

BRE National Solar Centre

# A Technical Guide to Multifunctional Solar Car Parks



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## Preface

Solar car park systems include a number of key components that require considerable electrical and mechanical design and integration. Solar car parks range in size from a single carport arrangement for one parking space (~2kW generation capacity) to large multi-bay car parks (multi-MW generation capacity) and can be ground or building mounted (e.g. on the top deck of a multi-storey car park).

This guide focuses on commercial and industrial sized systems (typically >50kW) that are connected to the distribution network.

This guide provides a brief overview of the technical requirements and considerations for the design and installation of multifunctional elements in a solar car park system, including battery storage and dedicated plug-in electric vehicle (EV) charge-points.

Inductive EV charge-points, off-grid systems and other forms of energy storage are not within the scope of this document.

All solar car park systems should be designed and installed by a competent person to current standards, complying with relevant regulations and legislation as highlighted in this document.

## Overview of multifunctional solar car parks

In this document a solar carport means a shelter for one or more cars that incorporates solar photovoltaic (PV) modules. A solar car park means a parking facility consisting of multiple solar carports.

### System functionality

Multifunctional solar car parks can provide a flexible energy system designed to fulfil a number of functions. Function requirements are site specific and take into account; onsite electrical loads (i.e. lighting, EV charging etc.) and storage capacity, solar generation capacity (size and performance of solar array installed) and local distribution network conditions (i.e. limited or curtailed connection). Common system functions are detailed in Table 1.

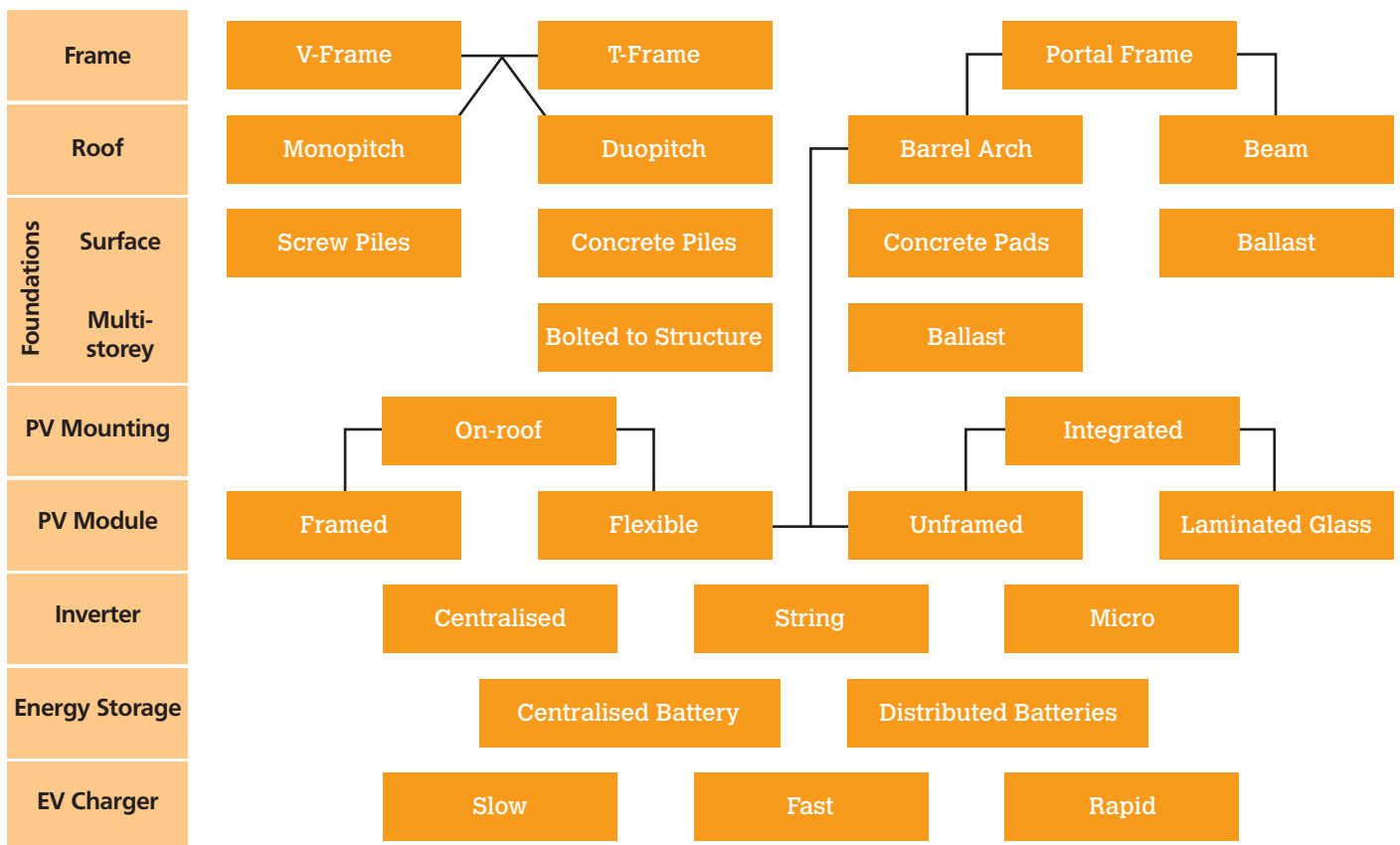
**Table 1 Common functions of a multifunctional solar car park system**

Function	Consideration
Generation of low carbon renewable energy	Generated electricity can be either consumed on site by any connected buildings, EV charge-points or other loads, or can be sold to a nearby energy consumer under a power purchase agreement (PPA) via a private wire.
Time-shifting for onsite consumption	The inclusion of energy storage may help to increase self-consumption of solar generated energy by storing surplus electricity for use when onsite energy consumption exceeds solar generation levels.
Export limiting	For systems that have a restricted distribution network connection, energy storage can be utilised to store surplus electricity for export when there is capacity to do so.
Peak lopping	The inclusion of energy storage can provide additional supply capacity in times when onsite electricity consumption exceeds the agreed supply capacity for short periods of time.
Arbitrage	For sites with a time of use (ToU) tariff, the inclusion of energy storage can allow for electricity to be stored for export when electricity prices are more favourable.
Back-up/ energy security	For systems in areas susceptible to power cuts there may be a requirement for the system to operate in 'island mode' for short periods of time. Typically, an energy storage reserve will be sized to be able to provide critical loads (such as for emergency lighting) for a specified period of time.
EV charging	Combining solar car parks with EV charging is an opportunity to store renewable electricity in the EV's batteries during daytime parking. This energy can then be utilized in the evening peak hours with vehicle-to-grid (V2G) technology. Power requirements will vary depending on the number of EV charge-points and the charging regimes employed. Frequent recharges may reduce distribution network connection costs for the solar car park. Energy storage may also assist with increasing the percentage of electricity consumed in EV charging.
Ancillary services	The inclusion of energy storage can also bring additional benefits through the provision of ancillary services to the transmission system operator and local services to the distribution system.

**Design options**

There are a number of key components that make up a multifunctional solar car park. Selection of these components may be dictated by an overall ‘solar carport’ product offering or can be defined by the client for aesthetic or practical reasons. Figure 1 details the most common design options available.

**Figure 1 Common multifunctional solar carport design options**



This guide provides information on the technical considerations for each component.

**System integration**

It is critical that a multifunctional solar carport is specified with due consideration to the onsite energy demands (now and in the future) and local distribution network. Typically, it is more difficult and costly to retrofit additional components or provide additional functionality at a later date.

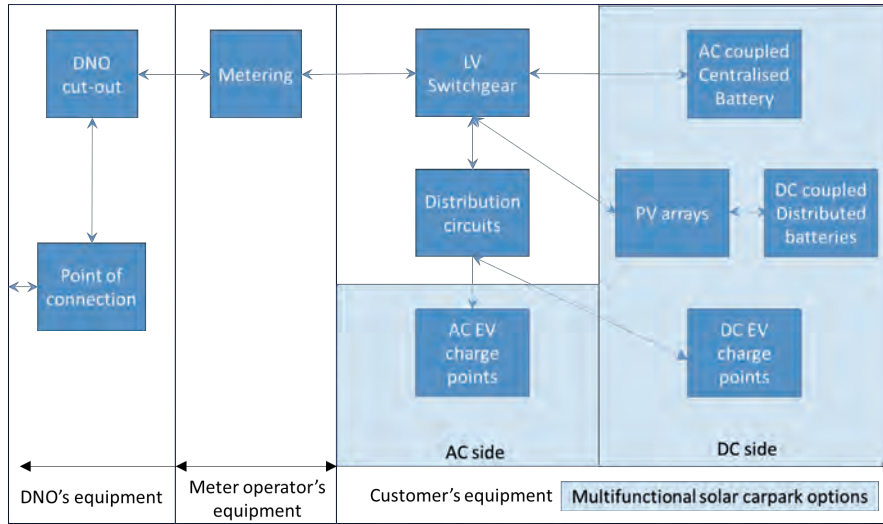
It is important to have a clear understanding of what functions the multifunctional solar car park is required to provide, the order in which those functions take priority and what other systems it may need to be integrated with (e.g. onsite energy management systems, Active Network Management systems, etc.).

This guide highlights areas where system integration needs to be considered.

Key components may be integrated on either the DC or AC side of the solar carport system. Some typical system configurations are shown in Figure 2.



Figure 2 Relationship between key components of an integrated multifunctional solar car park system



**Solar PV module technologies**

Solar PV modules are constructed from a number of solar cells composed of one or more materials. PV modules connected in series are referred to as a PV string.

There are many different makes and suppliers of PV modules. The vast majority of roof and ground-mounted PV installations use polycrystalline and monocrystalline silicon PV modules mounted into aluminium frames. Due to their low cost and availability, these are often used in solar carports. However, the design requirements of solar carports are more demanding than that of roof or ground-mounted PV systems and can lead to the use of other PV module formats such as:

- frameless – which use the strength of the glazing and PV mounting system to provide structural integrity

- laminated glass - two sheets of toughened glass sandwiching a layer of crystalline PV cells
- semi-flexible and flexible modules – PV cells applied to plastic, metal, or other substrates.

New technologies are being developed and manufacturing processes are continually maturing, leading to improved PV module efficiencies and performance. The choice of technology needs careful consideration. Certain technologies will be more appropriate for specific system designs or to achieve the desired functionality.

A comparison of the more common PV module technologies is given in Table 2.

Table 2 Comparison of common PV module technologies

	Crystalline silicon (c-Si)	Thin Film
<b>Types of technology</b>	Monocrystalline silicon (mono-Si) Poly-crystalline silicon (multi-Si)	Amorphous silicon (a-Si) Cadmium telluride (CdTe) Copper indium gallium selenide (CIGS)
<b>Typical efficiencies</b>	13% - 20%	6% - 17%
<b>Typical power output</b>	250W - 300W (60 cells) 300W - 400W (72 cells)	110W - 445W
<b>Typical module size</b>	1.6m <sup>2</sup> - 2.0m <sup>2</sup>	1.1m <sup>2</sup> - 2.2m <sup>2</sup>

Some thin-film modules have a characteristic unique to the technology, referred to as a 'soaking-in period'. This refers to a period of time when the thin-film module exhibits an increased voltage and current output (above their product specification), following their initial exposure to sunlight. It is important to ensure that the components specified for use with such modules is capable of accommodating these electrical characteristics.

Certain types of PV modules can be prone to potential induced degradation (PID), a voltage potential between the PV module and

the ground that can reduce PV module performance. The effects of PID can worsen in PV systems that experience high levels of humidity, temperature and soiling. Some module manufacturers may recommend specific earthing arrangements for the DC system to reduce or reverse the effects of PID.

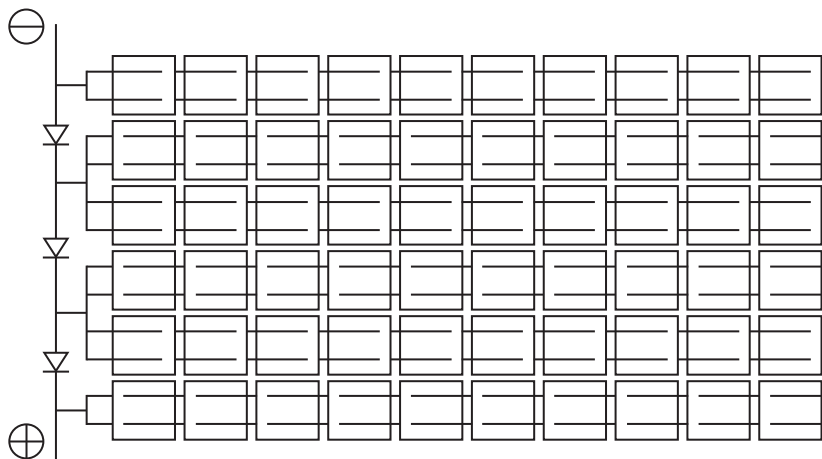
The PV module casing and pre-fitted connector cables should be double insulated (safety class II) as recommended by BS 7671 for any system where the string voltage (V<sub>oc-STC</sub>) exceeds 120V<sub>dc</sub>. Double insulated components minimise the risk of fire and electric shock.

Using polarised connectors prevents incorrect polarity connections in the system. It is important that polarised connectors from different manufacturers are not coupled together and all connectors are suitably rated to ensure safe operation of the system.

Most commercially available PV modules include one or more bypass diodes. Bypass diodes reduce the effect of shade on the output of

a module by diverting current from shaded cells. A suitable bypass diode configuration should be selected with respect to the carport array layout (e.g. PV modules in landscape or portrait) and with respect to any potential shading. Figure 3 shows an example of a PV module with 3 bypass diodes.

**Figure 3 Example of bypass diode arrangement in a PV module**



Any PV module selected should be certificated to 'BS EN 61730. Photovoltaic (PV) Module Safety Qualification'. Any structural glazing materials used in the construction of PV modules (as a superstrate or substrate) must also comply with the standard for safety glazing in 'ANSI Z97.1-93. American National Standard for Safety Glazing Materials Used in Buildings'<sup>1</sup>. If further safety testing of glazing is needed, refer to the BS 5516 Series 'Patent Glazing and Sloping Glazing for Buildings'<sup>2</sup>. In addition, solar PV modules can also be certificated under the Microgeneration Certification Scheme (MCS) product standard MCS 005.

### Frames

The majority of roof-based PV installations are retrofitted onto pre-existing roofs. Installing PV modules onto a pre-existing roof results in a double roof structure. Some carport designs adopt this method, choosing to mount modules on top of sheet roofing or similar. This is often done to simplify the design, and benefit from the cheap availability of common components and skilled labour. In areas of high risk of vandalism, double roof structures offer a permanent screen protecting the PV system from external impacts or damage.

PV glazing systems replace the roof with PV modules such that the modules form both the roof and the PV system. This can be achieved with specially-designed mounting and sealing solutions that ensure water tightness, structural strength and fire resistance.

A well-executed PV glazing system should use fewer materials and reduce project costs. PV glazing systems that use laminated glass PV

modules, may also allow a quantity of daylight through the carport.

Typically, the solar carport roof structure will provide the mounting system for a specified PV module. It is necessary to obtain confirmation from the PV module manufacturer that they approve of the mounting system design and method of securing the PV modules in place.

For integrated PV glazing systems, the mounting system has the role of directing rain water, securing the PV modules and providing fire resistance. On-roof mounting systems typically use standard sheet roofing, with standard rooftop mounting clamps securing the PV modules.

The design of a solar carport should include wind loading and wind induced effects (correct pressure coefficients chosen), self-weight of the PV module and mounting frame, snow loads, and loads imposed during construction<sup>3</sup>.

In the absence of existing standards, certification of a solar carport mounting system can be achieved under MCS product standard, MCS 012, demonstrating resistance to external fire spread, weather tightness and wind uplift resistance<sup>4</sup>.

### Drainage

Car parks must provide adequate surface water drainage measures incorporated in their design. Location of a solar car park within a built development can subsequently help manage control of surface water runoff. The Flood and Water Management Act (2010) requires all new developments to incorporate sustainable urban drainage

<sup>1</sup> Photovoltaic (PV) Module Safety Specification BS EN 61730 – 1:2007 + A11:2014, British Standards Institute (BSI, 2015).

<sup>2</sup> BS 5516-2 Patent glazing and sloping glazing for buildings code of practice for sloping glazing, (BSI, 2004).

<sup>3</sup> Analysis and guidance on calculating applied pressure from wind and subsequent wind loads on roof-mounted PV and solar thermal systems. Wind Loads on roof-mounted photovoltaic and solar thermal systems, BRE National Solar Centre, (Blackmore, 2014).

<sup>4</sup> MCS 012 Product Certification Scheme Requirements: Pitched Roof Installation Kits, Microgeneration Certification Scheme, (MCS, 2018).

<sup>5</sup> Car parks must provide surface water runoff measures and separation of grease and oil before discharge into drainage system. Car Parking Control of surface water-runoff, Environmental Agency of Scotland and Northern Ireland, (NetRegs, n.d.).

systems<sup>6</sup>, solar car parks must have adequate runoff management strategies to meet these requirements. When designing drainage layouts and calculating effective roof area to determine rainwater runoff calculations the total surface area of a solar carport should be considered as the total roof area.

Car parking drainage is specified in Building Regulation Part H: Drainage and waste disposal. The emphasis of these regulations is on structural integrity and rainwater disposal. As such, the runoff management strategy for the carport must be able to dispose of peak rainfall to prevent increased loading on the roof. Examples of strategies include; an eaves drop system which protects the structure from runoff by allowing rainwater to fall to the ground, and a gutter system which has the added benefit of protecting car park users from dripping and splashing rainwater.

Rainwater drainage pipes should discharge into either a drain or onto the car park surface. Existing car parks should have sufficient drainage capacity, as this would have been an original design requirement. Carports have no effect on the drainage requirement of the car park as they do not vary the total amount of rain water reaching the car park surface. Allowing the water to discharge onto the surface of the car park from the footer of a downpipe is sometimes preferred for solar carports, due to the prohibitive cost of connecting to below-ground drainage. Excessive streaming of water from rainfall can be avoided through regular placement of downpipes (e.g. at intervals of every 6-10 car parking bays).

### Advertising

Inclusion of advertising space in a multifunctional solar car park can provide an additional income stream for the car park operator. Planning permission may be required depending on the type, size and lighting arrangements of the advertisement board(s).

All outdoor advertisements must comply with the Town and Country Planning (Control of Advertisements) Regulation 2007, which defines the following 'standard conditions' that must be met<sup>8</sup>:

- be kept clean and tidy
- be kept in a safe condition
- have the permission of the owner of the site on which they are displayed (this includes the Highway Authority if the sign is to be placed on highway land)
- not obscure, or hinder the interpretation of; official road, rail, waterway or aircraft signs, or otherwise make hazardous the use of these types of transport
- be removed carefully where required by the planning authority.

### Lighting

Lighting of solar car parks must conform to lighting levels for outdoor car parks designated by BS 5489-1:2013 'Code of practice for the design of road lighting. Lighting of roads and public amenity areas.' Depending on the type and operation of the car park, a minimum

horizontal illuminance of 5-20 lux must be maintained through all night-time hours of use<sup>9</sup>. Lighting infrastructure should be placed in areas that maximise bay illumination without creating obstructions<sup>10</sup> as well as limiting spill and light trespass into adjacent areas<sup>11</sup>. Careful lighting design is required on the top deck of multi-storey car parks, to minimise the effects of lighting pollution.

Further supplementary standards to aid solar car park planners in the design of the lighting system include; BS EN 12464-2: 2014 'Lighting of work places. Outdoor work places',<sup>12</sup> BS EN 13201-2: 2015 'Road Lighting. Performance requirements'<sup>13</sup> and BS 5266-1:2016 'Emergency lighting. Code of practice for the emergency lighting of premises'<sup>14</sup>.

Consideration should be given to whether the multifunctional solar carport system is required to provide power to emergency lighting during times when the mains electricity supply is not available. If this is the case, then the system must be designed and installed in line with BS EN 50171 'Central Power Supply Systems.'

### Inverters - general

Different system architectures will incorporate different types, sizes and quantities of inverters. Multifunctional solar car parks that incorporate energy storage may have separate solar and battery inverters, each providing specific functions as well as converting DC electricity into AC electricity and vice versa. These functions may also be combined in a single hybrid (solar storage) inverter. The number of type of inverters will depend on the size of the system (generation and storage capacity) and the required functionality.

Unlike ground and roof-mounted solar PV systems there are fewer locations to position inverters and electrical connections safely, due principally to the need for clear access to the car parking space. Safety and security of inverters should be considered when selecting technology options. Options include; housing large centralised inverters in a dedicated building, using smaller string inverters that can be fitted inside a steel housing or attached to the carport frame, or installing micro-inverters on every single or pair of PV modules.

### Solar inverters

Solar inverters are a key component of the PV system, converting DC electricity generated by the PV modules into AC electricity that can be exported directly to the grid or used by onsite loads, such as lighting and EV charging. Solar inverters optimise output from the PV modules by using maximum-power point tracking of the string voltage. Such maximum-power point trackers (MPPTs) use software algorithms within the solar inverter, which adjust the solar PV array operating voltage and current to achieve maximum power output. The number of MPPTs in a solar inverter varies from model to model, with normally 1 or more strings per MPPT.

MPPTs usually improve the overall performance of the system but do add to the cost of the solar inverter, and limit string configurations. Solar inverters with multiple MPPTs are best used whenever there are variations across strings in; orientation, mismatched modules, modules with wide power output tolerances (leading to differing string outputs), or shading. A duopitch carport with a single solar inverter will require

<sup>6</sup> Sustainable Urban Drainage Systems design guidance, Local Flood Authorities of South East England, (Aecom, 2013).

<sup>7</sup> BS EN 12056-3:2000 Gravity drainage systems inside buildings. Roof drainage, layout and calculation, British Standards Institute, (BSI, 2000).

<sup>8</sup> Outdoor advertisements and signs: a guide for advertisers (DCLG, 2007)

<sup>9</sup> Code of Practice for Design of Road Lighting, BS 5489-1:2013, British Standards Institute, (BSI, 2013).

<sup>10</sup> How to guide: Lighting Car Parks, DW Windsor, (DW Windsor, 2012)

<sup>11</sup> Guidance note for the reduction of obtrusive light, Institute of Lighting Engineers, (ILE, 2005).

<sup>12</sup> EN 12464-2: 2007 Lighting of work places, British Standards Institute, (BSI, 2007)

<sup>13</sup> EN 13201-2: 2015 Road Lighting Performance requirements, British Standards Institute, (BSI, 2015)

<sup>14</sup> BS 5266-1:2016 Emergency Lighting of Premises, British Standards Institute, (BSI, 2016)



an inverter with more than one MPPT to optimise for dual orientation performance (i.e. east-west).

Solar inverters can also provide several other functions such as system monitoring and protection. See the sections on Monitoring and Lightning and surge protection for more information.

There are three common types of solar inverter architectures; centralised, string and micro, as detailed in Table 3.

**Table 3 Comparison of common solar inverter architectures**

	Centralised	String	Micro
<b>Typical size range</b>	100kW – 2,500MW	2 - 100kW	0.2 – 0.5kW
<b>Output voltage</b>	3 phase, LV/MV	1/ 3 phase 230/400V	1 phase 230V
<b>Installation</b>	Separate building/ container	Attached to carport frame	Attached to / incorporated into PV module(s)
<b>Connection to PV</b>	PV strings via PV combiner boxes	Directly to PV strings	Directly to individual/ pair of PV module(s)
<b>Typical modules/ MPPT</b>	1000 - 1500	8 - 24	1 - 2

### Battery inverters

Depending on the design of a multifunctional solar car park system there may be one or more battery inverters, installed on either the DC or AC side of the system. Typically, battery inverters provide an energy management function to the connected battery bank, controlling charging and discharging. In some applications this function is provided by a separate charge controller or battery management system (BMS) which may be built into the battery casing. BMSs are designed to manage the energy flows, health and protection of the battery. The functions provided range from individual cell monitoring, to preventing excessive discharging, overcharging, thermal runaway (in lithium based technologies) and localised control.

Using a charge controller or BMS that is not suitable for a specific battery technology and/or system size can not only be hazardous but may also damage the battery.

The key differences between installing on the AC side (AC coupled systems) and DC side (DC coupled systems) are detailed in Table 4.

**Table 4 Comparison of DC and AC coupled solar battery systems**

AC coupled systems	DC coupled systems
Battery charge-discharge system is wholly separate to the grid connected PV system	Typically a hybrid inverter is used to provide both the solar and battery inverter functionality
Can be provided as a packaged battery system or as a number of separate components	Provided as a packaged system
Battery can be retrofitted to solar carport	More cost effective to include battery system from outset
Battery storage system can be located away from solar carport, providing more choice for suitable locations	Battery needs to be within close proximity of hybrid inverter i.e. under solar carport (or may be incorporated within hybrid inverter unit)
Less electrically efficient system due to converting DC solar electricity into AC for transmission, before converting back in to DC for storage	More efficient system can be achieved but larger DC cables may be required
Separate metering can be installed at the battery and PV array	Metered on the AC side of the system and therefore will include battery cycling efficiencies
Centralised & decentralised options available	Decentralised options only

Hybrid battery inverters provide a solar and storage solution in one unit, typically reducing system cost, installation time and space required for components. They can also simplify control and monitoring systems, as well as fault diagnosis. Consideration should be given to the future availability of compatible batteries (especially for hybrid inverters with integral batteries) and for potential whole system down time.

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**Battery storage system**

A battery storage system generally comprises:

- an energy storage medium (i.e. batteries) based on cells, typically forming a battery bank or stack made up of multiple racks
- a battery management system (BMS)
- the battery ancillary systems (heating, cooling, fire protection and monitoring)
- a power conversion system (i.e. battery inverter)
- network interface.

Other energy storage systems might include flywheels, liquid air and compressed air. Although these are not in widespread use at the time of preparation of this guide, these systems are robust and may be considered for certain applications.

**Batteries**

Battery technology is evolving rapidly, facilitating a range of functions such as; the storage of solar electricity during peak generation, providing peak demand shaving and reducing the need for extra capacity on a system scale<sup>15</sup>. Profiling self-consumption of solar electricity (i.e. comparing onsite energy demand against expected PV generation) can help to determine the requirement and capacity of energy storage in a multifunctional solar car park.

There are a range of battery chemistries, with many commercially available products, including, but not limited to:

- lead-acid (i.e. vented lead-acid (VLA) and valve-regulated lead-acid (VRLA))
- lithium-ion
- flow batteries (i.e. vanadium redox)

The choice of battery will depend on many factors, such as the desired power rating (kW), energy storage nominal or effective capacity (kWh), charge/ discharge efficiency, round trip efficiency, expected duty cycle or battery life, loading or size restrictions.

**Electric vehicle charging**

Cleaner transport emissions are intrinsic to any shift to a low carbon system and EVs play a fundamental role in facilitating an energy mix supplied by cleaner fuels. EV uptake is increasing exponentially<sup>16</sup> and car manufacturers are shifting focus towards plug-in hybrid (PHEV) and fully electric models<sup>17</sup>. For these reasons strategically placed EV charging infrastructure must be developed to accommodate these changes in mobility modes, and multifunctional solar car parks can play an important role in this facilitation.

The Automated Electric Vehicles Bill<sup>18</sup>, which is currently under consideration, is set to require all new charging infrastructure to be able to communicate and respond to requests from a third party. The Alternative Fuels Infrastructure Regulations<sup>19</sup> which came into effect in 2017, also places requirements on EV infrastructure, such as ad-hoc access and minimum connector standards (e.g. Type 2). Smart EV charge-points on multifunctional solar car parks provide additional benefits, such as being able to optimise operating regimes in line with solar electricity generation, programming of usage and predictive maintenance.

EV charge-points themselves are divided into; slow, fast and rapid categories, which are determined by output power and associated charging times, as detailed in Table 5. Within these categories there are further variations on the level of power output provided, type of socket and connector, and the communication mode between the vehicle and charger<sup>20</sup>.

**Table 5 Comparison of EV charge-point categories.**

	Slow	Fast	Rapid
<b>Average charging time</b>	6-12 hours	3-4 hours	30 minutes
<b>Typical power</b>	< 7kW	7kW – 22kW	>43kW
<b>Type of development that different EV charge-points would be suitable for</b>	Domestic households Transport hub Warehouse and storage centres Airports Workplace charging	Office Schools Universities Hotels	Commercial Industrial Retail Hospitals Leisure centres Roadside services

15 A Good Practice Guide on Electrical Storage, EA Technology, Chester (ESOF, 2014)

16 Global EV Outlook 2017,(international Energy Agency, 2017), <https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf>

17 Ford have denoted that they will release 16 hybrid and 22 fully electric vehicles in their range by 2022

18 <https://services.parliament.uk/bills/2017-19/automatedandelectricvehicles.html>

19 <https://www.gov.uk/guidance/regulations-alternative-fuels-infrastructure>

20 Electric Vehicle Connectors and speeds, <https://pod-point.com/landing-pages/electric-vehicle-charging-connectors-and-speeds> (PodPoint, n.d)

V2G interfaces are out of the scope of this guide, but more information can be found in BS EN ISO 15118-1:2015 'Road vehicles - Vehicle to grid communication interface. Part 1: General information and use-case definition'.<sup>21</sup>

Any EV charge-point and associated equipment selected should comply with the current product standards (BS EN 61851 series 'Electric vehicle conductive charging system', BS EN 62893 series 'Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV' and BS EN 62196 series 'Plugs, socket-outlets, vehicle connectors and vehicle inlets').

Table 6 presents the standards and specifications associated with common EV charging equipment for both connections to infrastructure (electricity source) and vehicle. The requirement on public EV charging facilities deployed since November 2017 is defined in the Alternative Fuels Infrastructure Regulations<sup>22</sup>. The regulations specify a minimum of Type 2 sockets and connectors for AC charging and combined charging system (CCS) for DC charging, and the requirement for intelligent metering systems that allow any person to recharge an electric vehicle without entering into a pre-existing contract. This regulation will be extended to all existing public installations from November 2018.

**Table 6 Specification and associated standards for common EV charge-points (adapted from 'A Guide to EV infrastructure, BEAMA, 2015')<sup>23</sup>.**

Infrastructure side			
Connector type	UK household plug and socket	Industrial plug and socket	Specialist EV
Associated standard	BS 1363	BS EN 60309-2	BS EN 62196-2 Type 2
Charging mode <sup>24</sup> (1-4) (AC/DC)	2 (AC)	2 (AC)	3 (AC)
Maximum power (kW) and phase	Single – 2.3 continuous duty	Single - 74 Three – 22	Single – 16.1 Three – 43.7
Vehicle Side			
Connector category	Specialist EV	Specialist EV	Specialist EV
Associated standard	BS EN 62196-2 Type 1	BS EN 62196-2 Type 2	CHAdEMO BS EN 62196-2 Type 4
Changing mode (1-4) (AC/DC)	2, 3 (AC)	3 (AC)	4 (DC)
Maximum power (kW)	Single – 74	Single – 16.1 Three – 43.7	100

Currently, it is typical for high current DC (125A, 500V – Mode 4) or high current AC (>32A, 250/480V – Mode 3) EV charge-points to be installed in car parks connected to commercial/ industrial premises, providing fast or rapid charging facilities. At the time of publishing all new-to-market EVs sold in Europe must use a 'Type 2' connector on the vehicle for AC charging.

The provision of EV charge-points is becoming more of an expectation for employees, customers and the general public. EV charge-points that are intended to be publicly accessible are generally on a network for authorised electronic key holders, where individuals register to use the facility and make payments, or via smart phone apps.



Image courtesy of FlexiSolar

<sup>21</sup> BS EN ISO 15118-1:2015, Road vehicles – Vehicle to grid communication interface – Part 1: General information and use-case definition, (BSI Standards Ltd., 2015).

<sup>22</sup> <http://www.legislation.gov.uk/uksi/2017/897/contents/made>

<sup>23</sup> A guide to EV infrastructure, A BEAMA practical guide, (BEAMA, 2015)

<sup>24</sup> Charging modes define the communication protocol between the EV and the charge-point. Mode 1-3 uses the car's inbuilt battery charger. Mode 4 uses an external battery charger.

## Project Consents

### Distribution network connection

An application to connect to the distribution network needs to be submitted and a connection agreement with the local Distribution Network Operator (DNO) is required prior to the connection of any solar generation or energy storage device with an output greater than 16A per phase, or any single or multiple EV charge-point installation that increases the maximum demand of a site to more than 13.8kVA. For smaller scale systems an install and inform process is in place, requiring DNOs to be notified within 1 month of installation.

The maximum demand load of a site may be reduced through selecting lower capacity charge-points (increasing charging times) and/or back-office load management of networked EV charge-points, limiting the load to a specific value (temporarily increasing charging times or reducing number of EV charge-points simultaneously available).

The Energy Networks Association (ENA) publishes Engineering Recommendations for connecting generation equipment to the distribution network. Although these are guidance documents, they are recognised nationally and are regarded as strict rules, providing standards for AC power quality, safety measures, fault conditions, reaction times, metering requirements etc.

The ENA's Engineering Recommendations are currently being updated and new documents are due to be published in 2019 that cover the distribution network connection of renewable energy generation and energy storage technologies. Table 7 details the current and new guidance document scopes. Advice on connecting EV charge-points to the distribution network can be found on the ENA website<sup>25</sup>.

**Table 7 Application of ENA Engineering Recommendations for different sized systems**

	Current ENA guidance	Proposed new ENA guidance
Single installation <16A AC output per phase (<3.68kW single phase 230V, <11.04kW three phase 400V)	G83/2 – single premise	G98 – single premise
Multiple installations <16A AC output per phase (<3.68kW single phase 230V, <11.04kW three phase 400V)	G83/2 – multiple premises	G98 – multiple premises
<17kW single phase 230V, <50kW three phase 400V	G59/3 - <50kW	G99 – Type A
>17kW single phase 230V, >50kW three phase 400V	G59/3	
0.8kW – 1MW, <110kV		G99 – Type B
1MW – 10MW, <110kV		G99 – Type C
10MW – 50MW, <110kV		G99 – Type D
>50MW, <110kV and any sized system >110kV		
Export limiting schemes	As above plus G100	

At present solar and battery inverter manufacturers can type-test their products to G83/2 & G59/3, providing evidence to the DNO that they have complete autonomous grid operation, automatically synchronising with mains voltage and frequency, will disconnect when grid conditions deviate from allowable limits, or a problem is detected on the DC or AC sides, will isolate the generating plant from the Distribution Network and automatically reconnect when conditions become acceptable again. The ENA have an online register<sup>26</sup> for all generation equipment that has been type-tested and have submitted verification reports to the ENA.

A similar type-testing arrangement is proposed under G98 and G99.

The DNO may request a separate G59 relay is installed for systems that do not use type-tested inverters or have multiple inverters. A G59 relay is a voltage and frequency monitoring device which is located between the inverter(s) and the point of connection with the distribution network. A G59 relay will disconnect the inverter(s) from the distribution network when a fault is detected (for example when the grid voltage is too low/ high, a step change in frequency, or loss of mains power) and reconnect when normal operation is resumed.

25 <http://www.energynetworks.org/electricity/futures/electric-vehicle-infrastructure.html>

26 <http://www.ena-eng.org/ProductTypeTestRegister/Product.aspx>

27 <https://www.gov.uk/guidance/national-planning-policy-framework/4-promoting-sustainable-transport>

## Planning permission

The National Planning Policy Framework (2012) highlights the necessity to incorporate facilities for EV charge-points in developments<sup>27</sup>, which can be facilitated by the inclusion of multifunctional solar car parks.

Planning permission is required for a project if it fits within the definition of a development in accordance with the Town and Country Planning Act (1990)<sup>28</sup>. A multifunctional solar car park proposed to be installed over an existing parking area may be subject to an exemption, depending on the extent of groundworks, height of any associated structures and level of construction required. Typically planning permission is required, especially if the system incorporates large scale batteries and advertising space, and so you should always check with the Local Planning Authority if planning permission is required.

Consultation with the Local Planning Authority and local community is encouraged at an early stage. The information likely to be required includes:

- Location plan (typically 1:1250 metric scale).
- Site/ block plan (typically 1:500 metric scale).
- Elevation drawings (solar carport and any other structures).
- Design and access statement.
- Supporting statement.
- Specification of the proposed key multifunctional carport components (e.g. PV modules, inverters, energy storage system, EV charge-points, substation etc.).
- Structural and foundation details.
- Fencing specification and details (where applicable).
- Distribution network connection details.
- Details of any ancillary works, buildings proposed, or advertising space.
- Ecological assessment (where applicable).
- Landscape/ visual assessment (if the application site lies within, or would impact upon, an Area of Outstanding Natural Beauty; National Park or World Heritage Site).
- Historic environment statement (where applicable).
- Glint and glare impacting the surrounding environment (where local sensitivities are identified).
- Flood Risk Assessment (including drainage and surface-water management plans).
- Details of construction and decommissioning (including construction traffic management plans and compounds for material storage and contractor parking).
- Application fee where required.

## Building control

The installation of a multifunctional solar car park is notifiable under the relevant sections of the Building Regulations<sup>29</sup>.

Carports are classified as buildings and must comply with the Building Regulations<sup>30</sup>, in particular the following sections from Schedule 1:

**Part A: Structure** - This identifies the relevant legislation relating to the basis of structural design and loading, construction materials and workmanship, stability and foundations. This is particularly relevant for the solar carport frame and foundations.

**Part B: Fire Safety** – Volume 2 covers fire safety matters within and around non-domestic buildings, including means of warning and escape, internal and external spread of fire, access and facilities for fire services. This is particularly relevant for multi-storey car parks, car parks that provide the main access route to a building, and for installations of large scale energy storage systems.

**Part C: Resistance to contaminants and moisture** – Details the requirements for site preparation and ground conditions for construction projects. This is particularly relevant for any car parks located in a flood risk area, on contaminated land or in areas where there is a build-up of underground gases such as methane and radon.

**Part H: Drainage and waste disposal** – Covers the requirements for rainwater drainage, including the specification for guttering, surface water draining and oil separators. This is particularly relevant for car parks due to the potential of pollution from cars entering the local watercourses.

**Part K: Protection from falling, collision and impact** – This document details the requirements to provide protection measures for any users or activities in the car park. This is particularly relevant for any working at heights activities on or near the carports, such as window or PV cleaning.

**Part M: Access to and use of buildings** – Volume 2 covers access to non-domestic buildings from onsite car parks. This document provides specific advice with regards to inclusive design of car parks and due consideration should be given that a solar carport structure and layout can accommodate these requirements.

**Part P: Electrical safety** – All though this part of the Building Regulations refers to dwellings, it does apply to any electrical circuits connected to mixed-use developments. Certification of new electrical installations is still a requirement under BS 7671.

Please note that carports are listed as exempt from Part L: Conservation of fuel and power<sup>31</sup>.

Approved Documents<sup>32</sup> are available which describe means to meet the requirements of the relevant Parts of the Building Regulations. Please note that these documents are not the Building Regulations, although they reference the relevant sections.

<sup>28</sup> <https://www.gov.uk/guidance/when-is-permission-required#what-is-development>

<sup>29</sup> Building Regulations 2010, as amended for England & Wales or Building (Scotland) Regulations 2004, as amended for Scotland.

<sup>30</sup> <http://www.legislation.gov.uk/uk/si/2010/2214/schedule/1/made>

<sup>31</sup> Approved Document L2B: conservation of fuel and power in existing building other than dwellings, 2010 edition (incorporating 2010, 2011, 2013 and 2016 amendments).

<sup>32</sup> [https://www.planningportal.co.uk/info/200135/approved\\_documents](https://www.planningportal.co.uk/info/200135/approved_documents)

<sup>33</sup> Health and Safety at Work Act 1974 (TSO, 1974) and Health and Safety at Work Order 1978, Statutory Instrument 1978 no. 1039 (N.I. 9), (TSO, 1978)

<sup>34</sup> Construction site requirements and project management in relation to health and safety duties and roles. Construction (Design and Management) Regulations, Statutory Instrument 2015 No. 51, (TSO, 2015)



## Health and safety

To uphold stringent health and safety during the construction phase of a solar car park, all health, safety and welfare provisions for persons at work must be provided<sup>33</sup> as well as upholding the responsibilities enshrined within the Construction Design and Management Regulations 2015 (CDM)<sup>34</sup>. CDM covers civil and engineering works of any scale including construction, retrofitting, repair and decommissioning stages, applying to all life cycle phases of a solar car park.

Under CDM consideration must be given to the planning and co-ordination of maintenance and repair of all components of a multifunctional solar car park. Adequate site security should be provided to guard against theft and limit the danger of unauthorised persons causing self-inflicted injury.

Installation and maintenance of the PV modules must be carried out in accordance with the Work at Height Regulations (2005)<sup>35</sup> and the guidelines presented in Health and Safety in Roof Work (2012)<sup>36</sup>. Ensuring that only designated competent persons<sup>37</sup> carry out removals and replacement of damaged PV modules. Risks and hazards posed by fracture of the PV modules themselves mean that a response plan must be put in place to ensure that any breakage is swiftly communicated to, and handled by, the solar car park operator's competent person.

Methods of installation and maintenance of solar carport systems that negate the requirement to work at height should be considered. Further guidance on glazing at height as well as risk assessment examples and mitigation measures are provided in BRE publication BR471: Sloping glazing, Understanding the risks<sup>38</sup>.

Monitoring for signs of corrosion and/or deformation of steel members should be conducted to ensure that the structural integrity of solar carports are maintained. The design working life, accommodating for issues such as corrosion, is to be designed in accordance with BS EN 1990 and therefore the timeline of use for structural members including anticipated maintenance<sup>39</sup> can be developed. Using this method alongside monitoring for unexpected structural deformations such as those potentially resulting from heavy vehicular impact enables the solar carport structure to maintain integrity and subsequently the health and safety of users.

Consideration should be given to the health and safety risks arising from electrical connections and components<sup>40</sup>. Safe working practices<sup>41</sup> should be defined and observed with the electrical system of the solar carport. Particular attention should be taken of the risks posed by the DC side of the system. Each solar car park system should also have a bespoke maintenance and monitoring plan. During operation, health and safety is to be upheld through constant monitoring of correct system functionality and maintenance of safety and protective equipment.

In addition, multifunctional solar car parks that include energy storage may also need to be compliant with health and safety regulations<sup>42</sup> referring to dangerous substances.

Fire risk and prevention should be considered at all stages of the development of a multifunctional solar car park. Under law a nominated person will be responsible for the fire safety of the car park<sup>43</sup>. It is recommended that a fire risk assessment is completed by a competent person/organisation (such as BRE Global) when designing a multifunctional solar car park system and reviewed at installation and commissioning stages. Consideration should be given to the location of the system components with respect to any existing fire escape routes, mustering points etc. that may already be located in the car parking area. Any walk-in enclosures should feature hard-wired fire detection systems.

## System signage

System signage is critically important for informing users, maintenance engineers and emergency services of the system, its operation and any potential hazards it may introduce. Drawing attention to the presence of a hazard or potential danger is a minimum requirement for mitigation of most health and safety risks associated with multifunctional solar car parks. Signage should be appropriate, effective and well maintained<sup>44</sup>.

Signs warning of multiple electrical sources should be installed at the point of connection with the distribution network, any distribution boards or switchgear that are connected to the solar carport system (directly or indirectly) and at each inverter (solar and battery). Electrical schematics showing how the system is connected and the location of all key components and isolation devices should also be durably affixed at these locations. In addition labels should be affixed adjacent to each EV charging circuit RCD and any isolation devices explaining their operation.

It is recommended that DC cable runs are labelled every 5 – 10m. Suitable hazard warning signs need to be displayed to highlight battery hazards, the appropriate signs will depend on the battery type.

Guidance on appropriate signage for each part of the multifunctional system can be found in the corresponding IET Code of Practice Guides<sup>45</sup>.

## Considerations for end of life

The project should be designed with decommissioning and end of life responsibilities, in accordance with the good practice required by the CDM regulations. This should not only include the practicalities of dismantling and removing the infrastructure of the multifunctional solar car park systems (such as foundations) but also detail how the waste will be dealt with, any associated environmental impacts and what restoration work is required/ will be completed.

The decommissioning plan should clearly state how the applicable waste regulations<sup>46</sup> will be met, identify any reusable or recyclable components of the system and how these will be managed (i.e. through compliant waste management services such as PV Cycle<sup>47</sup>), and detail how other waste will be segregated and disposed of.

35 Working at Height Regulations 2005. Statutory instrument 2005 No. 735 (HSE, 2005)

36 Health and Safety in Roof work (HSE, 2012)

37 Technical Note 66 - Safety and Fragility of Glazed Roofing: guidance on specification (Centre for Window and Cladding Technology, 2012)

38 BR471 Sloping glazing: Understanding the risks, BRE, (Kelly and Garvin, 2004)

39 Designers Guide to Eurocode: Basis of Structural Design, ICE Publishing, (Gulvanessian et al., 2012)

40 Electrical Safety, Quality and Continuity Regulations 2002

41 HSG85 3rd edition. Electricity at work. Safe working practices (HSE, 2013)

42 The Dangerous Substances (Notification and Marking of Sites) Regulations 1990 and The Dangerous Substances and Explosive Atmospheres Regulations 2002

43 Regulation Reform (Fire Safety) Order 2005

44 The Health and Safety (Signs and Signals) Regulations 1996

45 Code of Practice for Grid Connected Solar Photovoltaic Systems (IET, 2015), Code of Practice for Electrical Energy Storage Systems (IET, 2017), Code of Practice for Electric Vehicle Charging Equipment Installation (IET, 2015)

46 Such as Waste Electrical and Electronic Equipment Regulations 2013 and Waste Batteries and Accumulators Regulations 2009

47 <http://www.pvcycle.org/>

## System performance

There are a number of design decisions, other than good component selection, that will affect the performance of a multifunctional solar car park system. Maximising the generation potential of a site can be achieved by locating and orientating the solar carports so that they are exposed to direct sunlight for as long a period as possible.

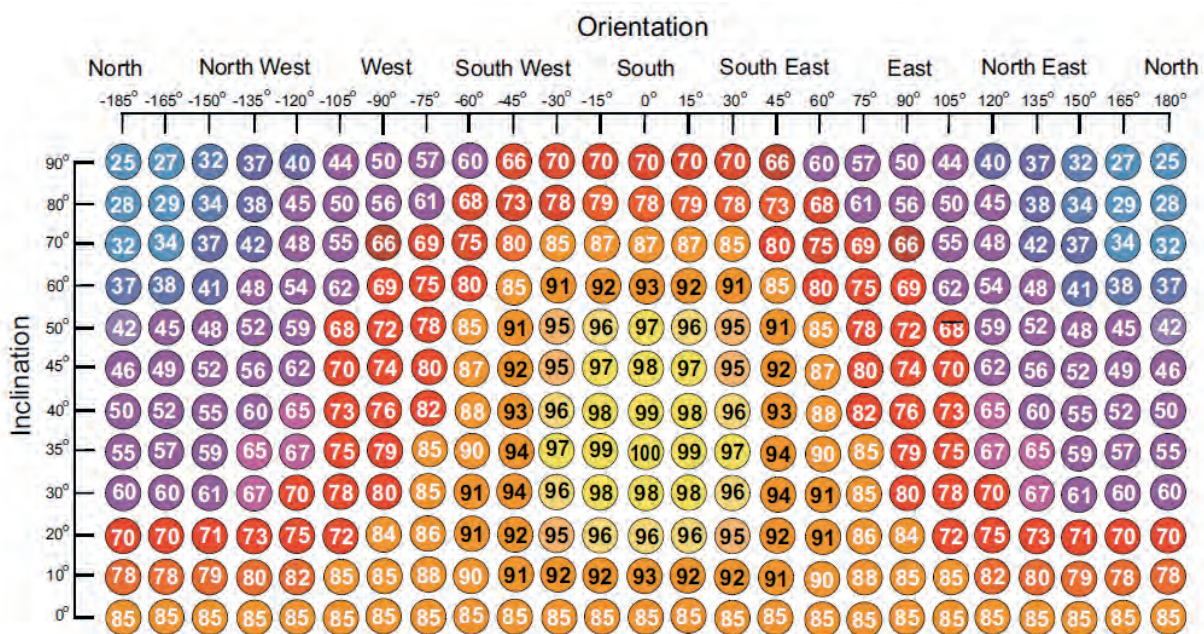
### System location

The location and arrangement of a solar carport system will have a direct bearing on its generation performance. The potential generation output of a PV system varies by approximately 35% across the UK<sup>48</sup>.

The orientation of the solar carports will normally be dictated by the pre-existing arrangement of parking bays, however for new car parks, or car parks that are being resurfaced there is an opportunity to layout the bays to optimise generation.

In the UK, common practice is align the PV modules in a southerly direction, although other alignments may be more favourable, as the generation profile can more closely match a specific load profile, or a restricted distribution network connection during peak generation times. The effect of solar carport orientation and inclination on solar generation is illustrated in Figure 4.

**Figure 4** The effects of variation in orientation and inclination on solar generation in the UK<sup>49</sup> (Image courtesy of MCS)



The pitch (inclination) of a solar carport is typically a compromise between solar generation and costs of the structural support required, however consideration should also be given to the following points:

- Car park user visibility – The design and layout of solar carports should not adversely affect a car park user’s view of other cars, pedestrians and surface mounted equipment.
- Environmental conditions – If the system is in a location that experiences regular snowfall each year, the pitch must be such that snow is shed effectively.
- Cleaning – It is recommended that PV modules should be mounted at a minimum pitch of 10° to improve self-cleaning. For sites that experience considerable dust or dirt it may be preferable to increase the angle or specify a regular cleaning regime to maintain performance.
- Inter-shading – The majority of solar carport frame designs should not cast shade on adjacent carports when installed in parallel rows of parking bays. There is a greater potential for inter-shading on

irregular car park layouts and carports with steeper pitches. 3D modelling can help to assess the potential loss of performance due to inter-shading.

- Planning – In locations of visual sensitivity it may be preferable to install solar carports with a shallower pitch to reduce the height of structures and the effect on views from roads, neighbours, national monuments etc.
- Glint and glare – When the sun reflects off an object it is referred to as a solar reflection. This comes in two forms; glint (direct reflected light) and glare (diffuse reflected light). The conditions are at their worst when an observer is facing the reflective object and in the shade of direct sunlight (e.g. with the sun directly behind them). If there are any highly sensitive observation points in the proximity of the site i.e. railway signals, air traffic control or on a coastal location then there may be a requirement to adjust the pitch of the solar carport to reduce instances of glint and glare.

<sup>48</sup> Based on Microgeneration Certification Scheme Standard Estimation Method for solar PV system performance, Guide to the Installation of Photovoltaic Systems (MCS, 2012)  
<sup>49</sup> Guide to the Installation of Photovoltaic Systems (MCS, 2012)

### Communications coverage

The location of a solar car park system also has bearing on its functionality. Some control and monitoring systems require GPRS coverage to function, others may need an internet connection with a minimum upload and download speed. For example EV charge-points typically require a communication connection (hard-wired or wireless) to facilitate back-office functions such as maintenance and billing.

It is important to understand any communication limitations on site to inform system design choices.

### System losses

There are a number of system losses involved in all the functions and processes of a multifunctional solar car park system. The majority of which can be reduced through good system design, component selection, system maintenance and land management. System losses can be categorised as follows:

- Solar conversion losses (solar cell temperature, PV module quality, PV module mismatch, soiling, shading, internal wiring losses)
- DC/AC Conversion losses (inverter efficiencies, MPPT losses<sup>50</sup>, EV charging efficiencies)
- Distribution losses (resistive connections, I<sup>2</sup>R losses<sup>51</sup>)
- Battery losses (charge/discharge efficiencies, temperature derating)
- Auxiliary system losses (power consumption for ventilation/ monitoring/ control systems, inverter power consumption at night)
- Downtime losses (grid conditions, faults, component failure, maintenance, restricted distribution network connection)

Current guidance<sup>52</sup> on voltage drop in conductors should be observed i.e. maximum 5% for AC distribution circuits, 3% for DC circuits, 1% for AC inverter circuits and 1% for solar circuits.

### Modelling

In order to appropriately size and understand the potential performance of a multifunctional solar car park it will be necessary to include the following site specific information into a system performance model;

- PV array size (kWp).
- Inverter size (kW).
- Estimated solar generation profile – preferably modelled half hourly (HH) data (kWh).
- Other onsite generation profiles/ power sources – HH data (kWh).
- Battery effective capacity (kWh).
- Battery charge/ discharge profiles (kWh).
- Battery degradation
- Onsite energy consumption profile – HH data (kWh).

- Proposed EV charging consumption profile – estimated HH data (kWh).
- Additional proposed new electricity loads i.e. EV charge-points – estimated HH data (kWh).
- Energy requirements and characteristics of any 'critical' loads – for back-up operation, if required (kWh).
- Site peak power requirement (kVA).
- Restricted distribution network connection information (KVA).
- Distribution network connection voltage (V), frequency (Hz) and power factor requirement.
- Electricity bill information (tariffs and charges).
- Operational/ business case requirements.

Systems should be optimised for operational/ business case requirements.

### Monitoring

Appropriate monitoring and control systems should be selected and installed for the safe operation of the whole system.

A number of the components installed will have their own inbuilt monitoring systems, such as the inverters, DC combiner boxes, battery management system and EV charge-points. Some systems may also provide data logging and reporting facilities, with data being communicated via GPRS or internet, and an alerts system that notifies users of specific events via SMS or email.

Monitoring can also be provided by standalone devices including environmental monitoring.

### Remote control

There may also be a requirement to provide remote control of a system. This could be to disconnect or reconnect parts of the system under specific conditions.

Multifunctional solar car park systems with a restricted distribution network connection are required to remain within a specified export capacity limit, either continuously or during specified time periods. This is normally facilitated by an export limiting device either integral to the solar inverter or installed as an additional component.

Some systems may also be subject to Active Network Management, where the DNO continually monitors the distribution network and allocates the maximum available capacity to generators in order of age of connection (i.e. first in last out). The DNO has the capability to take generators on and off line remotely.

Other types of remotely operated control functions that can be incorporated are rapid shutdown devices. Designed to de-energise solar generation at PV module level in the event of an emergency or specific DC faults. These systems are starting to be installed as a method of reducing the risks of DC arcing (that could potentially lead to fire).

<sup>50</sup> Due to variation in individual module electrical characteristics and partial shading.

<sup>51</sup> Due to current flow through a resistor.

<sup>52</sup> BS 7671:2008+A3: 2015 Requirements for Electrical Installations - IET Wiring Regulations (17th Edition) and Guide to the Installation of Photovoltaic Systems (MCS, 2012)



## Considerations for electrical design

There are a number of safety legislation, standards and considerations that should be factored in to the system design. All components should be designed, manufactured and tested in accordance with relevant safety standards (see Appendix A for more details). The electrical system as a whole will need to comply with the following regulations;

- Electricity at Work Regulation 1989
- Electrical Safety, Quality and Continuity Regulations 2002
- Electrical Equipment (Safety) Regulations 2016
- Electromagnetic Compatibility Regulations 2016
- Control of Electromagnetic Fields at Work Regulations 2016
- BS 7671 (IET Wiring Regulations)
- ENA Engineering Recommendations G59, G83, G100, G98 or G99 (as appropriate)

Typically, a multifunctional solar carport is sold as a pre-packaged system that will cover a specified number of parking bays, where the whole system has been designed as a flexible power supply that can be connected to any car park. It is important for each component to be capable of operating as part of the whole system, providing the desired function and output.

### DC system

Unlike other DC circuits, PV arrays do not provide a fixed voltage and/or current output, as this varies with the solar irradiance and operating temperature the PV modules are exposed to. It is therefore important to ensure that other components within the system are able to tolerate the maximum voltage (open-circuit voltage,  $V_{oc}$ ) and current (short-circuit current,  $I_{sc}$ ) that the PV modules, strings, and arrays can produce.

For PV circuits it is recommended that the minimum rating for all DC components should be established, using the crystalline PV module characteristics under standard test conditions (stc)<sup>53</sup>, as  $V_{oc} (stc) \times 1.15$  and  $I_{sc} (stc) \times 1.25$ .

For non-crystalline PV modules the  $V_{oc}$  and  $I_{sc}$  should be calculated from manufacturer's data as the maximum value under the conditions of irradiance: 1,250 W/m<sup>2</sup>, temperature range: -15°C to 80°C, including any increased electrical rating expected during the 'soaking in period'.

PV modules generate electricity whenever exposed to daylight; as a result, they should always be considered to be live, as should the terminals of batteries and all connected DC components. Particular care needs to be taken to mitigate electrical shock and fire hazards during the installation, operation and maintenance of systems.

Short circuit currents on batteries can be very high, it is therefore important to consider the risks associated with arc flashes<sup>54</sup>.

It should be noted that not all equipment designed for DC applications is rated for bi-directional current flow and many AC isolation/protection devices are not suitable for DC applications. Please refer to manufacturer's information to ensure components are appropriate for the function they are required to provide.

### DC connectors

DC solar connectors provide a quick, safe and durable means of interconnecting components within the PV system. DC solar connectors should be class II rated and certified in accordance with BS EN 50521 'Connectors for photovoltaic systems – safety requirements and tests'.

To ensure safe functionality, only DC solar connectors of the same type and from the safe manufacturer should be connected together and assembled as per the manufacturer's specification. A number of fires on PV systems have been attributed to poorly fitted, specified or mismatched DC solar connectors<sup>55</sup>.

All live DC connections should be protected and located out of the reach of the general public.

All DC connections should be periodically checked to confirm that they are tight and secure (referring to manufacturer for torque setting).

### DC isolation and circuit protection

PV cells are current-limiting devices and therefore the short-circuit current of a PV module; string; or array is not much bigger than the operational current. Batteries subject to short-circuits may overheat and if unprotected will be irreversibly damaged. As a result, DC isolation and circuit protection requires careful selection.

The selection and specification of DC safety equipment depends on the inverter configuration and earthing arrangements. Current discrete RCD technology is not suitable for the protection of DC circuits. All system components should be specified in line with BS 7671.

DC isolators are a safety-critical component. The poor design, selection and installation of DC isolators has been the cause of a number of system failures and on occasion leading to other more serious incidents, such as fire. Suitable methods should be used to isolate the system at; PV string, PV sub-array, PV array and battery level. Not all methods are suitable to break DC circuits under load, i.e. DC connectors and removable fuses.

Switch-disconnectors provide both load-break-switching and isolations function. DC switch-disconnectors must comply with BS EN 60947, shall not be polarity sensitive and must isolate all live conductors.

Suitably specified double pole DC isolation devices should be installed as close as possible to, or as part of, overcurrent protection devices for both PV arrays and batteries (regardless as to whether they are connected to the DC or AC side of a system).

Effective DC protective devices safeguard equipment against adverse operating conditions and help to ensure that the system is safe. The DC side of the system should be protected from overcurrent, overvoltage, and overload (for batteries).

Requirements for overcurrent protection will be different for systems with a DC connected battery. Adequate fault current protection from both the PV and battery should be afforded to all components (i.e. cables, connectors, isolators etc.). Overcurrent protection should be installed as close as is practically possible to the battery.

String fuses are required when the short-circuit current from a number of parallel PV strings is greater than the maximum series fuse rating of a single PV module. String fuses are installed at the point where PV

<sup>53</sup> standard test conditions for Europe are irradiance: 1000 W/m<sup>2</sup>, temperature: 25°C, air mass: 1.5

<sup>54</sup> The light and heat produced by an electrical discharge that results from a low impedance connection through air to ground.

<sup>55</sup> Fire and Solar PV Systems – Investigations and evidence (S Pester & C Coonick, BRE, 2017)

strings are connected in parallel, typically a DC combiner box or inside the inverter. The earthing arrangement for the PV array will dictate whether one or both string cables require overcurrent protection.

DC combiner boxes provide easy access and simple arrangement of protective and isolation devices for larger systems. The DC combiner box should be rated for the maximum voltage and current conditions (under stc) of the system and take into consideration segregation between positive and negative parts, permitting safe installation and maintenance and to minimise the risks of arcs. All enclosures should be manufactured using insulating materials with self-extinguishing properties to help minimise the fire risks.

DC insulation faults can occur for a variety of reasons; water ingress, environmental damage to insulation, damage to cables etc. Selecting quality, robust components and following good installation practices will minimise the likelihood of problems developing, however it is important to implement fault-detection measures. Earth insulation resistance and residual current monitoring devices should be utilised to detect insulation faults and trigger earth fault alarms; these can either be incorporated within inverters or provided by separate devices.

There are three types of DC arcs; series, parallel and 'to ground.' DC series arc fault detection is normally provided as a protective device integral to the inverter to reduce the risk of fire should a series arc develop. Rapid shutdown devices are also available that isolate the affected part of the circuit down to PV module level should a DC arc be detected. An assessment should be made of the risk posed by potential DC arc faults and how best to mitigate these within the system.

All DC isolation and circuit protection equipment should be easily accessible and clearly identified on electrical schematics and safe isolation procedures.

Access to any uninsulated conductors and batteries should be restricted and arranged so that it is not possible to touch simultaneously two uninsulated conductive parts with a potential difference of  $>120\text{Vdc}$ .

### PV modules

All solar carport systems should use certified & CE marked PV modules. Crystalline modules should be certified to IEC 61215 & IEC 61730 and thin-film modules should be certified to IEC 61646 & IEC 61730. It is also recommended that systems installed within coastal areas should also be certified for resistance to salt mist corrosion (IEC 61701).

### PV array configuration

Typically, the PV array is specified and sized for the carport frame and desired visual aesthetic or features (e.g. provision of natural light to the car parking bay area through use of glass laminated PV modules).

The PV string configuration will be determined by the requirements of the solar inverter (the majority of inverters are rated to a maximum input of  $1,000\text{V}_{\text{dc}}$ ) and the fuse rating of the PV module.

A number of inverter manufacturers provide design tools that can help verify the compatibility of a specified PV string configuration and their solar inverter(s).



Image courtesy of FlexiSolar



### Solar inverter selection

In addition to the electrical characteristics of the PV array, the solar inverter(s) should be selected with respect to the distribution network connection capacity available. Common practice is to undersize solar inverters to optimise power output and overall inverter efficiency for weather conditions typical to the installation location<sup>56</sup>. This may cause the solar inverter output to be regulated at times of high PV generation so as not to exceed the inverter's maximum power rating. Occasional loss of production at peak generation is balanced against improved solar inverter efficiencies at times of lower generation. Solar inverters may also be undersized to maximise on generation throughout the day on systems with a restricted distribution network connection (i.e. export limit).

Typically, inverter:array power ratios range from 0.8 – 1.1, and remain within the electrical limits of the inverter, as stated by the manufacturer.

Multiple solar inverters may be connected in parallel. It is good practice to use solar inverters from the same manufacturer to ensure compatibility of system monitoring and control.

All inverters should be CE marked, comply with BS EN 62109 Series. 'Safety of power converters for use in photovoltaic power systems' and BS EN 62116 'Utility-interconnected photovoltaic inverters' and must be either type tested to the relevant Engineering Recommendation (G83/ G59/ G98/ G99) or have an additional G59 relay which has been witness tested by the DNO.

Type testing provides evidence that the inverter will provide the following protection to the distribution network:

- Under-voltage
- Over-voltage
- Under-frequency
- Over-frequency
- Loss of mains

In addition, some solar inverters can also provide the following functions to the PV system:

- MPPT/ IV optimisation
- DC switch-disconnect
- Integrated cooling (active/ passive)
- AC/DC over-voltage/ surge protection
- Ground fault protection
- Over-current protection/ string fuses
- DC arc fault detection
- Export limiting/ power reduction control/ grid management services
- Monitoring (system and performance)
- Data logging
- Fault diagnosis
- Internet/ GPRS/ WLAN communication
- Remote control

### Energy storage system configuration

All power conditioning equipment must comply with BS EN 50160 'Voltage characteristics of electricity supplied by public electricity networks.' In addition consideration should be given to the general safety requirements of the installation as detailed within the BS EN 50272 series.

The energy storage system design should take in to consideration the following;

- DC input voltage range
- Maximum DC input current
- AC output voltage, frequency and power factor (compliance with G83/ G59)
- Efficiency
- Electrical separation (to determine whether an RCD is required)

Specification of the battery and battery inverter is dependent on how the multifunctional solar car park system is required to operate and what function/service the battery needs to provide. A number of functions were discussed in Table 1.

Understanding how much energy needs to be stored, over what time period it needs to be supplied and how quickly the battery needs to be recharged, will provide the basic information to start specifying a suitably sized energy storage system.

The physical sizing and housing of the energy storage system must be considered when the layout of the car park and carport structure is being designed. Energy storage systems should be designed and installed in line with BS EN 61427-2:2015 'Secondary cells and batteries for renewable energy storage. General requirements and methods of test. On-grid applications'.

Batteries present a number of potential hazards. In addition to the electrical hazards discussed previously, batteries also present chemical hazards (due to the incorporation of corrosive, caustic or toxic chemicals) and charging hazards (due to potential gas generation and/or thermal considerations). Consideration should also be given to minimising the risk of fire or other damage, both accidental or deliberate.

An energy storage system of less than 1MWh is unlikely to face environmental restrictions under the COSHH<sup>57</sup> or COMAH<sup>58</sup> regulations.

Suitably ventilated and corrosion resistant enclosures should be used and installed in a way that will avoid any contamination of ground water and the environment.

### Battery inverter selection

Typically, an energy storage system will have the functionality to charge its batteries from both the PV array and the distribution network providing greater flexibility in systems sizes. If the battery cannot be charged via the distribution network then the size of the battery inverter and battery may be dictated by the size of the PV array.

As with the solar inverter a battery inverter provides a wide range of functions (operational and protective). Some functions may be automatic, others may require programming and integration with other

<sup>57</sup> Control of Substances Hazardous to Health Regulation 2002

<sup>58</sup> Control of Major Accident Hazards Regulation 2015

<sup>59</sup> Maximum instantaneous current drawn by an electrical device when it is first turned on.

components such as a BMS. Battery inverters typically provide the following functions:

- Monitoring of battery conditions (i.e. state of charge, cell voltages, temperature etc.)
- Battery management
- Data logging
- Fault diagnosis
- Internet/ GPRS/ WLAN communication
- Remote control
- Back-up power supply/ island operation
- Integrated cooling (active/ passive)

Larger scale battery inverters may also provide dynamic grid management.

Inverter technology and BMS are continually evolving and there are already products available that provide intelligent operation, including predictive charging or optimisation of charging regimes for ToU tariffs.

### Back-up operation requirements

If a system is required to operate in 'island' mode, i.e. continuing to provide power to critical loads during times when the distribution network is not available, it is important to understand the load handling and load shedding capabilities of the energy storage system.

As well as being capable of operating in 'island' mode, the battery/ hybrid inverter must be rated to supply the power required by the load (including any inrush current<sup>59</sup>).

Typically, critical loads will be separated from other loads and connected to the energy storage system via a dedicated distribution board. An automated make and break contactor disconnects mains supply and connects the energy storage system to these loads, so that they receive a continuous electricity supply while ensuring power from the electrical storage system is not fed back to the distribution network.

Additional consideration should be given to the operation of protective devices and the provision of continuous earthing when operating in island mode. RCDs for the critical loads will need to be capable of operating under both supply conditions and not trip as a result of the transition.

### AC system

As with any electrical installation in the UK, multifunctional solar car park systems are required to be designed and installed in compliance with the current wiring regulations, BS 7671. Every component should be selected and installed to provide the proper function for intended use and environment, and adequate protection for safety.

### AC isolation and circuit protection

In order to facilitate safe installation and maintenance, each inverter (solar and battery) and EV charge-point must have its own accessible and lockable AC switch, that isolates all phase and neutral conductors. This switch may be part of the inverter or EV charge-point.

For systems with multiple inverters, an additional 'main' AC isolator should be installed to disconnect all inverters simultaneously. Often this is facilitated as part of a dedicated sub-distribution board.

All AC isolators should be rated to break the circuits safely while under maximum load.

An over-current protective device should be provided for each inverter and EV charge-point circuit, and RCD protection should be provided in accordance with BS 7671. All protective devices should be selected in accordance with the inverter manufacturer's instructions.

A risk assessment, similar to the one detailed in Appendix E1 of the IET Code of Practice for Electric Vehicle Charging Equipment Installation, should be completed to identify and mitigate any risks of electric shock.

### Cabling

The selection and specification of cables for any electrical system is a fundamental element of the overall system design. Incorrect sizing of cables can cause inefficiencies through resistive losses, component failure or excessive capital costs. Cables should be rated for the maximum voltage and current-carrying capacity for the circuit as per BS 7671 and specified to ensure safety, reliability and to minimise voltage drop and energy losses. Inverters continuously monitor the supply voltage and frequency, and nuisance tripping may occur if there is a significant voltage drop between the distribution network connection point and the inverter.

All cables should be identifiable by colour and alphanumeric marking and selected and installed so as to minimise the risk of earth faults and short-circuits, using double insulated or reinforced cables will help achieve this. PV cables are required to comply with BS EN 50618 'Electric cables for photovoltaic systems.' Consideration should also be given to the routing of cables, ensuring selected cables provide adequate resistance to any environment that they may experience, i.e. moisture, sunlight, heat, chemicals, abrasion or animal damage. AC and DC cables should be separated and clearly identified.

Adequate space should be provided for the routing of cables to enable good installation practices. All cables and connections should be adequately supported using conduit, cable cleats, cable clips, cable ties etc. to minimise the stress from wind or thermal effects and to provide safe continual operation throughout the lifetime of the system.

Particular consideration should be given to the installation and protection of cables from vehicle impact and any on-going land management, such as grass cutting.

It is usual for DC cables to be run in conduit within the carport structure between the PV arrays and solar inverters, and for AC cables to be armoured and routed underground between the inverters/ EV charge-points and the point of connection. Cable connections between batteries and charge controllers/battery inverters should adhere to any specifications (i.e. maximum length, cross-sectional area, level of protection etc.) recommended by the component manufacturers.

### System earthing and bonding

Systems earthing must satisfy the requirements of the Distribution Licence issued by the DNO. The design and selection of suitable earthing and bonding arrangements will ensure hazards are minimised by providing an appropriately low impedance path for earth, fault and lightning currents.

Earthing and bonding of the AC side of the system should be completed in accordance with BS 7671, conform with the requirements of BS 7430 'Code of Practice for protective earthing of electrical installations and BS EN 50522 Earthing of Power Installations Exceeding 1kV AC,' satisfy the DNOs requirements and comply with equipment manufacturer's instructions.

As per BS 7671, the type of earthing arrangement on the supply circuit (i.e. TN-C, TN-S, TN-C-S or TT) will dictate how adequate

protection against electric shock should be. The earthing and bonding arrangements detailed in Table 8 should be considered for all multifunctional solar car park systems, and the most demanding requirement applied. Earth cables should be laid parallel and in close contact to DC cables to reduce the risk of multiple paths to earth and should be appropriately sized to afford sufficient conductance.

The method of earthing will vary depending on the requirements of the components, please refer to component manufacturer's guidance.

**Table 8 Earthing and bonding requirements for multifunctional solar car park systems**

Earthing/ bonding arrangement	Requirement
Protective earthing	Should be provided for all connections in the energy storage system, and is also required for the carport frame if it is considered to be an exposed conductive part.
Functional earthing	Is required for all components with an AC connection (i.e. inverters, EV charge-points, control and distribution equipment).
Protective equipotential bonding	Required if any parts of the system are considered to be an extraneous conductive part. EV charge-points and batteries (installed in metallic enclosures separate from the inverter/charger) normally require equipotential bonding.
PID earthing	As per the PV module manufacturer's instructions
Lightning protection	Required if a lightning protection system is required on site, or if the solar carports are in close proximity to an existing lightning protection system.

**Earthing provisions in off-grid operation**

Careful consideration should be given to the earthing of systems that have the facility to operate in 'island' mode. Depending on the AC earthing arrangements on site, additional independent earthing may need to be provided (as required by BS 7671 and BS 7430) to ensure a continuation of earthing when the system is disconnected from the distribution network. More information can be found in the IET Code of Practice for Electrical Energy Storage Systems<sup>60</sup>.

**Metering**

Depending on the connection arrangement with the distribution network a separate Measuring Instrument Directive (MID) compliant import/ export meter may be required in addition to the sites existing metering arrangement.

An MID approved generation meter and, in some cases, export meter is also required to claim financial incentives such as Feed-in-tariff (FIT) payments and Renewable Obligation Certificates (ROCs). Additional metering may also be required for any additional functions and services provided by the system.

GSM and web enabled meters allow system owners to take readings automatically or remotely.

**Lightning and surge protection**

All multifunctional solar car park systems need to consider the possible effects of a direct or indirect lightning strike. Installations in open locations require as much consideration as those installed on multi-storey car parks. A lightning and surge protection risk assessment, including of data or control circuits and existing lightning protection system (LPS), should be carried out according to BS EN 62305.

Additional consideration should be given to multifunctional solar car parks that have the potential to operate in 'island' mode as the impact of surges may increase when operating in 'island' mode.

If the risk assessment indicates the need for lightning and surge protection then appropriately rated devices must be selected and installed in the correct lightning protection zone (LPZ) as detailed in BS EN 62305. For multifunctional solar car parks this will normally mean the installation of Type 1 and/ or Type 2 surge protection devices (SPDs), details of their function are presented in Table 9.

**Table 9 Function and typical location of surge protection devices.**

SPD Type	Function	Typical Location
Type 1	Discharges very high levels of lightning current.	AC side of the equipment and at the distribution network connection.
Type 2	Diverts lightning induced surges to specific components or parts of the system.	DC input of the solar inverter (can come pre-fitted to the DC combiner box).
Combined Type 1-Type 2	Combining both the above functions.	AC side of the equipment and at the distribution network connection.

60 Code of Practice for Electrical Energy Storage Systems (IET, 2017), 61 Lightning protection guide 3rd Edition (DEHN, 2015)



## Considerations for mechanical design

### Structure

Regardless of the type of solar carport frame, (i.e. V-frame, T-frame, portal-frame etc.), the structural integrity of a solar carport frame is fundamental in ensuring that a system is fit for purpose.

Compliance with BS EN 1990:2002+A1:2005 'Eurocode. Basis of Structural design' and BS EN 1991-1 Series. 'Eurocode 1. Actions on Structures', ensures that structural safety and loading characteristics are accounted for in the design of a solar carport.

BS EN 1991-1-7:2016+A1:2014 and the accompanying UK National Annex provide strategies for safeguarding against impact forces from vehicles and normalisation of impact loads from vehicles as static loads acting on the solar carport structure.

Adherence to BS EN 1993-1 Series. 'Eurocode 3. Design of steel structures' is required for any solar carport that includes a steel structure. In addition, solar carport foundations and columns may require geotechnical design of spread foundations, piles and retaining structures as per BS EN 1997-1:2004+A1:2013. 'Eurocode 7. Geotechnical design. General rules'. For any concrete members of a solar carport, reference should be made to BS EN 1992-1-1:2004+A1:2014 'Eurocode 2. Design of concrete structures. General rules and rules for buildings.'

Compliance with Government guidelines on materials and workmanship<sup>62</sup> as presented in the Building Regulations (2010) ensures that best practice in both design and construction is carried out. This guidance includes determination of expected loading capabilities and ground movement potential in relation to location and prevalent environmental conditions, such as average wind speed.<sup>63</sup>

Design durability of a solar carport can be defined as the ability for the structure to have no to low maintenance for a minimum of 20 years<sup>64</sup> and therefore steps should be taken to ensure that the materials chosen are robust and resistant to medium and long term environmental exposure. Wood for carport frames will need to be carefully selected and preservative-treated as recommended in BS EN 335:2013 'Durability of wood and wood-based products.'

Critical to durability are the connections of structures, such as between purlins, supporting beams and column connections, where ingress of moisture and water over time can lead to corrosion or degradation of the structure unless adequate protection measures are provided<sup>65</sup>. Consequently the solar carport design and materials must be evaluated on a site by site basis to ensure sufficient and durable protective measures against corrosion or degradation have been fully considered and implemented.

A plan should be put in place to monitor, assess and maintain solar carport structures.

Solar carports that do not fit within the definition of steel structures as detailed in BS EN 1993-1 Series, must instead be compliant with the relevant section(s) of BS EN 1090 Series. 'Execution of steel structures and aluminium structures.'

All steel construction products should be certified under the CE marking framework<sup>66</sup>. Consideration should also be given to the Construction Products Regulation<sup>66A</sup>.

### Carport frame

The solar carport frame should be manufactured from corrosion resistant materials that are appropriate for the environment in which they are to be installed and that are suitable for the expected lifetime of the system. Galvanic effects should be considered when selecting a frame that uses components of different metals. The design should make allowances for thermal expansion and contraction i.e. providing expansion gaps in structures with long extrusions. In addition, the design and specification of the carport should prevent the accumulation of snow, ice, water and debris on the PV array.

All PV module clamping should be carried out in accordance with manufacturer's requirements.



62 Building Regulations (2010) Approved Document 7 Materials and Workmanship (Department for Communities and Local Government, 2013).

63 Building Regulations (2010) Approved Document A Structure denotes average wind speeds for England and Wales, used to determine design loads of wind actions on solar car park structure and mounting system (Department for Communities and Local Government, 2013).

64 Design Criteria for Structural Solar Supports for Parking Canopies Installations (Structural Solar LLC, 2013).

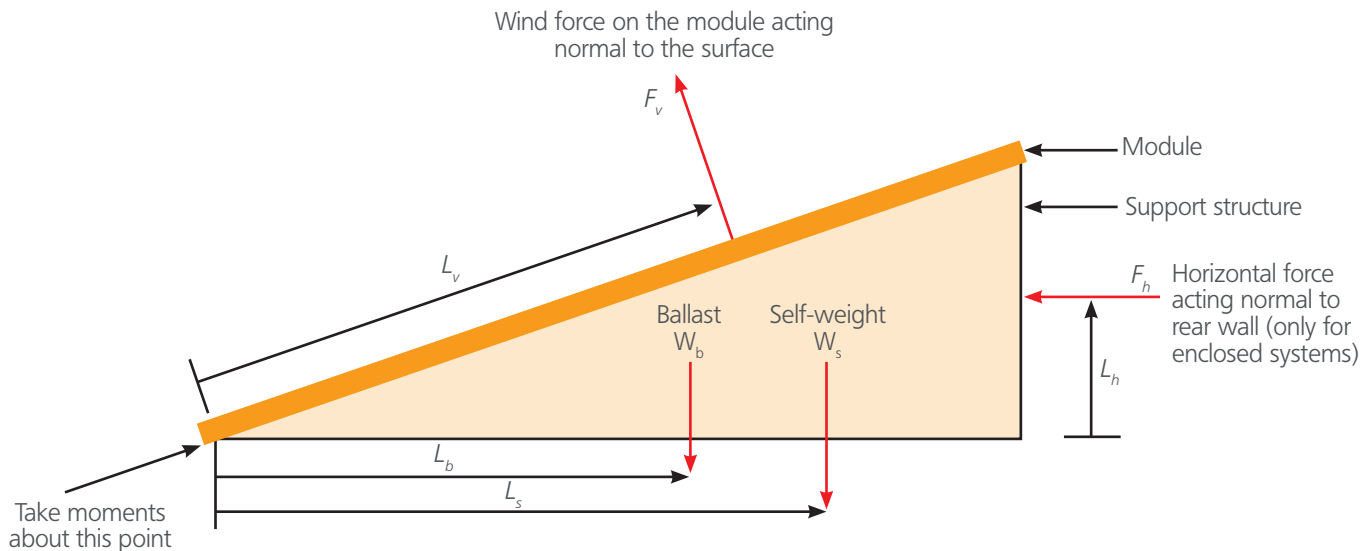
65 Corrosion protection measures include hot dip galvanization and corrosion resistant paint coatings. Durability, Lifespan and Economics Cost of Solar Carports (Structural Solar LLC, 2013).

66 Steel construction products must be certified under the CE marking regulations as presented by the BSI Update to the BS EN 1090 Marking for structural steel and aluminium fabricators (BSI, 2014).

66A [http://ec.europa.eu/growth/sectors/construction/product-regulation\\_en](http://ec.europa.eu/growth/sectors/construction/product-regulation_en)

**Figure 5 Definition of forces and lever arms for overturning moments (© IHS Markit)**

Reproduced with permission from Wind loads on roof-mounted photovoltaic and solar thermal systems (DG 489), 2014 edition



### Loading

The carport structure, ground fixings, PV modules and mounting fixings need to be able to withstand all forces that are anticipated to be imposed on them throughout the lifetime of the system, as illustrated in Figure 5. Methods for calculating potential wind loads (including uplift, sliding and overturning momentum) vary depending on the type of car park (i.e. surface or multi-storey).

The wind uplift force, calculated for each carport, will determine the quantity, location and pull-out strength of the ground and mounting fixings required. It is important to ensure that the fixing capacity provided by the manufacturer includes a safety factor, as this information can vary from product to product.

BRE Digest 489<sup>67</sup> provides a method for calculating the wind loading of roof-mounted PV systems, the methodology for flat roofs can also provide an indication for the wind loading on surface car parks by setting the building height to 0m.

The procedure for determining snow loads in the UK is defined in BS EN 1991 'Eurocode 1: Actions on structures.'

### Foundations

In addition to the requirements stipulated by Part A of the Building Regulations, all foundation types should conform to BS 8004:2015 'Code of practice for foundations' and BS EN 1997-1:2004 + A1:2013 'Eurocode 7. Geotechnical design'.

Solar carport structures can be affixed to a surface car park or top deck of a multi-storey car park by either penetrating or non-penetrating methods. The decision as to which method is suitable for a specific car park will come down to the site conditions ascertained by geotechnical data and investigations, examples of which are listed below.

- Surface car parks - soil structure, flooding, ground stability, surface finish and underground activities (i.e. underground services, archaeology, previous site activity, contaminated land etc.).
- Multi-storey car parks - building structure, building material, location of supports etc.

Consideration should be given to the permanence of the foundations, it may be a requirement of the planning consent that the system should be fully removable at the end of the systems useful life. Other multifunctional solar car park infrastructure, e.g. for large scale battery containment or sub-station housing, may also require foundations.

### Surface carparks

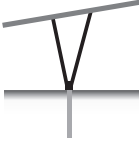
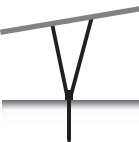


Foundation solutions suitable for surface car parks tend to fall into two categories; piles or spread foundations (i.e. concrete pads and ballast). Spread foundations should generally not be used on engineered fill.<sup>68</sup>

In general foundation design should take into account; the stability of the ground (i.e. potential for post-construction settlement, presence of weak layers, shear failure due to the construction process etc.), the effect of groundwater and drainage, potential global ground movements that can stress or deform the foundations and the construction of the foundations.

Some common foundation approaches for solar carports are detailed below.



Some common foundation approaches for solar carports are detailed below.

Foundation type	Description
 <p data-bbox="209 696 347 730">Rammed piles</p>	<p data-bbox="486 577 1495 658">Steel or reinforced concrete piles are driven into the ground. The depth of the pile is site specific and can vary across un-even or complex terrains. Steel piles require a small section of car park surface to be removed for installation and may require coating depending on the ground composition.</p>
 <p data-bbox="209 936 347 969">Screw piles</p>	<p data-bbox="486 810 1473 891">Ground screws are similar to rammed pile foundations and can be more appropriate for certain types of ground condition. Ground conditions will determine the screw size and length. Screw piles may require a small section of car park surface to be removed for installation and can be easily removed at the end of life.</p>
 <p data-bbox="209 1122 347 1155">Concrete pads</p>	<p data-bbox="486 1037 1495 1088">These can be either pre-cast or cast in-situ depending on the ground conditions. All concrete should be specified to BS EN 206:2013 and the BS 8500 Series.</p>
 <p data-bbox="209 1308 347 1346">Ballast</p>	<p data-bbox="486 1200 1485 1303">Ballast based systems rely on the weight of the ballast to keep the carport in place. Ballast can be in the form of pre-cast concrete, sleepers or filled gabion baskets. These are frequently supplemented by ground anchoring bolts. They are ideal for rocky ground conditions, where ground penetration is not appropriate, or for installations of a temporary nature or which need to be relocated from time to time.</p>

### Multi-storey car parks

The installation of solar carports on to the top deck of a multi-storey car park requires the early involvement of a competent structural engineer who can assess the building's structure and loading capabilities. Typically, solar carports are either bolted to elements of the car park structure that can spread the load or utilise a ballast system. The location of suitable anchoring points on a multi storey car park may dictate the location and layout of the carports.

Reference should be made to the Institution of Structural Engineer's 'Design recommendations for multi-storey and underground car parks'<sup>68A</sup>, which details requirements for structural design and durability, and considerations for mixed-use buildings.

## Solar car park layout

In addition to the requirements of the technologies and optimisation of system performance, a multifunctional solar car park should be laid out to facilitate safe car park operations.

There are no regulations that specifically target the layout and design of solar car parks. Therefore, in terms of the layout of solar car parks as an effective parking system, it is considered that relevant regulations, guidelines and best practice for the plan of parking bays, car park utility and end user safety for conventional car parks are applied.

The Parking Standards (2005) delineate minimum standards for parking bay sizes for all types of vehicles and denote the minimum number of parking spaces provided for different development types relative to gross floor area<sup>69</sup>. For individual bay sizes, it is recommended that best practice is followed for solar car parks, as structural carport supports can impose parking bay space constraints and impact on bay vehicular manoeuvrability. Minimum parking bay sizes are defined as 2.5 m by 4.8 m for standard bays, and 3.3 m by 6.6 m for disabled bays<sup>70</sup>.

Consideration should also be given to the location and visibility of car park entrances for car park users, other road users and pedestrians. For further information on car park design and illustrations of a range of car park plans, reference should be made to the 'Car park designers' handbook'<sup>72</sup>.

So that solar car parks maintain safety and levels of functionality for the car park end-user, guidelines such as those included in the Park Mark safer parking scheme<sup>73</sup> should be followed. This will enable car park operators to adhere to best practice for adequate signage, lighting and pedestrian access as well as providing a design framework for a safe car park environment.

For security measures such as closed circuit television (CCTV) cameras the 'Surveillance Camera Code of Practice'<sup>74</sup> and the 'data protection code of practice for surveillance cameras and personnel information'<sup>75</sup> should be followed.

### Underground/ overhead services

The layout of a multifunctional solar car park system should take account of other services installed at the site, including those located underground and overhead, and especially those that require access.

Underground services can include; electricity cables, gas pipes, water pipes, sewers, wells, communication cables, mining infrastructure and gas extraction infrastructure. Enquiries and surveys should be completed during the project planning stages to understand and map out all car park installation and operational activities and how these might impact on other services. Particular attention should be given to areas requiring excavation and/or penetration for foundations or trenching for cables. Test pits may need to be excavated to confirm data.

Overhead services such as electricity network cables and communication cables are easier to identify, but require just as much consideration. Special precautions will need to be taken for the use of any lifting equipment required for construction or maintenance.

### Component layout

A number of the components installed in a multifunctional solar car park may present a health and safety risk to system installers; users and the general public if they are not located and installed according to the manufacturer's instructions. When selecting locations for components, thought should be given to; minimising the requirement for working at height and manual handling; the weight of individual components and the integrity of the structures (wall/ floor/roof) to which they are to be attached; any noise from components when in operation; ease of installation; maintenance and decommissioning.

Particular attention should be given to the following:

### Protection from damage

It is necessary to consider the layout and location of all equipment installed within the car park to reduce the risk of damage from vehicle impact. Where it is not possible to locate equipment in a position that minimises the risk of damage, then additional protection should be provided as defined in BS 7671 (impact severity AG2). In addition, system components should be protected from vandalism or abuse, either by being placed out of reach or through selecting devices with anti-vandalism and/or anti-tampering features. In particular batteries should be protected from damage.

Carport structures should be designed to withstand vehicles impacting the structure at speeds of up to 20mph. This is described by BS EN 1991-1-7 'General Actions. Accidental Actions'.

The battery system, including power conversion system and other equipment may be installed in a building or delivered to site in ISO shipping containers. Where ISO containers are used, suitable foundation pads or raised supports to eliminate the risks from flooding, ingress of snow or ice. External protection, such as bollards, should also be provided to prevent damage from vehicle collisions.

### Environmental protection of equipment

Attention should be given to the location and layout of all components of a multifunctional solar car park to ensure that manufacturer's instructions concerning protection from environmental conditions are followed. Environmental conditions which could be detrimental to solar car park equipment include:

- Ambient temperature range
- IP rating
- Maximum humidity
- Ventilation
- Maximum altitude

All components should have a suitable IP rating for their installation location, as detailed in BS EN 60529 and presented in Table 10. This should include consideration of where they are to be located (i.e. flood zones), any activities or incidents that may take place in or adjacent to that location (i.e. car washing, PV cleaning, burst water pipe).

69 P4-12, tables for minimum number of bays and development types, Parking Standards, UK Department of Environment, (Department of Environment, 2005)

70 Minimum parking bay sizes referenced however necessary width of entry to a parking bay is related to the available width of carriageway of a road or aisle of a car park. Where this width is limited, alternatives can be developed by adjusting the width of the parking bay to suit the available carriageway or aisle width. Transportation Development Guidelines: Designing the layout of roads, parking and servicing's, (Fife Council, 2006)

71 Development Control advice note 15, Vehicular Access Standards, 2nd Edition Vehicular Access Standards, (Department of Environment, 1999)

72 Car park designers' handbook, Thomas Telford, (Hill, 2005) 73 Park Mark. New Build Car Park Guidelines for Car Park Designers, operators and owners, Safer Parking Scheme, (British Parking Association, 2010)

74 Surveillance Camera Code of Practice, (Home office, 2013) 75 In the picture: a data protection code of practice for surveillance cameras and personal information, Information Commissioners office, (ICS,2017)

**Table 10 Definition of IP ratings<sup>76</sup>**

IP rating 1st digit	Protected against described solid foreign object	IP rating 2nd digit	Protected against described water state
0	Non-protected	0	Non-protected
1	50mm diameter +	1	Vertically falling water drops
2	12.5mm diameter +	2	Vertically falling water drops when enclosure tilted to 15°
3	2.5mm diameter +	3	Spraying water
4	1.0mm diameter +	4	Splashing water
5	Dust protected	5	Water jets
6	Dust tight	6	Powerful water jets
		7	Temporary immersion in water
		8	Continuous immersion in water
		9	High pressure & temperature water jets

Moisture ingress into enclosures containing DC components is the main cause of fire incidents involving PV<sup>77</sup> and therefore due care should be given to preserving the IP rating of components through good installation and maintenance practices. Cables should be routed and suitably protected from environmental conditions for their full length, i.e. through correct installation of appropriate conduit, trays and cable glands.

Equipment that has the potential to create a spark (such as DC isolators) should not be located in areas where flammable gases, combustible materials or explosive atmospheres (including dust) may build up. In addition components should not be located near heat sources or sources of ignition.

Battery enclosures and any components routed through them should be suitably corrosion resistant. Most batteries need to be kept within a set temperature range (often between -10 to +25 °C) and so exposure to direct sunlight and deep frosts will need to be avoided.

Components of heating and ventilation systems, e.g. compressors, pumps and fans, may be a source of noise which that will need mitigation.

Adequate protection against fire (ingress and spread) must be provided in accordance with local fire regulations. Whilst these risks are small in carefully designed and installed systems, the potential impact of an incident should not be overlooked.

### Accessibility

During both construction and operation, access to a multifunctional solar car park needs to be carefully considered. This includes specific access requirements for construction equipment, large delivery vehicles (i.e. HGVs), and emergency vehicles accessing and traversing the car park. In particular, the solar carport and equipment layout needs to provide suitable access, including to isolation switches, for emergency services.

Consideration should be given to specific access requirements for intended additional uses of the solar car park, e.g. staging outdoor events, and any operational requirements (facilitating deliveries, accommodating emergency muster points, car washing, land management etc.).

All components within the system will require some maintenance throughout their lifetime and it is important that provision is made for this. It must be possible to access all serviceable equipment, including being able to remove covers. Particular consideration should be given to how serviceable components (such as inverters, batteries and fuses) will be accessed, and potentially replaced, during the lifetime of the system.

Carport structures that do not require access onto the roof canopy during the construction and maintenance phases are preferable. This can be achieved using mounting solutions that give access to modules from underneath the canopy. Minimising the need to access the roof also protects the PV modules from damage which could lead to underperformance or an electrical fault.

Access must be restricted to any live connections or terminals. Battery terminals should also be protected from accidental short-circuiting.

Unlike other system components, EV charge-points do require good accessibility for members of the public to use. At present the inlet position (the charging socket on the vehicle) has not been standardised. This means particular consideration needs to be given to how to facilitate connection between an EV charge-point and vehicle inlet position whilst minimising the length of charging lead (to reduce trip hazards and to prevent accidental damage to equipment and vehicles).

All EV charge-point socket outlets should be installed between 0.75-1.2m above ground level.



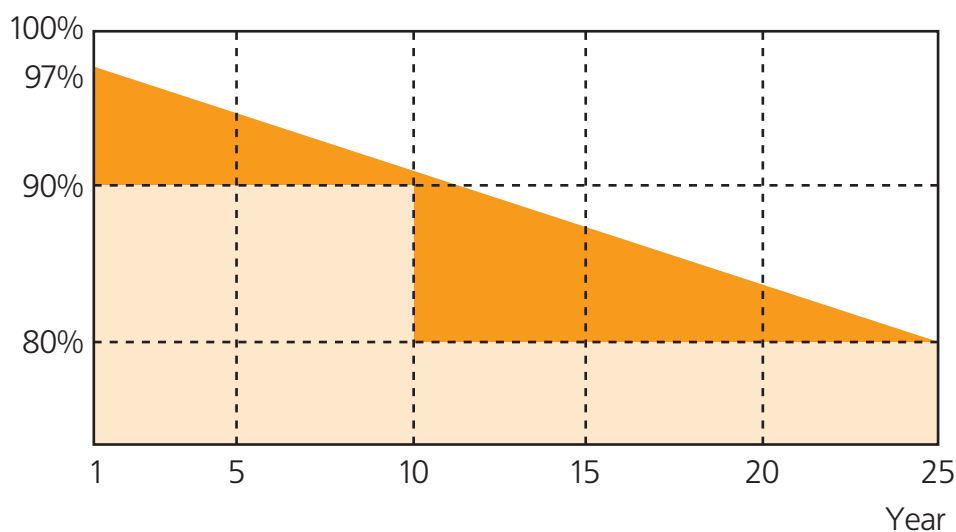
Image courtesy of FlexiSolar

## Component warranties/ guarantees

The majority of components within a multifunctional solar car park system will come with some form of warranty or guarantee. Generally, manufacturers will stipulate certain terms and conditions around the provision of a product warranty or performance guarantee. Typically, these will be around intended use, system design, method of installation, maintenance provisions and other influencing factors (such as installation environment and the interaction with other components). Performance guarantees may also require specific monitoring of the system to detect when a system is operating outside its guarantee conditions.

Most manufacturers will guarantee PV module power output for a defined period, commonly referred to as a degradation rate. This rate is generally expressed as a percentage of the rated power that will be achieved over a given period e.g. 90% power output for the first 10 years then 80% for a further 15 years, giving a guaranteed power output for 25 years. It is common for PV module manufacturers to provide such guarantees either as a stepped rate or as a linear warranty. A comparison of the different approaches can be seen in Figure 6.

**Figure 6 Comparison of stepped and linear PV module warranty**



Similar to PV modules, batteries are usually provided with a product warranty and performance guarantee. A battery's performance will depend on both its calendar life, the number of cycles used and the depth of discharge of each cycle. Different battery types have different performance characteristics. Monitoring of the charging/ discharging energy flows is required to determine whether a battery is operating within its warranty conditions.

As with many electrical components, inverters (solar and battery) have a limited lifespan and commonly have to be replaced at least once within the lifetime of a multifunctional solar carport, or more often when systems are poorly designed or poor quality components are used. Some inverter manufacturers offer longer term service packages on top of their standard warranty, which can include remote monitoring and replacement inverters.

### Commissioning

Commissioning procedures should include full inspection and testing of the complete system according to the requirements of the component manufacturers, BS 7671, BS EN 62446-1 and the appropriate ENA Engineering Recommendation.

A visual inspection should verify that the system complies with current standards and has been installed according to the agreed design and manufacturer's instructions, using appropriately specified, selected and undamaged equipment.

Electrical and functional testing should be completed, ensuring that all

protective and isolation devices operate as required. Functional tests of the control and operational systems should also be completed, including ventilation, fire protection and systems relying on internet connectivity.

Depending on the requirements of the DNO, an additional witnessed test of the operation of the G59 relay may be required prior to connecting the system to the distribution network.

A complete operations and maintenance manual should be provided to the system owner that includes:

- Copies of all commissioning, inspection, testing and risk assessment documents
- Copies of the grid connection agreement and protection settings
- The system technical specification
- Copies of as-built system drawings
- Component manufacturer's manuals
- Warranty/ guarantee details
- Operating instructions
- Emergency shutdown procedures
- Maintenance instructions and schedule
- Decommissioning and disposal instructions



## Operation and maintenance

All systems will require a certain level of maintenance to ensure they continue to operate safely and function as specified. Depending on the capabilities of the car park owner, some basic maintenance tasks such as cleaning PV modules may be managed in-house. For larger systems it is common to contract an operation and maintenance provider to monitor system performance (often remotely) and to complete scheduled maintenance and periodic verification testing. Due to the multi functionality of the system this may involve one or more contractors who have specialist knowledge of the functions installed.

Good system maintenance and regular inspections will ensure a multifunctional solar car park system is operating and performing as designed, components are kept in good operational condition, component failure is identified early on and risks are mitigated.

### Scheduled maintenance

Depending on the system installed; the monitoring in place; and the requirements of product warranty conditions, service contracts, performance guarantees etc., the requirement and timings of scheduled maintenance will vary. Typically, component manufacturers will make recommendations for what maintenance is required and at what intervals. This information can be collated to form the basis of a scheduled plan of maintenance for the entire system and which might include the following tasks:

- Cleaning fans and ventilation systems.
- PV array cleaning (especially in areas of high air pollution and soiling).
- Testing of RCDs and other protective devices.
- Functional testing of isolation devices.
- Testing of fire detection systems.
- Cleaning of sensors (typically irradiance sensors and reference cells will require periodic cleaning).

### Triggered maintenance

This happens when an event occurs that requires maintenance outside the planned schedule. This can be because of:

- A system fault.
- An alarm or error message being reported through the monitoring system.

- The performance monitoring system or customer has flagged up unexpected system behaviour or poor performance.
- A change of system ownership or maintenance contract.

### Periodic verification

As with other electrical installations, periodic performance verification is recommended to ensure that the system remains in a satisfactory operational condition. During periodic verification it is normal for comprehensive inspections and testing to be completed. The frequency of periodic verification is normally specified by the system designer, installer or owner. It is recommended that, as a minimum, periodic verifications are completed at the same intervals as other AC electrical testing requirements, as specified in 'IET Guidance Note 3: Inspection and testing', and will therefore vary depending on what type of building (if any) the multifunctional solar car park is connected to.

### Regular inspections

In addition to the requirement of scheduled maintenance and periodic verification it is recommended that regular inspections are completed to verify the safe operation of the multifunctional solar car park system, regardless of its size or function. It is common for owners/ operation and maintenance contractors to use remote monitoring and webcams to complete regular inspections, preferring an automated and non-obtrusive system to verify system performance on a regular basis. It is important that monitoring equipment and their data-feeds are set up correctly and correctly interpreted to ensure problems are detected as soon as possible.

Depending on the type and level of monitoring installed it may be difficult to identify smaller faults within the system (e.g. down to component level). A comprehensive risk assessment should identify whether additional onsite regular inspections are required.

It is recommended that a stockholding of essential items are kept on site to ensure system down time is minimised.









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