5	764	763	763	762	762	760	759	758	756	754
6	770	770	769	768	767	766	764	763	760	758
7	776	776	775	774	773	771	770	767	765	762
8	782	782	781	780	779	777	775	772	769	766
9	788	787	787	786	784	782	780	777	774	770
10	793	793	792	791	789	787	784	781	778	774
11	799	798	798	796	794	792	789	786	782	778
12	804	804	803	801	799	797	794	790	786	782
13	809	809	808	806	804	801	798	794	790	785
14	814	814	813	811	809	806	802	798	794	788
15	819	818	817	816	813	810	806	802	797	792
16	823	823	822	820	818	814	810	806	801	795
17	828	827	826	824	822	818	814	809	804	798
18	832	832	831	829	826	822	818	813	807	801
19	836	836	835	833	830	826	821	816	810	803
20	840	840	838	836	833	829	825	819	813	806
21	844	844	842	840	837	833	828	822	815	808
22	848	847	846	843	840	836	831	825	818	811
23	851	851	849	847	843	839	834	828	820	813
24	854	854	852	850	846	842	836	830	823	815
25	857	857	855	853	849	844	839	832	825	817
26	860	860	858	855	852	847	841	834	827	818
27	863	862	861	858	854	849	843	836	828	820
28	865	865	863	860	856	851	845	838	830	821
29	868	867	865	862	858	853	847	840	831	822
30	870	869	867	864	860	855	849	841	833	823
31	872	871	869	866	862	857	850	842	834	824
32	873	873	871	868	863	858	851	844	835	825
33	875	874	872	869	865	859	852	844	835	825
34	876	875	873	870	866	860	853	845	836	826
35	877	876	875	871	867	861	854	846	836	826
36	878	877	875	872	868	862	855	846	837	826
37	879	878	876	873	868	862	855	846	837	826
38	879	879	877	873	868	862	855	846	837	826
39	880	879	877	873	869	862	855	846	836	825
40	880	879	877	873	869	862	855	846	836	825
41	880	879	877	873	868	862	854	845	835	824
42	879	879	877	873	868	862	854	845	834	823
43	879	878	876	872	867	861	853	844	833	822
44	878	878	875	872	867	860	852	843	832	820
45	877	877	874	871	866	859	851	842	831	819

Zone 9S

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	738	738	738	738	738	738	738	738	738	738
1	745	745	745	744	744	744	744	743	743	742
2	752	752	752	751	751	751	750	749	748	748
3	759	759	759	758	758	757	756	755	754	753
4	766	766	766	765	764	763	762	761	759	758
5	773	773	773	772	771	770	768	767	765	763
6	780	780	779	778	777	776	774	772	770	767
7	787	786	786	785	784	782	780	778	775	772
8	793	793	792	791	790	788	785	783	780	776
9	799	799	798	797	796	794	791	788	785	781
10	806	805	805	803	801	799	796	793	789	785
11	812	811	810	809	807	805	801	798	794	789
12	817	817	816	815	813	810	806	803	798	793
13	823	823	822	820	818	815	811	807	803	797
14	829	828	827	825	823	820	816	812	807	801
15	834	834	832	831	828	825	821	816	811	805
16	839	839	838	836	833	829	825	820	815	808
17	844	844	843	840	838	834	829	824	818	812
18	849	848	847	845	842	838	834	828	822	815
19	854	853	852	850	846	842	837	832	825	818
20	858	858	856	854	850	846	841	835	829	821
21	862	862	860	858	855	850	845	839	832	824
22	866	866	864	862	858	854	848	842	835	827
23	870	870	868	865	862	857	852	845	837	829
24	874	873	872	869	865	860	855	848	840	832
25	877	877	875	872	869	864	858	851	843	834
26	881	880	878	876	872	867	860	853	845	836
27	884	883	881	879	874	869	863	855	847	838
28	887	886	884	881	877	872	865	858	849	839
29	889	889	887	884	880	874	867	860	851	841
30	892	891	889	886	882	876	870	862	852	842
31	894	894	892	888	884	878	871	863	854	844
32	896	896	894	891	886	880	873	865	855	845
33	898	898	896	892	888	882	874	866	856	846
34	900	899	897	894	889	883	876	867	857	846
35	902	901	899	895	890	884	877	868	858	847
36	903	902	900	897	892	885	878	869	859	847
37	904	903	901	897	892	886	878	869	859	847
38	905	904	902	898	893	887	879	870	859	847
39	905	905	903	899	894	887	879	870	859	847
40	906	905	903	899	894	887	879	870	859	847
41	906	905	903	899	894	887	879	870	859	846
42	906	905	903	899	894	887	879	869	858	846
43	906	905	903	899	894	887	878	869	857	845
44	906	905	903	899	893	886	878	868	856	844
45	905	904	902	898	893	885	877	867	855	843

Zone 9E

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	742	742	742	742	742	742	742	742	742	742
1	748	748	748	748	748	748	747	747	747	746
2	756	756	755	755	755	754	754	753	752	751
3	763	763	762	762	762	761	760	759	758	756
4	770	770	769	769	768	767	766	765	763	761
5	777	777	776	775	775	773	772	770	768	766
6	783	783	783	782	781	779	778	776	773	771
7	790	790	789	788	787	785	783	781	778	775
8	796	796	796	795	793	791	789	786	783	780
9	803	802	802	801	799	797	794	791	788	784
10	809	809	808	806	805	802	800	796	793	788
11	815	815	814	812	810	808	805	801	797	793
12	821	820	819	818	816	813	810	806	801	797
13	826	826	825	823	821	818	814	810	806	800
14	832	831	830	828	826	823	819	815	810	804
15	837	836	835	834	831	828	824	819	814	808
16	842	842	840	838	836	832	828	823	817	811
17	847	846	845	843	840	837	832	827	821	815
18	852	851	850	848	845	841	836	831	825	818
19	856	856	854	852	849	845	840	834	828	821
20	861	860	859	856	853	849	844	838	831	824
21	865	864	863	860	857	853	847	841	834	826
22	869	868	867	864	861	856	851	844	837	829
23	873	872	870	868	864	860	854	847	840	831
24	876	876	874	871	868	863	857	850	842	834
25	880	879	877	875	871	866	860	853	845	836
26	883	882	881	878	874	869	862	855	847	838
27	886	885	884	881	876	871	865	857	849	840
28	889	888	886	883	879	874	867	860	851	841
29	891	891	889	886	882	876	869	861	853	843
30	894	893	891	888	884	878	871	863	854	844
31	896	895	894	890	886	880	873	865	855	845
32	898	898	896	892	888	882	875	866	857	846
33	900	899	897	894	889	883	876	867	858	847
34	902	901	899	895	891	884	877	868	858	847
35	903	902	900	897	892	886	878	869	859	848
36	904	904	901	898	893	887	879	870	860	848
37	905	905	902	899	894	887	880	870	860	848
38	906	905	903	900	894	888	880	871	860	848
39	907	906	904	900	895	888	880	871	860	848
40	907	906	904	900	895	888	880	871	860	848
41	907	907	904	900	895	888	880	870	859	847
42	907	907	904	900	895	888	880	870	859	846
43	907	906	904	900	895	888	879	869	858	845
44	907	906	903	900	894	887	878	868	857	844
45	906	905	903	899	893	886	877	867	856	843

Zone 10

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	750	750	750	750	750	750	750	750	750	750
1	757	757	757	757	757	757	756	756	756	755
2	765	765	764	764	764	763	763	762	761	760
3	772	772	772	771	771	770	769	768	767	765
4	779	779	779	778	777	776	775	774	772	770
5	786	786	785	785	784	783	781	779	777	775
6	793	793	792	791	790	789	787	785	783	780
7	799	799	799	798	796	795	793	790	788	785
8	806	806	805	804	803	801	798	796	793	789
9	812	812	811	810	808	806	804	801	797	794
10	818	818	817	816	814	812	809	806	802	798
11	825	824	823	822	820	817	814	811	807	802
12	830	830	829	828	825	823	819	815	811	806
13	836	836	835	833	831	828	824	820	815	810
14	842	841	840	838	836	833	829	824	819	814
15	847	847	845	843	841	838	833	829	823	817
16	852	852	850	848	846	842	838	833	827	821
17	857	857	855	853	850	847	842	837	831	824
18	862	861	860	858	855	851	846	841	834	827
19	866	866	865	862	859	855	850	844	838	831
20	871	870	869	867	863	859	854	848	841	833
21	875	875	873	871	867	863	857	851	844	836
22	879	879	877	874	871	866	861	854	847	839
23	883	882	881	878	874	870	864	857	850	841
24	887	886	884	882	878	873	867	860	852	844
25	890	890	888	885	881	876	870	863	855	846
26	893	893	891	888	884	879	873	865	857	848
27	896	896	894	891	887	882	875	868	859	850
28	899	899	897	894	890	884	877	870	861	851
29	902	901	899	896	892	886	880	872	863	853
30	904	904	902	899	894	888	882	873	864	854
31	907	906	904	901	896	890	883	875	866	855
32	909	908	906	903	898	892	885	876	867	856
33	911	910	908	904	900	894	886	878	868	857
34	912	912	909	906	901	895	887	879	869	858
35	914	913	911	907	902	896	888	879	869	858
36	915	914	912	908	903	897	889	880	870	858
37	916	915	913	909	904	898	890	881	870	858
38	917	916	914	910	905	898	890	881	870	858
39	917	917	914	911	905	899	890	881	870	858
40	918	917	915	911	906	899	890	881	870	858
41	918	917	915	911	906	899	890	880	869	857
42	918	917	915	911	905	898	890	880	869	856
43	918	917	914	910	905	898	889	879	868	855
44	917	916	914	910	904	897	889	878	867	854
45	916	916	913	909	904	896	888	877	866	853

Zone 11

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	750	750	750	750	750	750	750	750	750	750
1	756	756	756	756	756	755	755	755	754	754
2	763	763	763	762	762	762	761	760	760	759
3	769	769	769	769	768	767	767	766	765	763
4	776	776	775	775	774	773	772	771	769	768
5	782	782	782	781	780	779	778	776	774	772
6	788	788	788	787	786	785	783	781	779	777
7	794	794	794	793	791	790	788	786	783	781
8	800	800	799	798	797	795	793	791	788	785
9	806	806	805	804	802	800	798	795	792	789
10	811	811	810	809	807	805	803	800	796	792
11	817	816	816	814	812	810	807	804	800	796
12	822	822	821	819	817	815	812	808	804	800
13	827	827	826	824	822	819	816	812	808	803
14	832	831	830	829	827	824	820	816	811	806
15	837	836	835	833	831	828	824	820	815	809
16	841	841	840	838	835	832	828	823	818	812
17	845	845	844	842	839	836	832	827	821	815
18	849	849	848	846	843	840	835	830	824	818
19	853	853	852	850	847	843	838	833	827	820
20	857	857	856	853	850	846	842	836	830	823
21	861	860	859	857	854	850	845	839	832	825
22	864	864	862	860	857	853	848	841	835	827
23	868	867	866	863	860	855	850	844	837	829
24	871	870	869	866	863	858	853	846	839	831
25	874	873	871	869	865	861	855	848	841	833
26	876	876	874	871	868	863	857	850	843	834
27	879	878	877	874	870	865	859	852	844	835
28	881	881	879	876	872	867	861	854	846	837
29	883	883	881	878	874	869	863	855	847	838
30	885	884	883	880	876	870	864	857	848	838
31	887	886	884	881	877	872	865	858	849	839
32	888	888	886	883	879	873	866	859	850	840
33	890	889	887	884	880	874	867	859	850	840
34	891	890	888	885	881	875	868	860	851	840
35	892	891	889	886	881	876	868	860	851	840
36	892	892	890	887	882	876	869	860	851	840
37	893	892	890	887	882	876	869	860	851	840
38	893	893	891	887	882	876	869	860	850	839
39	893	893	891	887	882	876	869	860	850	839
40	893	893	891	887	882	876	868	859	849	838
41	893	892	890	887	882	875	868	859	848	837
42	893	892	890	886	881	875	867	858	847	836
43	892	891	889	885	880	874	866	857	846	834
44	891	890	888	884	879	873	865	855	845	833
45	890	889	887	883	878	872	863	854	843	831

Zone 12

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	805	805	805	805	805	805	805	805	805	805
1	812	812	811	811	811	811	811	810	810	809
2	819	819	819	818	818	817	817	816	815	814
3	826	826	826	825	825	824	823	822	821	820
4	833	833	833	832	831	830	829	828	826	824
5	840	840	839	839	838	837	835	833	831	829
6	847	847	846	845	844	843	841	839	837	834
7	853	853	853	852	850	849	847	844	842	839
8	860	860	859	858	856	854	852	849	846	843
9	866	866	865	864	862	860	857	854	851	847
10	872	872	871	870	868	865	863	859	856	851
11	878	878	877	875	873	871	868	864	860	855
12	884	883	882	881	879	876	873	869	864	859
13	889	889	888	886	884	881	877	873	868	863
14	894	894	893	891	889	886	882	877	872	867
15	900	899	898	896	894	890	886	881	876	870
16	905	904	903	901	898	895	890	885	880	873
17	909	909	908	906	903	899	894	889	883	877
18	914	913	912	910	907	903	898	893	887	880
19	918	918	916	914	911	907	902	896	890	882
20	922	922	921	918	915	911	906	900	893	885
21	926	926	924	922	919	914	909	903	896	888
22	930	930	928	926	922	918	912	906	898	890
23	934	933	932	929	925	921	915	908	901	892
24	937	937	935	932	928	924	918	911	903	894
25	940	940	938	935	931	926	920	913	905	896
26	943	943	941	938	934	929	923	915	907	898
27	946	945	944	941	937	931	925	917	909	899
28	949	948	946	943	939	934	927	919	911	901
29	951	950	948	945	941	935	929	921	912	902
30	953	952	951	947	943	937	930	922	913	903
31	955	954	952	949	945	939	932	924	914	904
32	957	956	954	951	946	940	933	925	915	905
33	958	958	955	952	947	941	934	926	916	905
34	959	959	957	953	948	942	935	926	916	905
35	961	960	958	954	949	943	936	927	917	905
36	961	961	959	955	950	944	936	927	917	905
37	962	961	959	956	950	944	936	927	917	905
38	962	962	959	956	951	944	936	927	916	905
39	963	962	960	956	951	944	936	927	916	904
40	962	962	959	956	951	944	936	926	915	903
41	962	961	959	955	950	943	935	925	914	902
42	962	961	959	955	949	943	934	925	913	901
43	961	960	958	954	949	942	933	923	912	899
44	960	959	957	953	948	941	932	922	911	898
45	959	958	956	952	946	939	931	921	909	896

Zone 13

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	789	789	789	789	789	789	789	789	789	789
1	795	795	795	795	795	795	794	794	794	793
2	802	802	802	802	801	801	800	800	799	798
3	809	808	808	808	807	807	806	805	804	803
4	815	815	814	814	813	812	811	810	809	807
5	821	821	821	820	819	818	817	815	813	811
6	827	827	826	826	825	823	822	820	818	815
7	833	833	832	831	830	829	827	825	822	819
8	839	838	838	837	835	834	832	829	826	823
9	844	844	843	842	841	839	836	834	831	827
10	849	849	848	847	846	844	841	838	835	831
11	855	854	853	852	850	848	845	842	838	834
12	859	859	858	857	855	853	850	846	842	838
13	864	864	863	862	860	857	854	850	846	841
14	869	869	868	866	864	861	858	854	849	844
15	873	873	872	870	868	865	861	857	852	847
16	878	877	876	874	872	869	865	861	855	850
17	882	881	880	878	876	872	869	864	858	852
18	886	885	884	882	879	876	872	867	861	855
19	889	889	888	886	883	879	875	870	864	857
20	893	892	891	889	886	882	878	873	866	860
21	896	896	894	892	889	885	881	875	869	862
22	899	899	898	895	892	888	883	878	871	863
23	902	902	900	898	895	891	886	880	873	865
24	905	905	903	901	897	893	888	882	875	867
25	908	907	906	903	900	895	890	884	876	868
26	910	909	908	905	902	897	892	885	878	870
27	912	912	910	907	904	899	894	887	879	871
28	914	914	912	909	906	901	895	888	880	872
29	916	915	914	911	907	902	896	889	881	872
30	917	917	915	912	909	904	898	890	882	873
31	919	918	916	914	910	905	898	891	883	874
32	920	919	918	915	911	906	899	892	883	874
33	921	920	918	915	911	906	900	892	884	874
34	921	921	919	916	912	907	900	893	884	874
35	922	921	920	917	912	907	900	892	884	874
36	922	922	920	917	913	907	900	892	883	873
37	922	922	920	917	913	907	900	892	883	873
38	922	922	920	917	912	907	900	892	882	872
39	922	921	919	916	912	906	899	891	881	871
40	921	921	919	916	911	905	898	890	880	870
41	921	920	918	915	910	905	897	889	879	868
42	920	919	917	914	909	903	896	888	878	867
43	919	918	916	913	908	902	895	886	876	865
44	917	916	915	911	907	901	893	885	875	863
45	916	915	913	910	905	899	891	883	873	861

Zone 14

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	701	701	701	701	701	701	701	701	701	701
1	707	706	706	706	706	706	706	705	705	705
2	713	713	712	712	712	711	711	710	710	709
3	719	719	718	718	718	717	716	715	714	713
4	725	725	724	724	723	722	721	720	719	717
5	730	730	730	729	729	728	726	725	723	722
6	736	736	736	735	734	733	731	730	728	725
7	742	741	741	740	739	738	736	734	732	729
8	747	747	746	745	744	743	741	738	736	733
9	752	752	752	751	749	747	745	743	740	737
10	758	757	757	755	754	752	750	747	744	740
11	762	762	761	760	759	756	754	751	747	744
12	767	767	766	765	763	761	758	755	751	747
13	772	772	771	769	768	765	762	759	755	750
14	776	776	775	774	772	769	766	762	758	753
15	781	781	780	778	776	773	770	766	761	756
16	785	785	784	782	780	777	773	769	764	759
17	789	789	788	786	784	780	777	772	767	762
18	793	793	792	790	787	784	780	775	770	764
19	797	796	795	793	791	787	783	778	773	767
20	800	800	799	797	794	790	786	781	775	769
21	804	803	802	800	797	793	789	784	778	771
22	807	806	805	803	800	796	792	786	780	773
23	810	809	808	806	803	799	794	789	782	775
24	813	812	811	809	806	802	797	791	784	777
25	815	815	814	811	808	804	799	793	786	779
26	818	818	816	814	810	806	801	795	788	780
27	820	820	818	816	813	808	803	797	790	782
28	823	822	821	818	815	810	805	798	791	783
29	825	824	822	820	816	812	806	800	792	784
30	826	826	824	822	818	813	808	801	793	785
31	828	827	826	823	819	815	809	802	794	785
32	829	829	827	825	821	816	810	803	795	786
33	831	830	828	826	822	817	811	804	796	787
34	832	831	830	827	823	818	812	804	796	787
35	833	832	830	828	824	818	812	805	796	787
36	833	833	831	828	824	819	812	805	796	787
37	834	833	832	829	824	819	813	805	796	787
38	834	834	832	829	825	819	813	805	796	786
39	835	834	832	829	825	819	813	805	796	786
40	835	834	832	829	825	819	812	804	795	785
41	834	834	832	829	824	819	812	804	795	784
42	834	833	831	828	824	818	811	803	794	783
43	833	833	831	828	823	817	810	802	793	782
44	833	832	830	827	822	816	809	801	792	781
45	832	831	829	826	821	815	808	800	790	779

Zone 15

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	758	758	758	758	758	758	758	758	758	758
1	766	765	765	765	765	765	764	764	764	763
2	773	773	773	773	772	772	771	771	770	769
3	781	781	781	780	780	779	778	777	776	774
4	789	789	788	788	787	786	785	783	781	779
5	796	796	796	795	794	793	791	789	787	785
6	804	803	803	802	801	799	797	795	793	790
7	811	811	810	809	808	806	804	801	798	795
8	818	818	817	816	814	812	810	807	804	800
9	825	824	824	822	821	818	816	812	809	805
10	831	831	830	829	827	824	821	818	814	809
11	838	838	837	835	833	830	827	823	819	814
12	844	844	843	841	839	836	833	828	824	818
13	851	850	849	847	845	842	838	833	828	823
14	857	856	855	853	850	847	843	838	833	827
15	862	862	861	859	856	852	848	843	837	831
16	868	868	866	864	861	858	853	848	842	835
17	874	873	872	869	866	862	858	852	846	839
18	879	878	877	875	871	867	862	856	850	842
19	884	883	882	880	876	872	867	861	854	846
20	889	888	887	884	881	876	871	865	857	849
21	893	893	891	889	885	880	875	868	861	852
22	898	897	896	893	889	884	879	872	864	855
23	902	902	900	897	893	888	882	875	867	858
24	906	906	904	901	897	892	886	879	870	861
25	910	910	908	905	901	896	889	882	873	863
26	914	913	912	909	904	899	892	884	876	866
27	918	917	915	912	908	902	895	887	878	868
28	921	920	918	915	911	905	898	890	880	870
29	924	923	921	918	913	908	900	892	883	872
30	927	926	924	921	916	910	903	894	885	874
31	930	929	927	923	918	912	905	896	886	875
32	932	931	929	926	921	914	907	898	888	876
33	934	933	931	928	923	916	909	900	889	878
34	936	935	933	930	925	918	910	901	890	879
35	938	937	935	931	926	920	912	902	891	879
36	940	939	936	933	928	921	913	903	892	880
37	941	940	938	934	929	922	914	904	893	880
38	942	941	939	935	930	923	914	904	893	881
39	943	942	940	936	930	923	915	905	893	881
40	944	943	940	936	931	924	915	905	894	881
41	944	943	941	937	931	924	915	905	893	880
42	944	944	941	937	931	924	915	905	893	880
43	944	944	941	937	931	924	915	904	892	879
44	944	943	941	937	931	923	914	904	892	878
45	944	943	940	936	930	923	914	903	891	877

Zone 16

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	712	712	712	712	712	712	712	712	712	712
1	718	718	718	718	718	718	717	717	717	716
2	725	725	725	725	725	724	724	723	722	721
3	732	732	732	732	731	730	730	729	727	726
4	739	739	739	738	737	737	735	734	733	731
5	746	746	745	745	744	743	741	740	738	736
6	752	752	752	751	750	749	747	745	743	740
7	759	759	758	757	756	754	753	750	748	745
8	765	765	764	763	762	760	758	755	753	749
9	771	771	771	769	768	766	763	761	757	754
10	777	777	776	775	773	771	769	765	762	758
11	783	783	782	781	779	777	774	770	766	762
12	789	789	788	786	784	782	779	775	771	766
13	795	794	793	792	789	787	783	779	775	770
14	800	800	799	797	795	792	788	784	779	774
15	805	805	804	802	799	796	792	788	783	777
16	810	810	809	807	804	801	797	792	787	781
17	815	815	814	812	809	805	801	796	791	784
18	820	819	818	816	813	810	805	800	794	788
19	824	824	823	820	818	814	809	804	798	791
20	829	828	827	825	822	818	813	807	801	794
21	833	833	831	829	826	821	816	811	804	797
22	837	837	835	833	829	825	820	814	807	799
23	841	840	839	836	833	828	823	817	810	802
24	844	844	842	840	836	832	826	820	812	804
25	848	847	846	843	839	835	829	822	815	806
26	851	851	849	846	843	838	832	825	817	808
27	854	854	852	849	845	840	834	827	819	810
28	857	857	855	852	848	843	837	830	821	812
29	860	859	858	855	851	845	839	832	823	814
30	862	862	860	857	853	848	841	834	825	815
31	865	864	862	859	855	850	843	835	826	817
32	867	866	864	861	857	851	845	837	828	818
33	869	868	866	863	859	853	846	838	829	819
34	871	870	868	865	860	854	847	839	830	820
35	872	871	869	866	862	856	849	840	831	820
36	873	873	871	867	863	857	850	841	831	821
37	875	874	872	868	864	858	850	842	832	821
38	876	875	873	869	865	858	851	842	832	821
39	876	876	873	870	865	859	851	842	832	821
40	877	876	874	870	866	859	851	843	832	821
41	877	876	874	871	866	859	852	842	832	821
42	877	877	874	871	866	859	851	842	832	820
43	877	877	874	871	866	859	851	842	831	819
44	877	876	874	870	865	859	850	841	830	818
45	877	876	874	870	865	858	850	840	829	817

Zone 17

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	691	691	691	691	691	691	691	691	691	691
1	697	697	697	697	697	697	696	696	696	695
2	704	703	703	703	703	702	702	701	700	700
3	710	710	710	709	709	708	707	706	705	704
4	716	716	716	715	714	714	713	711	710	708
5	722	722	722	721	720	719	718	716	715	713
6	728	728	727	727	726	724	723	721	719	717
7	734	734	733	732	731	730	728	726	724	721
8	740	739	739	738	737	735	733	731	728	725
9	745	745	744	743	742	740	738	735	732	729
10	750	750	750	748	747	745	742	739	736	733
11	756	756	755	753	752	750	747	744	740	736
12	761	761	760	758	757	754	751	748	744	740
13	766	766	765	763	761	759	756	752	748	743
14	771	770	769	768	766	763	760	756	751	747
15	775	775	774	772	770	767	764	760	755	750
16	780	780	779	777	774	771	768	763	758	753
17	784	784	783	781	778	775	771	767	762	756
18	788	788	787	785	782	779	775	770	765	759
19	792	792	791	789	786	783	778	773	768	761
20	796	796	795	793	790	786	782	776	771	764
21	800	800	798	796	793	789	785	779	773	766
22	804	803	802	800	797	792	788	782	776	769
23	807	806	805	803	800	795	791	785	778	771
24	810	810	808	806	803	798	793	787	781	773
25	813	813	811	809	805	801	796	790	783	775
26	816	815	814	811	808	804	798	792	785	777
27	819	818	816	814	810	806	800	794	786	778
28	821	821	819	816	813	808	802	796	788	780
29	823	823	821	819	815	810	804	797	790	781
30	826	825	823	821	817	812	806	799	791	782
31	827	827	825	822	818	813	807	800	792	783
32	829	829	827	824	820	815	809	801	793	784
33	831	830	828	826	821	816	810	803	794	785
34	832	832	830	827	823	817	811	803	795	785
35	833	833	831	828	824	818	812	804	795	785
36	834	834	832	829	825	819	812	805	796	786
37	835	835	833	830	825	820	813	805	796	786
38	836	835	833	830	826	820	813	805	796	786
39	836	836	834	831	826	820	813	805	796	785
40	837	836	834	831	826	820	813	805	796	785
41	837	836	834	831	826	820	813	805	795	784
42	837	836	834	831	826	820	813	804	795	784
43	836	836	834	830	826	820	812	804	794	783
44	836	835	833	830	825	819	811	803	793	782
45	835	835	832	829	824	818	811	802	792	780

Zone 18

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	645	645	645	645	645	645	645	645	645	645
1	650	650	650	650	650	649	649	649	649	648
2	656	656	655	655	655	655	654	654	653	652
3	661	661	661	661	660	660	659	658	657	656
4	667	667	666	666	665	664	664	663	661	660
5	672	672	671	671	670	669	668	667	665	664
6	677	677	677	676	675	674	673	671	669	667
7	682	682	682	681	680	679	677	675	673	671
8	687	687	687	686	685	683	681	679	677	675
9	692	692	691	691	689	688	686	683	681	678
10	697	697	696	695	694	692	690	687	684	681
11	701	701	701	699	698	696	694	691	688	684
12	706	706	705	704	702	700	698	695	691	687
13	710	710	709	708	706	704	701	698	695	691
14	714	714	713	712	710	708	705	702	698	693
15	718	718	717	716	714	711	708	705	701	696
16	722	722	721	720	718	715	712	708	704	699
17	726	726	725	723	721	718	715	711	706	701
18	730	729	728	727	724	721	718	714	709	704
19	733	733	732	730	728	725	721	717	712	706
20	736	736	735	733	731	728	724	719	714	709
21	740	739	738	736	734	730	726	722	717	711
22	742	742	741	739	736	733	729	724	719	713
23	745	745	744	742	739	736	731	726	721	714
24	748	748	746	744	742	738	734	729	723	716
25	751	750	749	747	744	740	736	730	724	718
26	753	752	751	749	746	742	738	732	726	719
27	755	755	753	751	748	744	739	734	728	720
28	757	757	755	753	750	746	741	735	729	722
29	759	758	757	755	752	748	743	737	730	723
30	761	760	759	756	753	749	744	738	731	724
31	762	762	760	758	755	750	745	739	732	724
32	764	763	762	759	756	751	746	740	733	725
33	765	764	763	760	757	752	747	741	734	726
34	766	765	764	761	758	753	748	741	734	726
35	767	766	765	762	758	754	748	742	734	726
36	767	767	765	763	759	754	749	742	735	726
37	768	767	766	763	759	755	749	742	735	726
38	768	768	766	763	760	755	749	742	735	726
39	768	768	766	764	760	755	749	742	734	725
40	768	768	766	763	760	755	749	742	734	725
41	768	768	766	763	759	754	748	741	733	724
42	768	767	766	763	759	754	748	741	733	723
43	767	767	765	762	758	753	747	740	732	722
44	767	766	764	762	758	752	746	739	731	721
45	766	765	763	761	757	751	745	738	729	720

Zone 19

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	617	617	617	617	617	617	617	617	617	617
1	622	622	621	621	621	621	621	621	620	620
2	627	627	627	627	626	626	625	625	624	624
3	632	632	632	632	631	631	630	629	628	627
4	637	637	637	637	636	635	635	634	632	631
5	642	642	642	642	641	640	639	638	636	635
6	647	647	647	646	646	645	643	642	640	638
7	652	652	652	651	650	649	647	646	644	642
8	657	657	656	656	655	653	652	650	647	645
9	662	662	661	660	659	657	655	653	651	648
10	666	666	665	664	663	661	659	657	654	651
11	671	670	670	669	667	665	663	661	658	654
12	675	675	674	673	671	669	667	664	661	657
13	679	679	678	677	675	673	670	667	664	660
14	683	683	682	681	679	677	674	671	667	663
15	687	686	686	684	682	680	677	674	670	666
16	690	690	689	688	686	683	680	677	673	668
17	694	694	693	691	689	687	683	680	675	671
18	697	697	696	695	692	690	686	682	678	673
19	701	700	699	698	696	693	689	685	680	675
20	704	703	702	701	698	695	692	687	683	677
21	707	706	705	704	701	698	694	690	685	679
22	710	709	708	706	704	701	697	692	687	681
23	712	712	711	709	706	703	699	694	689	683
24	715	715	713	711	709	705	701	696	691	684
25	717	717	716	714	711	707	703	698	692	686
26	720	719	718	716	713	709	705	700	694	687
27	722	721	720	718	715	711	707	701	695	689
28	724	723	722	720	717	713	708	703	697	690
29	725	725	724	721	718	714	710	704	698	691
30	727	727	725	723	720	716	711	705	699	692
31	729	728	727	724	721	717	712	706	700	692
32	730	729	728	726	722	718	713	707	700	693
33	731	730	729	727	723	719	714	708	701	693
34	732	731	730	728	724	720	715	709	702	694
35	733	732	731	728	725	721	715	709	702	694
36	733	733	731	729	725	721	716	709	702	694
37	734	733	732	729	726	721	716	709	702	694
38	734	734	732	730	726	722	716	709	702	694
39	735	734	732	730	726	722	716	709	702	693
40	735	734	732	730	726	721	716	709	701	693
41	734	734	732	730	726	721	715	708	701	692
42	734	734	732	729	725	721	715	708	700	691
43	734	733	731	729	725	720	714	707	699	690
44	733	732	731	728	724	719	713	706	698	689
45	732	732	730	727	723	718	712	705	697	688

Zone 20

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	599	599	599	599	599	599	599	599	599	599
1	604	604	603	603	603	603	603	603	602	602
2	609	609	609	608	608	608	607	607	606	606
3	614	614	614	613	613	612	612	611	610	609
4	619	619	619	618	618	617	616	615	614	613
5	624	624	623	623	622	621	620	619	618	616
6	629	629	628	628	627	626	625	623	622	620
7	633	633	633	632	631	630	629	627	625	623
8	638	638	637	637	636	634	633	631	629	626
9	642	642	642	641	640	638	637	634	632	630
10	647	647	646	645	644	642	640	638	635	633
11	651	651	650	649	648	646	644	642	639	636
12	655	655	654	653	652	650	648	645	642	638
13	659	659	658	657	656	654	651	648	645	641
14	663	663	662	661	659	657	654	651	648	644
15	667	667	666	665	663	661	658	655	651	647
16	671	670	669	668	666	664	661	657	654	649
17	674	674	673	672	670	667	664	660	656	652
18	677	677	676	675	673	670	667	663	659	654
19	681	680	679	678	676	673	670	666	661	656
20	684	683	682	681	679	676	672	668	663	658
21	687	686	685	684	681	678	675	670	666	660
22	689	689	688	686	684	681	677	673	668	662
23	692	692	691	689	686	683	679	675	670	664
24	695	694	693	691	689	685	681	677	671	665
25	697	697	695	694	691	688	683	679	673	667
26	699	699	698	696	693	689	685	680	675	668
27	701	701	700	698	695	691	687	682	676	670
28	703	703	701	699	697	693	689	683	677	671
29	705	704	703	701	698	694	690	685	678	672
30	706	706	705	703	700	696	691	686	680	673
31	708	708	706	704	701	697	692	687	680	673
32	709	709	707	705	702	698	693	688	681	674
33	710	710	709	706	703	699	694	688	682	675
34	711	711	710	707	704	700	695	689	682	675
35	712	712	710	708	705	701	696	690	683	675
36	713	712	711	709	705	701	696	690	683	675
37	713	713	711	709	706	701	696	690	683	675
38	714	713	712	709	706	702	696	690	683	675
39	714	714	712	710	706	702	696	690	683	675
40	714	714	712	710	706	702	696	690	682	674
41	714	713	712	709	706	701	696	689	682	674
42	714	713	712	709	706	701	695	689	681	673
43	713	713	711	709	705	700	695	688	681	672
44	713	712	711	708	704	700	694	687	680	671
45	712	711	710	707	703	699	693	686	679	670

Zone 21

Inclination (variation from horizontal)	Orientation (variation East or West from South)									
	0	5	10	15	20	25	30	35	40	45
0	711	711	711	711	711	711	711	711	711	711
1	717	717	717	716	716	716	716	715	715	715
2	723	723	723	722	722	722	721	721	720	719
3	729	729	729	728	728	727	727	726	725	723
4	735	735	735	734	734	733	732	731	729	728
5	741	741	741	740	739	738	737	735	734	732
6	747	747	746	746	745	743	742	740	738	736
7	752	752	752	751	750	748	747	745	742	740
8	758	758	757	756	755	753	751	749	746	743
9	763	763	762	761	760	758	756	753	750	747
10	768	768	768	766	765	763	760	758	754	751
11	774	773	773	771	770	767	765	762	758	754
12	778	778	777	776	774	772	769	766	762	758
13	783	783	782	781	779	776	773	769	765	761
14	788	787	787	785	783	780	777	773	769	764
15	792	792	791	789	787	784	781	777	772	767
16	797	796	795	793	791	788	784	780	775	770
17	801	800	799	797	795	792	788	783	778	772
18	805	804	803	801	798	795	791	786	781	775
19	808	808	807	805	802	799	794	789	784	777
20	812	812	810	808	805	802	797	792	786	780
21	815	815	814	811	809	805	800	795	789	782
22	819	818	817	815	812	808	803	797	791	784
23	822	821	820	818	814	810	805	800	793	786
24	825	824	823	820	817	813	808	802	795	788
25	827	827	825	823	820	815	810	804	797	789
26	830	829	828	825	822	817	812	806	799	790
27	832	832	830	828	824	819	814	807	800	792
28	835	834	832	830	826	821	816	809	801	793
29	837	836	834	832	828	823	817	810	803	794
30	838	838	836	833	830	825	819	812	804	795
31	840	839	838	835	831	826	820	813	804	795
32	841	841	839	836	832	827	821	814	805	796
33	843	842	840	837	833	828	822	814	806	796
34	844	843	841	838	834	829	822	815	806	797
35	845	844	842	839	835	830	823	815	806	797
36	846	845	843	840	836	830	823	816	807	797
37	846	845	844	840	836	830	824	816	806	796
38	846	846	844	841	836	830	824	815	806	796
39	847	846	844	841	836	830	823	815	806	795
40	847	846	844	841	836	830	823	815	805	795
41	846	846	844	840	836	830	823	814	804	794
42	846	845	843	840	835	829	822	813	803	793
43	845	845	843	839	834	828	821	812	802	791
44	845	844	842	838	834	827	820	811	801	790
45	844	843	841	837	832	826	819	810	800	788

Further Reading

In addition to the standards already mentioned in the text (eg BS 7671) the following documents may be of relevance to the PV system designer / installer:

- Electricity Network Association Distributed Generation Connection Guides (Free downloads from the ENA Website)
- BRE Digest 489 – 'Wind loads on roof-based photovoltaic systems'
- BRE Digest 495 – Mechanical installation of roof-mounted photovoltaic systems
- BS 5534 'Code of practice for slating and tiling (including shingles)
- BS EN 50272-1 2010, 'Safety requirements for secondary batteries and battery installations. General safety information' Note: This includes guidance on design, operation & maintenance of battery systems.

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