Fire and Solar PV Systems – Investigations and Evidence

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Contents

1 Introduction

1.1 Background

Over the past few years, there have been a number of media reports linking photovoltaic power systems (PV) with fire. With nearly 940,000 PV systems now installed in the UK, an increase in incident reports is to be expected.

The National Statistics website[1] shows that, as of the end of December 2017, overall UK solar PV capacity stood at approximately 12.75 GW. Figure 1 shows the scale of the increase in deployment since 2010, when the feed-in tariff (FIT) was first introduced.

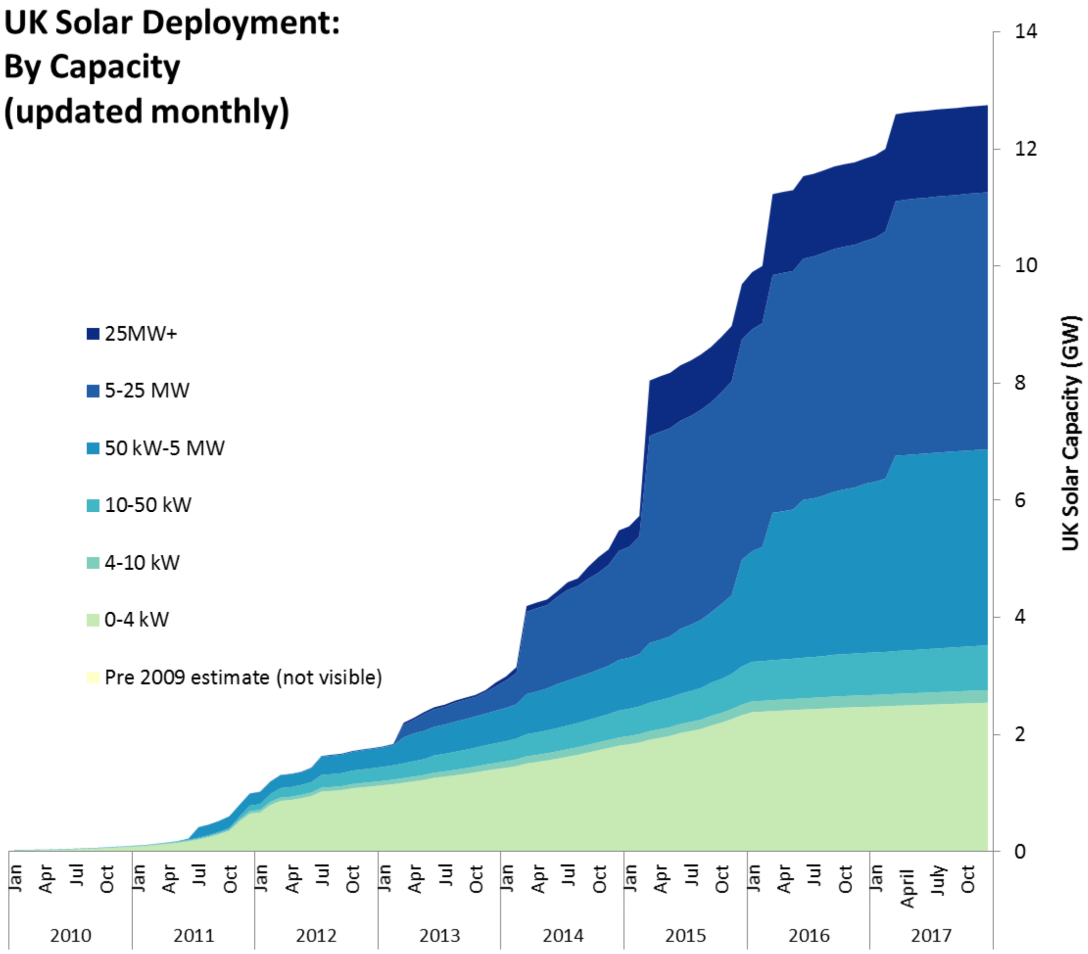

Figure 1: UK PV deployment to December 2017[1]

[1] www.gov.uk/government/statistics/solar-photovoltaics-deployment

At this point in time (December 2017), 46% (5,893 MW) of total installed UK solar PV capacity came from large scale installations greater than 5 MW, with 20% (2,531 MW) coming from small scale 0 to 4 kW installations, and the overall UK solar PV capacity stood at 12,748 MW across 937,421 installations (provisional figure). This is an increase of 32% (3,057 MW) compared to December 2015.

Prior to this project there was little information available with regards to PV related fire incidents. Statistics relating to fire incidents attended by Fire and Rescue Services (FRS) are published by the Government[2], however, the data is high level and it is not possible to identify which incidents may have involved a solar PV system. Typically PV related fires have been reported by the press[3], other incidents have become known through word of mouth[4], and it seems likely that a larger number of fire incidents have not been reported to FRS or through consumer protection channels (such as the Microgeneration Certification Scheme and Renewable Energy Consumer Code), especially where installers have been able to contain and rectify the fault without intervention from the FRS.

Previously, there appears to have been no detailed follow-up investigation in order to properly understand the causes of these fires, or how the presence of PV on a building may have influenced firefighting operations.

The main causes for ignition of PV related fires are not seen as common hazards in traditional AC electrical systems. This is partly because the electrical industry standards, practices and component designs have evolved over the last 100 years or so to a point where most modern installations are very safe. Despite the now significant number of PV systems installed in the UK and elsewhere PV standards, practices and components, however, are relatively young by comparison and are still evolving[5].

The acquisition of incident data from the field, analysis of root causes and reporting is therefore vital to ensure that standards committees have the latest information to work with, creating the conditions for standards to remain relevant and effective. Safety is overarching and it should be the industry's ambition to minimise risk in PV systems.

Also, how PV systems can influence firefighting operations may be an essential input during the ongoing development of standards. Standards provide information on safety consideration, however, at present there is a lack of coverage of fire safety issues, including firefighting response.

This project has therefore been established in order to collate accurate information - both historical (pre-project start) and contemporary (reported to BRE since July 2015 for this project) – on fire incidents involving PV systems, and on relevant previous research. The aim of the project is to feed

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[2] https://www.gov.uk/government/collections/fire-statistics

[3] http://www.bbc.co.uk/news/uk-england-sussex-32382795, http://www.telegraph.co.uk/news/2017/07/02/fire-sweeps-new-block-london-flats-witness-claims-started-solar/

[4] Following conversations with members of the Solar Trade Association

[5] There are currently 67 published British Standards relating to PV technologies, 19 of which were published in 2017.

the data and conclusions into industry standards (e.g. [1], [2]) and the National Occupational Guidance system [3], which is used to disseminate information to the fire and rescue services.

The project team has completed the following work:

- a literature review
- a review of standards
- a review of available PV installer training and PV training for firefighters
- a database of PV fire incidents
- a series of on-site investigations and desk studies of contemporary incidents
- disseminated the findings and recommendations of the research to the fire sector, including presenting at BRE's Fire Research Conference and the UK Association of Fire Investigators Annual Training Conference
- disseminated the findings and recommendations of the research to the relevant national and international standards committees, including BSi, IEC and MCS
- disseminated the findings and recommendations of the research to the UK solar industry through a PV Fire Workshop
- disseminated the findings and recommendations of the research to solar installation training providers through a Train the Trainer event

The public project description can be found on BRE National Solar Centre's website: http://www.bre.co.uk/nsc/page.jsp?id=3676.

2 Project outline

The project began in July 2015 and finished February 2018. This report is the final output from work package (WP) 4. A short outline of the project is presented below.

2.1 Organisations involved

The project team comprises the following organisations and individuals:

- BRE National Solar Centre (NSC)
- BRE Global Fire Investigation Group
- Fire Investigations (UK) LLP (FI-UK)
- A representative of the Chief Fire Officer's Association (CFOA)
- A representative of Prometheus Forensic Services Ltd
- Individual PV experts

The project is funded by the Department for Business, Energy and Industrial Strategy (BEIS).

2.2 Programme

Table 1 gives a brief description of the complete three year project, formed from the following work packages:

WP	Description	Status
1	Review of relevant literature. The literature review produced a total of 184 references, mainly from the PV industry, academia and fire services. The full report was submitted to BEIS 25/11/15.	Completed November 2015, minor modifications March 2017
2	Surveys of standards and training. Standards were mainly international (e.g. IEC), whilst training courses were mainly domestic. The full report was submitted to BEIS 25/11/15 and incorporated into the literature review report.	Completed November 2015
3	Survey of historical incidents in the UK – the survey involved contacting installers, building owners, the fire services and DCLGs Incident Reporting System. 37 unique historical incidents of fire involving PV systems in the UK were identified. The output was reported as part of WP5.	Completed January 2016
4a	Investigations of live and recent PV fire incidents in the UK. WPs 1 – 3 and 5 laid the foundations for on-going investigations into incidents, as they arise (WP4).	Completed February 2018
4b	Additional Work Package introduced as a variation to the contract to enable laboratory examinations of components suspected of causing fires on PV systems to be undertaken. The data from these examinations feed into WP4 and are stored within the database.	Completed February 2018
5	Database development and initial population with historical records.	Completed December 2015
6	Fire and Solar PV Systems – *Literature Review, Including Standards and Training** derived from WP1 & 2).	Completed March 2017
7	Fire and Solar PV Systems – *Investigations and Evidence** (derived from WP3, 4 & 5).	Completed March 2017, updated February 2018
8	Fire and Solar PV Systems – *Recommendations*:* a) *for PV Industry* (derived from WP6 & 7). This report. b) *for the Fire and Rescue Services* (derived from WP7 & 8)	Completed March 2017
9	Dissemination to BEIS and the solar and fire safety industries	Completed February 2018

Table 1: Project work packages and status*

***** Note: Following a meeting with BEIS in November 2016, the outputs from work packages 6, 7 and 8 have been recast, as shown in the table. The original work packages were as follows:

WP6: Recommendations for improving design and maintenance standards

WP7: Recommendations for improving training

WP8: Recommendations for the safety of fire-fighters in the event of fires involving PV

2.3 Reports

The following reports form the published output from the project. The Investigation and Evidence report (this report) has been revised from the interim report published by BEIS in July 2017[8].

- A review of relevant literature, standards and training [4]
- Fire and Solar PV Systems – *Investigations and Evidence* - this report
- Recommendations for the PV industry [5]
- Recommendations for Fire and Rescue Services [6]

3 Methodology

3.1 Review of literature, standards and training

The starting point for the project was a review of relevant literature (WP1). The literature review produced a total of 184 references, mainly from the PV industry, academia and fire services. Next, two further reviews were conducted on relevant standards and training courses.

These reviews are presented as a separate document: Fire and Solar PV Systems – *Literature Review, Including Standards and Training* [4].

3.2 Communications

Under WP3, members of the team used contacts in the fire and PV sectors to seek historical information on known fire incidents involving PV systems. The information gathered was then fed into a database, developed by the project team (described below).

Communications via the Chief Fire Officers Association (CFOA) and the Microgeneration Certification Scheme (MCS) allowed relevant organisations and individuals to be informed of the live incident investigation capability of the project (WP4) and request that any incidents involving PV systems be reported to the team in real time, or as soon as possible after the event.

A project description was also set up on the NSC website: http://www.bre.co.uk/nsc/page.jsp?id=3676 and an approved article was published in Renewable Energy Installer magazine in December 2016. All communications carried contact details specifically set up for the project:

email: solarfire@bre.co.uk and a telephone number: 0333 0033 314.

As a result of the communications efforts, as well as regular media searches, data on live or recent incidents started to arrive. In cases where remedial measures had been completed, or evidence destroyed, the team opted not to visit the site, but to collect data by telephone and email ('desk studies').

3.3 Establishment of the database

In order to provide a secure and durable location to store data on fire incidents collected during the life of the project, a basic database with a secure web portal interface was designed, tested and implemented on a server located at BRE headquarters in Watford (WP5).

The information to be captured by the database was selected by discussion with BEIS (then DECC) and fire and PV experts at BRE.

The information necessarily contains personal data (names and addresses) and commercially sensitive data (names of products, suppliers, etc.). This is to ensure validation of information sources and to prevent duplication of incident records. Therefore, in accordance with the contract with BEIS and BRE's own procedures, the data resides only on the secure server at BRE, with only named members of the BRE team having controlled access. The database has the facility to export anonymised records only.

The diagram in Figure 2 illustrates the flow of incident data and the conceptual structure of the database.

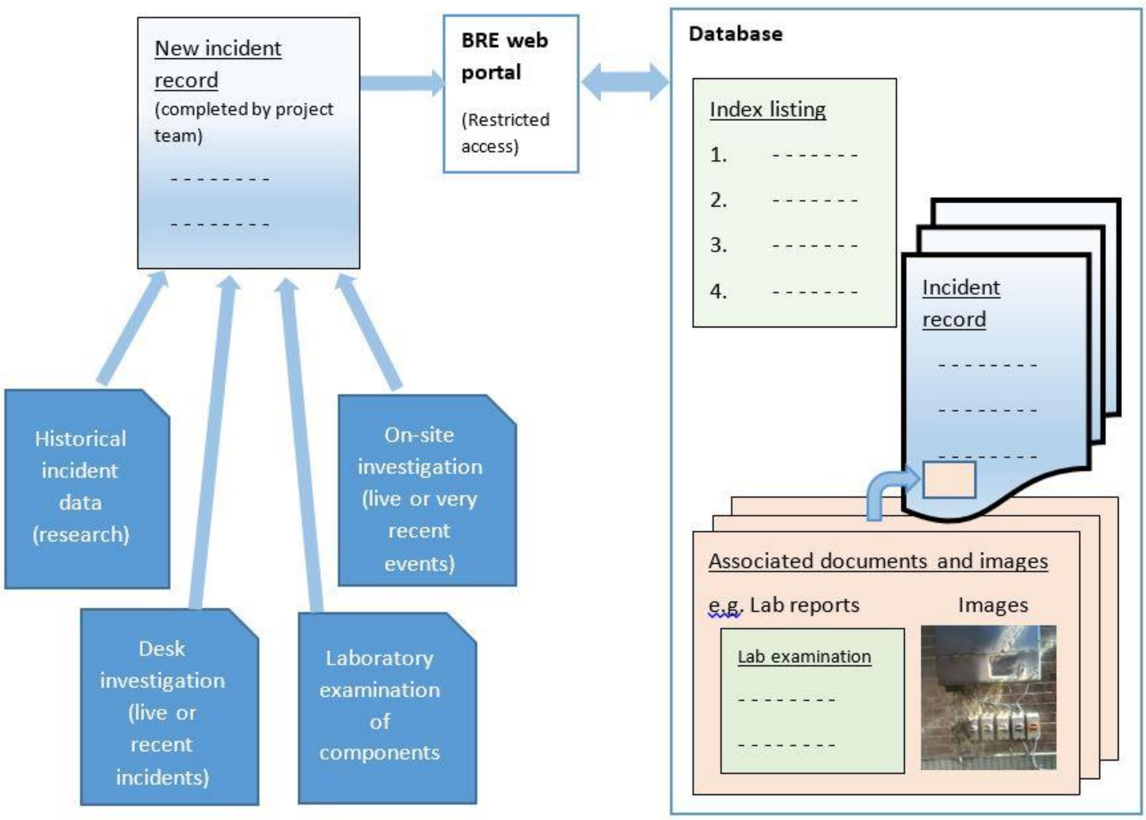


Figure 2: Fire incident data flow and conceptual structure of database. Each record consists of some 75 data fields.

A more detailed description of the database data fields and images of the interface portal can be seen in Appendix A. An anonymised summary of the records to date is provided in Appendix B.

There are currently a total of 80 unique records of fire incidents involving PV in the database. These are made up of 33 historical incidents and 47 that have been investigated by the team, either on-site or by desk studies.

3.4 Incident investigations

Once the database and portal had been set up and tested, the historical incident data collected under WP3 were entered. Data from new incidents were entered as the information became available from on-site, laboratory and desk investigations. Each incident is assigned a unique identification label, of the form “PVFxxxx”, where “xxxx” is a serial number. The various data collection activities are described below.

It should be noted that data on “thermal events”, incidents in which overheating occurred, but did not develop into a fire, were also captured where possible. These incidents are interesting because they can provide direct evidence of potential causes of fires, with only the overheated components being affected and the area around them being undamaged. Usually, thermal events are noticed when smoke is seen to be issuing from a component.

3.4.1 Historical incident research

The historical incident data was gathered mainly by networking with PV industry contacts and fire services, as well as internet searches.

Under WP3, members of the team used contacts in the fire and PV sectors to gather information on known historical fires involving PV systems (see details in 3.2, above). The DCLG Incident Reporting System (IRS) used by the fire services to record fires was also interrogated. However, the IRS records tend to contain little technical detail on PV-related incidents. Some members of the team were already aware of some incidents and this information was also used where possible.

A data capture form was developed to reflect the database fields, so as to record the data as consistently and completely as possible. The content of the form is virtually identical to that shown in Appendix A, User interface.

The resulting data from the above exercise were then filtered for duplications, as several reports were found to refer to incident data already captured, but with a slightly different name or description.

Data was collected on a total of 33 historical incidents: PVF0002 – PVF004, PVF0006 – PVF0028, PVF0030 – PVF0034, PVF0036 and PVF0038. (The incident numbers are not continuous because data from some earlier investigations, commissioned outside of the project, have been included, and also there was a brief period when live and historical data was arriving simultaneously).

3.4.2 Site investigations

An important feature of the project is the active, fast response, on-site forensic investigations conducted whenever the team was made aware of a suitable incident. The criteria for whether or not to send a team to site is detailed below.

There are three potential scenarios in deciding whether or not to send an investigation team to the site:

a) Any incident where a PV system is **clearly implicated** as a possible cause of the fire, or a significant hazard for fire fighters. The team would normally seek access to the site in order to investigate. This is not always straightforward as the Fire & Rescue Service (FRS) will not give out any contact details of building owners, so we are often reliant on the FRS to pass our details to the site owner.

b) Where a PV system is present, but **clearly not implicated** as a cause (e.g. common kitchen fire, such as that from a deep fat fryer). We enquire with the FRS to determine if the PV system caused any concerns or created extra hazards during the firefighting activities. If there were any such issues, these would be recorded, but we would not generally visit the site.

c) Where a PV system is present, but it is **unclear whether it is implicated** as a possible cause of a fire, we will interview the relevant FRS and, based on the information received, make a decision on whether the site should be visited. In general, if a part, or parts, of the PV system appear to have been damaged, we will send a team to investigate. Where the PV system appears to be undamaged and the FRS reports no issues relating to the PV system we will not investigate further.

In general, a fast response is required so that evidence can be viewed on site prior to any further disturbance from restoration works. The team was normally able to mobilise within 24 hours if permission to access the site had been obtained.

3.4.2.1 Interactions with insurance investigators

It is important to understand that there are other parties with an interest in building fires, aside from the owner and the FRS. Generally, insurance companies will commission their own investigation into the causes of a fire, via a loss adjuster and specialist investigator.

Part of the team's process when attempting to gain access to a site is to establish and make contact with the relevant insurer, loss adjuster or investigator if possible, so as to explain the purpose of the project and give confidence that the team will not disturb evidence likely to be of interest to the insurer's investigator. Usually, if this communication is handled appropriately, the other parties are happy to have the site investigation team on site and will generally agree a time when all parties can be present and can exchange observations and thoughts. This arrangement can be of mutual benefit, allowing more pairs of expert eyes and PV and forensic knowledge to be applied to the investigation at the scene of the fire.

3.4.2.2 Site investigation team

The site investigation team is composed of PV experts and forensic fire investigators. Wherever possible, a PV expert and a fire investigator coordinate to visit the site at the same time. The site investigators underwent training in an early stage of the project in August 2015 and February 2017. The PV experts trained the site investigators and vice versa, with the major focus on health and safety aspects of such site visits.

The site investigation team consisted of 7 professional fire investigators and 6 PV experts. The fire investigators are drawn from FI-UK, the PV experts are from the BRE NSC, BRE Scotland, BRE Wales and one independent consultant.

3.4.2.3 Health, safety and communications on site

Damaged PV systems can be dangerous, so the first priority at fire scenes is health and safety. In each case a risk assessment (RA) is undertaken at BRE prior to the site visit, using available information. Upon arrival on site, the RA is updated with a dynamic assessment of the potential hazards. Typical risks to be assessed and controlled are as follows:

- Falls
- Trips & slips
- Electrocution
- Burns
- Collisions with objects (e.g. banging head on scaffold)

The building is only entered once the hazards have been assessed and controlled sufficiently (e.g. assessing and avoiding dangerous areas, wearing suitable PPE, etc.) to reduce the risk to an acceptable level. Risk assessments have been stored on a server located at BRE headquarters in Watford.

At non-domestic sites, a briefing is sought in order to comply with site regulations, obtain contacts and for orientation.

Good communication with all parties is essential to ensure access to the site, avoid misunderstandings and avoid causing any extra stress to building owners. Therefore, building owners or operators, FRS, insurance investigators, trade, installers, safety officers, site services, etc. must be consulted, as appropriate at each scene. In general, once the research project has been explained, our experience is that most people are supportive and helpful.

3.4.2.4 Physical inspection

The same data capture form that has been used for historical incident research has also been used on site investigations to capture the details of new incidents. All information has been collated in the database.

After the health and safety processes have been completed, the visit normally continues with a short survey of the whole PV system (if possible) and the areas affected by the fire. If the building owner/operator or any witnesses are on hand and they are happy to share information, a conversation is initiated to help piece together the sequence of events leading to the fire incident.

If the relevant parts of the building are deemed stable (this is usually the subject of discussion with FRS operatives/investigators and fire investigators) a detailed search of the apparent seat of the fire, as determined by burn patterns and witness reports, then ensues. This can involve sifting through debris in great detail to look for clues.

Figure 3 shows an example of a domestic roof, with a PV system fitted, destroyed by fire.

Figure 3: Example burnt-out roof with parts of the PV system intact.

Some examples of evidence and its interpretation are shown in section 4.

To date, there have been a total of 21 on-site investigations (incident references PVF0001, PVF0005, PVF0039, PVF0041, PVF0051-58, PVF0060, PVF0062, PVF0065-67, PVF0071-72 and PVF0075-76) in

- 10 dwellings,
- 4 commercial buildings,
- 2 residential homes,
- 2 leisure centres,
- 1 school,
- 1 industrial building and
- 1 ground-mounted system.

The sequence of reference numbers shows an increase in frequency of site visits over project duration, as occurrences of PV fires tend to increase in early spring, when the first very sunny days of the year occur, and tail off in late autumn. The project commenced in winter 2015, with more frequent incident in months leading up to the summers of 2016 and 2017.

3.4.3 Laboratory examinations

In cases where a component is identified as the likely cause of a fire incident, the remains may be removed from the scene (with the owner's permission) and transported to a laboratory at BRE for further forensic inspection. A typical example would be a DC isolator switch (see Figure 4), which requires disassembly in a controlled environment and close inspection of small parts in order to arrive at conclusions on the probable cause.

Figure 4: Remains of a DC isolator being disassembled and inspected in the laboratory
(Photo courtesy of Fire Investigations (UK) LLP)

The bench examinations were performed by staff from FI-UK, in their dedicated laboratories at BRE.

A typical examination involves the careful and methodical disassembly of the part under scrutiny, whilst recording any observations. The operative then uses their fire investigation experience to weigh the evidence and arrive at a conclusion on the likely cause of the damage, if possible.

In total, 7 laboratory examinations of components removed from sites have taken place: (incident references PVF0005, PVF0035, PVF0039, PVF0041, PVF0047, PVF0053 and PVF0058).

An example laboratory examination report (redacted) can be seen in Appendix C.

3.4.4 Desk investigations

On the occasions when the project team has been made aware of an incident sometime after the event, or has been unable to gain prompt site access (i.e. longer than 5-10 days), it is likely that there is less value in completing an onsite investigation, due to onsite activities disturbing, or the removal of, potential evidence. In these cases a desktop study has been completed. This research approach is limited to interviews by telephone and other desk-based activities. If useful data is acquired, it is entered directly into the database.

To date, 26 desk-based investigations have taken place: incidents: PVF0035, PVF0037, PVF0040, PVF0042-50, PVF0059, PVF0061, PVF0063-64, PVF0068-70, PVF0073-74, and PVF0077-81.

4 Mechanisms for ignition of fires on PV systems

4.1 Introduction

This research has investigated 80 potential PV related fire incidents, representing approximately 0.01% of the current number of installations installed in the UK.

Fire incidents can have a marked impact on people and property. For PV fires, where little detailed information currently exists, it is important to understand the likely mechanisms of ignition in PV systems.

4.2 Electrical Arcing

Electrical arcing is the flow of electrical energy through an air gap by way of ionised gas molecules. Whilst air is normally regarded as a non-conducting medium, a high potential difference (voltage) between two conductors in close proximity can cause the air molecules to break down into their ionised constituents (called a 'plasma'), which can then carry a charge from one electrode to the other.

The temperature of an electrical arc depends on a number of factors, such as the level of current flow, but on a typical PV system, it is easily hot enough to melt glass, copper and aluminium, and to initiate the combustion of surrounding materials.

Arcing is not seen as a common hazard in traditional AC electrical systems due to established electrical industry standards, practices, component designs and experienced workforce.

Another reason that arcing is less of an issue in AC systems is that arcs tend to self-extinguish as the voltage alternates, passing through 0 volts 100 times per second for standard grid supplies. This means that for an arc to be self-sustaining, the conditions for starting the arc have to be present continuously. DC, on the other hand, remains at a continuous voltage and, once an arc has been established, tends to support its continuation.

Thus any evidence of arcing found on sites, whilst not conclusive, points towards a possible, even probable, cause of the fire.

4.3 Evidence of arcing

Figure 5 shows a photograph of evidence of a typical arcing event affecting a DC connector, alongside a similar component that was in the same area of the fire, but without arc damage.

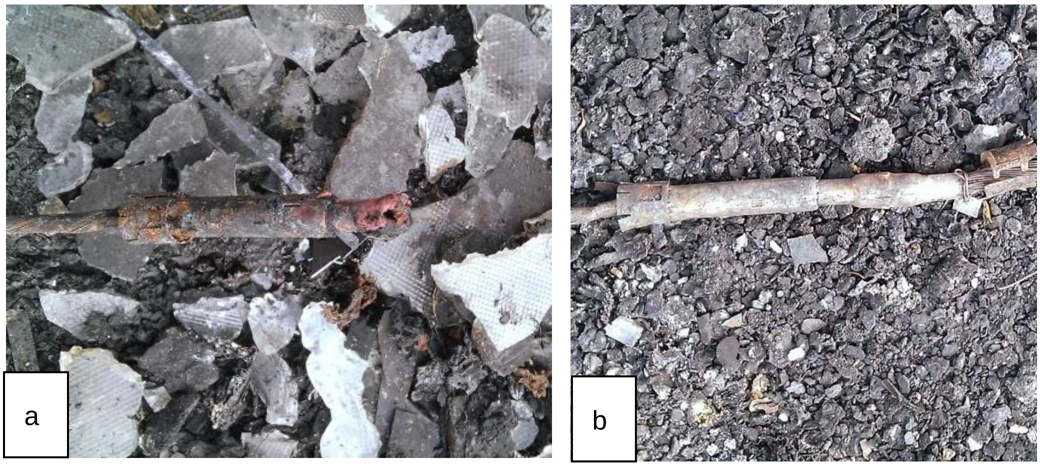


Figure 5: Remains of a DC connector ablated by arcing (a), and by contrast, a connector with contacts still intact and engaged, merely damaged by the surrounding fire (b). In both cases, the insulating body of the connector has been burnt off.

4.4 Causes of arcing

Other sources of heat, such as resistive heating in a corroded connection, could also be an ignition point for a fire, but the temperatures involved tend to be much lower than for an arc. However, such heating can still be a precursor to establishing an arc. For example, it is known that electrical contacts that are exposed to water and oxygen are likely to corrode. It is also known that the build-up of oxide layers on the contacts can lead to resistive heating which, over a period of time, is likely to cause the breakdown of surrounding materials. Once this has occurred, the loss of mechanical integrity of the component can then lead to a break in the circuit and, if conditions allow, the establishment of an arc.

Another potential cause of arcing is the existence of a simple poor connection. Thus the likely causes of arcing on a PV system may be summed up as follows:

- Moisture ingress degrading connections in connectors, junction boxes and switches
- Incorrectly crimped connector contacts
- The mating of incompatible plugs and sockets
- Plugs and sockets not fully engaged
- Loose screw terminals within junction boxes or isolator switches
- Poorly soldered joints within a PV module junction box or other junction box defect
- Damage to a component (e.g. broken busbar within a PV module).

4.5 Other potential mechanisms

Aside from arcing, resistive heating (alone) can be the cause of fires. However, the energy involved tends to be self-limiting: the higher resistance reduces the current in the circuit, which reduces the heating effect disproportionately (Heat = Current^2 x Resistance). Therefore, it is far less likely than arcing to be the only causative mechanism, but as mentioned above, can be a precursor to arcing.

Breakdown of electronic components, such as capacitors or transformers, is possible and these are thought to be likely causes of fires in inverters. However, the statistics collected do not highlight inverters as a common origin of fires.

4.6 Spread of fire

For some of the incidents investigated it was clear to see how the fire had spread from an arc or single component to other areas of the PV system and/or building. Although spread of fire was not included as a specific point to include in this research, there is anecdotal evidence which highlights the increase risk of spread of fire for components installed in loft spaces, where the roof timbers and stored items can provide an additional fire load.

One specific incident also demonstrated the spread of fire along an ‘in-roof’ mounting system, where the PV modules replace the roofing fabric.

5 Findings

5.1 Overview

A total of 80 incidents have been investigated and incorporated into the database.

The information resulting from the research on historical incidents is less complete than that gathered during active investigations, mainly because previously such incidents have not been logged in any central information store and varying levels of detail are recoverable. However, the completeness of information improves from record PVF0039 onwards as the later records are of investigations conducted by the project team (on-site, from desk or laboratory examinations).

A summarised, anonymised listing of the database records can be seen in Appendix B.

5.2 Data sources

- 33 are historical incidents[6], arising before the initiation of the project
- 21 of the recorded incidents were desk investigations
- 26 records are of on-site investigations
- 7 of the above records include laboratory examinations of components

5.3 Fire severity and PV involvement

Table 2 shows a breakdown of the types of fire by severity and the relative involvement of the PV system.

Severity of fires	PV involvement			
	Caused by PV	Involving PV but not caused by	Cause unknown	*Total*
Serious fires	22	15	1	*38*
Localised fires	27	1	5	*33*
Thermal events	9	0	0	*9*
Total	*58*	*16*	*6*	***80***

Table 2: Summary of severity of fire and PV involvement

The severity of fires (historical and contemporary) have been classified by the researching/ responding BRE fire investigator, using the following reasoning:

- *Serious fires* were difficult to extinguish and spread beyond the area of origin.
- *Localised fires* caused some damage to areas surrounding the point of origin, mainly affect PV system components, but did not spread beyond that or threaten the building.

[6] Information provided by IRS, internet searches and interviews with UK solar industry and FRS.

- *Thermal events* consist of components that over-heated, often observed to be smouldering or producing smoke, but did not develop into a fire.

5.4 Casualties

Generally, PV fires have caused damage to PV installations themselves and sometimes to the buildings on which they are mounted. To date and in the incidents reviewed for this report, a total of 12 casualties have been reported. The analysed Fire and Rescue Services statistical data does not link the presence of PV systems to fatalities from fire originating from these PV systems. Table 3 shows the number of casualties recorded from all sources of information[7].

Injuries / fatalities	Fire caused by PV	Fire not caused by PV	Cause unknown	*Total*
Injuries / psychological trauma	9[8]	1[9]	0	*10*
Fatalities	0	3[10]	0	*3*
Total	*9*	*4*	*0*	***13***

Table 3: Numbers of casualties recorded in all incidents

The injury types are broken down as shown in Table 4:

Types of injury	Number of people
Smoke inhalation (treated at scene)	6[11]
Minor burn	1[12]
Shock and anxiety	1[13]
Minor injury to knee	1[12]

[7] The confidence levels in the numbers resulting from site visits and desk studies is high. Information from the historical incidents is less complete.

[8] Information obtained by BRE as follows: 5 onsite investigations, 1 desktop investigation, 3 historical incidents (from other sources)

[9] Information obtained by BRE from other sources

[10] Information obtained by BRE as follows: 2 from 1 onsite investigation, 1 historical incidents (from other sources)

[11] Information obtained by BRE as follows: 4 onsite investigations, 2 historical incidents (from other sources)

[12] Information obtained by BRE from onsite investigation

[13] Information obtained by BRE from other sources

Electric shock	1[14]
Fatality	3
Total	*13*

Table 4: Break down of injury types (all incidents)

5.5 Building or site type

There is an even split between domestic buildings and non-domestic buildings. The latter encompasses commercial as well as public buildings (e.g. schools).

Type of building / site	
Domestic buildings	37[15]
Non-domestic buildings	37[16]
Solar farms	6[17]
Total	*80*

Table 5: Type of building / site affected by fire

Generally, non-domestic buildings are easier to investigate. In these buildings, permission to access the site tend to be quicker to obtain, there may be a knowledgeable facilities operative and/or maintenance records. Many commercial buildings accessed had flat roofs, which are easier to, access and work from than damaged pitched roofs, typical in domestic properties.

Solar farms tend to have a tightly controlled maintenance agreement with an Operation and Maintenance (O&M) company. Anecdotal evidence indicates that many solar farm incidents have occurred that have not been reported to the project, or even to the local fire services in some instances. This is because the O&M companies, usually on rapid response service level agreements, tend to deal with issues as they arise and buildings and people are often not affected.

[14] Information obtained by BRE from desktop investigation

[15] Information obtained by BRE as follows: 10 onsite investigations, 10 desktop investigation, 17 historical incidents (from other sources)

[16] Information obtained by BRE as follows: 11 onsite investigations, 14 desktop investigation, 12 historical incidents (from other sources)

[17] Information obtained by BRE as follows: 2 desktop investigation, 4 historical incidents (from other sources)

5.6 PV components implicated

Of the incidents that are either known or likely to have been caused by the PV system, fires were recorded to have originated within particular components with the following frequency:

PV Components	Probable	Possible further	*Total*
DC isolators	26	2	*30*
DC connectors	5	7	*12*
DC cables	1	4	*5*
Inverters	6	3	*9*
PV modules	2	3	*5*
DC Combiner Box	1	0	*1*
Unidentified components	4	0	*4*
Total	*45*	*19*	

Table 6: Frequency with which PV components were recorded as the likely cause of fire

All of the samples examined in the laboratory were DC isolators (in just one of these cases the source of the fire was attributed to a connector adjoining the isolator, rather than to the isolator itself). A description of how the above statistics were obtained from the evidence is given in section 5.7, below.

5.7 Root cause

Our analysis suggests there are three possible root causes for PV fires:

- an error in the system design,
- a faulty product (design or quality issue) or
- poor installation practice.

Whilst in some cases it has been possible to identify the root cause, it is not always possible to discern which of these caused a particular incident. However, the best interpretation we have from the information in the database is as follows:

Root cause	Probable	Possible further
System design issue	6	3
Faulty product	3	10
Poor installation	21	2
Unknown	28	0
N/A (fire not caused by PV)	22	0
Total	*80*	

These figures should be treated with caution until there is more data available.

6 Interpretation of scene evidence

In this report, for the sake of brevity, we do not attempt to describe how every factor and piece of evidence noted at each site or in each witness statement contributed to the interpretation of the data for each incident. However, the examples below illustrate typical evidence for the most common causes of fire attributed to PV systems.

It is suspected that where a non-specialist (e.g. building owner, site manager or FRS) has supplied the information, the terminology may not be as precise as would be used by a PV specialist. For example, 'connectors' may be referred to as 'cables'. Therefore, it is important to understand that there are inevitably uncertainties in the data caused by the variable level of PV expertise on the part of the person reporting. Where the project team has investigated on-site, this is not an issue.

6.1 DC Isolators

DC isolators were found to present the greatest fire risk within the database of incidents. Approximately 30% of the incidents recorded in this study were caused by malfunctions within this component. Often, the evidence is clear, especially where the fire is localised. An example is shown in Figure 6.

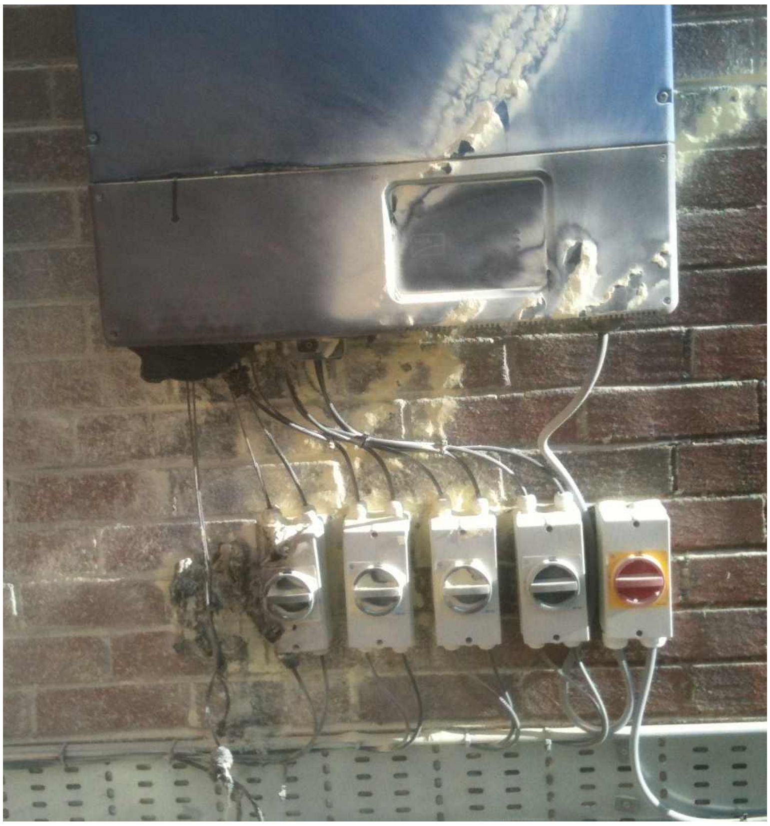


Figure 6: Localised fire in which the left hand DC isolator is completely missing, destroyed by a fire, with collateral damage to the adjacent isolator and inverter above.

In this case the evidence from the site and also the laboratory report (included in Appendix C) indicated that the isolators, which were mounted on an exposed exterior wall, were filling with water via the top-mounted cable entries. Across all the incidents reviewed, 7 incidents involved ingress of water into DC isolators, all with upward-facing cable glands.

There is also evidence of fires originating within DC isolators with poor contact design (originally being designed for AC operation and being re-designated as DC-rated by the manufacturer) and with incorrect internal wiring. An example with both of these issues is shown in Appendix D.

In 2014, prior to the start of the PV fire project, evidence of such issues submitted to BRE prompted the publication of a report on the correct selection and deployment of DC isolators on PV systems [7].

Interpreting the data, there appear to be three separate issues with DC isolators:

1) Poorly designed or constructed products - The contact design is particularly important for DC isolators. Models that were originally designed for AC are unlikely to be reliable over the life of a PV system. There is 1 possible instance of this (PVF0047), but there was also a pertinent installer error in that case, so the evidence to date is anecdotal and not yet conclusive.

2) Incorrectly specified DC isolators – there were 2 instances of this type of fault (PVF0037 and PVF0049). In both cases, the isolators were under-rated for the current or voltage of the PV strings connected.

3) Poor installation practice - 9 instances of poorly installed DC isolators were identified. This category therefore accounts for the majority of DC isolator failures leading to fires or thermal events.

   In 7, possibly 8, cases of poor installation, the result of the error was the ingress of water into the isolator casing, subsequently causing arcing. In several cases, this was caused by multiple cables being passed through a sealing gland designed to hold one cable. This issue is most acute when the gland is mounted on the upper surface of an isolator enclosure that is exposed to weather – see Figure 7.

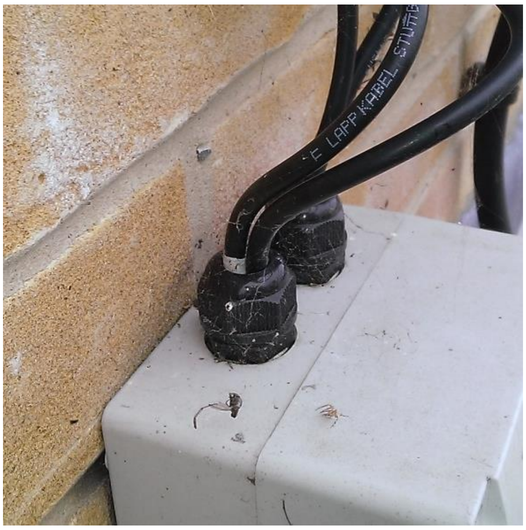


Figure 7: More than one cable passing through an upward-facing sealing gland on a DC isolator enclosure mounted on an outside wall.

Even where one cable of the correct size passes through an upward-facing, exposed gland, water may penetrate the enclosure – this was the case for at least 2 incidents – see Figure 8.

Figure 8: Water can be seen inside this enclosure, even though only one cable passes through each gland.

Another issue noted on 4 installations was the drilling of mounting holes through the back of enclosures designed to be weathertight (IP65). An example is shown in Figure 9. The hole on the top right-hand corner of the enclosure is outside of the weather seal and is designed to be used for a mounting screw without compromising the sealing. However, installers sometimes view drilling through the rear of the box as an easier option, most likely because of the types of screws they have to hand.

Figure 9: Rear of isolator enclosure drilled through for mounting screws. Note that the screw on the right hand side is rusty, indicating water ingress.

In at least 3 case, loose terminal connections were found during laboratory examination.

There were 12 instances of fires most likely caused by DC isolators for which the underlying reason is unknown. In some cases, there was more than one fault.

6.2 DC connectors and cables.

The second PV component most likely to be implicated as the cause of a fire is the DC connector: in 5 cases, the connectors were most likely the source of the fire, in a further 7 cases, they may have been the source.

The DC circuits connect the PV modules together, increasing the voltage in a similar way to connecting batteries in series. Parallel strings of PV modules increase the current. The DC circuits are fed back to the inverter, sometimes via a DC isolator. Figure 10 shows a simplified schematic diagram of the DC side of a typical small PV system. Larger systems have further parallel strings of PV modules and may also have fuses and junction boxes.

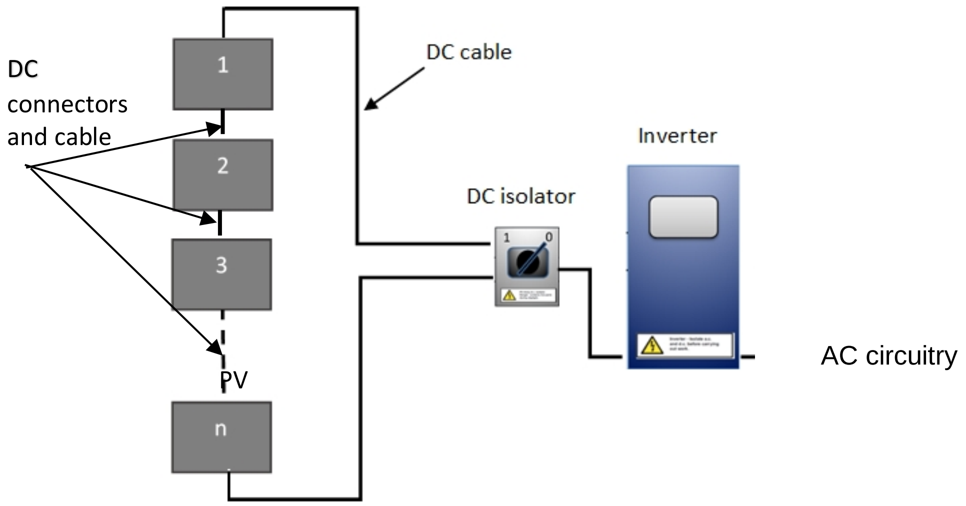


Figure 10: Simplified schematic diagram of DC components in a typical domestic PV system

As mentioned above, in some cases it is suspected that where a non-specialist (e.g. building owner, site manager or FRS) has supplied the information, the terminology may not be as precise as would be used by a PV specialist, and connectors are referred to as ‘cables’, adding some uncertainty to the number of fires where connectors or cables are thought to be responsible.

Figure 11 shows a typical ‘MC4’-type DC connector – these are almost universally used on UK PV installations at this point in time. The metal contacts are crimped onto the ends of the cable and latched into place inside the plastic barrels. Both halves of the connector are touch-proof, improving safety for installation and maintenance crews. Barbs on the upper right hand image lock into slots on the other half to prevent the connector from accidentally separating once the two halves have been pushed together.

Figure 11: Typical (undamaged) DC connectors, separated (top image) and coupled (bottom image)

If the evidence can be accessed at the fire scene, it is often clear if a DC connector has been subject to electrical arcing – molten beads of contact material can usually be observed, as shown in Figure 12.

Figure 12: Example of DC connector contact that has been subject to electrical arcing. The right hand end has been melted.

The finding of such evidence does not necessarily mean that the component caused the fire, since the arcing may have occurred as a result of the fire. However, the experience of the investigating teams has been that the metal contacts of DC connectors tend to remain connected by frictional forces, even when the supporting plastic body has been burnt off – see Figure 5. Therefore, any DC connectors that have been subject to arcing should be suspected as a likely source of ignition.

6.3 Inverters

Inverters form the most complex part of a PV system and they have to actively manage the power continuously flowing through them. From this perspective, it is surprising that a greater proportion of the incidents are not caused by inverter fires. However, unlike DC isolators and connectors, they are 'intelligent' devices, with sophisticated sensors and safety features, and this helps to prevent catastrophic malfunctions.

Nevertheless, in the database there are currently 6 incidents of fires logged as initiating in an inverter and a further 3 incidents that *may* have been caused by inverters.

As with the connectors and cables, it is suspected that where a non-specialist has supplied the information, the terminology may not be as precise as would be used by a PV specialist. In some cases, it is possible that an isolator mounted near to an inverter has ignited but been reported as an 'inverter fire'.

Where an inverter has caught fire, the burn patterns observed at the scene often make this clear – see Figure 13.

Figure 13: Inverter fire with clear burn patterns showing this as the source of the fire.

Further corroborating evidence may be that there were no isolators mounted nearby, or if there were, their conducting parts have not been subject to arcing or resistance heating, and no evidence of arcing at the inverter connectors.

6.4 PV Modules

Where PV modules are the source of fire, there may be evidence of arcing within the remains of one or more of the modules – an example can be seen in Figure 14.

Figure 14: Damaged part of a PV module junction box laid over an identical undamaged component, showing where material has been ablated through arcing.

7 Fire & Rescue Services

7.1 Awareness

In most cases that the team has investigated (desk or site investigations), direct contact has been made with the relevant FRS, which have been supportive of the project. As a result of the majority of incidents logged involving a FRS the results are skewed more towards serious incidents, which have resulted in less certainty over exact cause (due to the extent of damage to systems and components).

It has been harder to engage with solar installers, with only a small proportion of the incidents being reported by a solar/ maintenance engineer. The number of thermal events (near-misses) may be higher than suggested by this research.

7.2 Issues reported by FRS

Issues for FRSs caused by PV systems when they were tackling fires (whether or not caused by the PV system) were reported in a total of 19 incidents.

The issues recorded are as follows:

- Potential for electrocution (6 reports) and 1 actual minor electrocution
- Fear of [roof] collapse and live cables
- Unable to isolate live PV cables. Towards the end of the incident, engineers were in attendance [not clear where engineers came from]
- Fire crews could not access the loft to isolate the PV system
- Access may have been slightly more difficult [with PV system in place]
- The roof had metal tiles and fire crews were concerned that a fault in the PV panels could result in the roof becoming live
- [The Distribution Network Operator] knew very little about these systems and how to make them safe. There were lots of uncertainties which made safe systems of work for fire service unpredictable
- After PV system made safe by installer, no issues [delay implied]

We had some particular assistance from Devon and Somerset FRS, who held a formal incident de-brief following one of the fires that the team investigated. We sent two representatives to the briefing and the key messages for the project were as follows:

- Fire crews need a method of making the PV system as safe as possible on arrival at the scene. Knowing the system remains live did not prevent the tackling of the fire, but it caused a short delay whilst a dynamic risk assessment was carried out and a suitable strategy put in place.

- Once the fire had been extinguished, the fire crews attempted to make the house as safe as possible and then hand over to the owner. However, there was concern that live DC cables were still exposed in the upper floor.

8 Conclusions

8.1 This report

This report, *Fire and Solar PV Systems – Investigations and Evidence* forms the published output from WP3 and 4 (see below). This report is an updated revision of the interim Investigation and Evidence report published by BEIS in July 2017.

In the report, background information is given before describing the main work packages making up the project. The methodology is described for the reviews, communications and data collection exercises involved.

A short explanation of electrical arcing is given. This is thought to be the main mechanism of ignition in fires originating in PV systems.

The findings of the data collection exercise are then presented, with a description of the sources of data, severity of fires, numbers and types of human casualties, building types and the PV components most likely to be implicated in the initiation of the fire.

A section on the interpretation of the evidence explains how the conclusions have been arrived at and a short section on feedback from the fire services assists with an understanding of their point-of-view and the issues they face when tackling a fire involving a PV system.

8.2 Project overview

Since its inception in July 2015, the project team has conducted several strands of research on the topic of PV-related fires. We have completed and reported the following outputs:

- A literature review identifying a total of 184 relevant papers
- A review of technical standards
- A review of relevant training courses
- A review of 33 historical fire incidents involving PV systems
- The design and initial population of a database of the historical incidents
- Investigations into 47 new fire incidents involving PV systems as they occurred, incorporating the data into the database

The public description of the project can be found on the following BRE NSC web page: http://www.bre.co.uk/nsc/page.jsp?id=3676. We have communicated with the PV industry via targeted articles in the trade press and communications via the Microgeneration Certification Scheme (MCS).

Communications with the fire and rescue community has mainly been via CFOA. The intention is to feed into the National Occupational Guidance system, as suitable reports are produced.

Fire incidents tend to be seasonal, allowing the project team to produce a set of reports over the winter months and to prepare for the next 'season' of investigations into PV-related fires, most likely beginning in April.

The reviews of historical incidents, relevant literature, standards and training are complete and have been reported separately [4]. Therefore, going forward the project activity will consist of investigations into new incidents by desk studies and site visits, further reporting and dissemination activities.

8.3 Summary of findings

A total of 80 unique incidents have been investigated and incorporated into the database:

- 33 are historical incidents, arising before the initiation of the project
- 21 of the incidents were investigated remotely (“desk investigations”)
- 26 incidents were investigated on-site shortly after the incident had occurred
- 7 of the investigations include laboratory examinations of fire-damaged components

The severity of the fires varied. 22 of the incidents that were caused by PV systems were classified as ‘serious’ (i.e. difficult to extinguish and spreading beyond the PV system). 36 incidents were localised fires (affecting only PV components and the immediate area) or ‘thermal events’ (smoking or smouldering that did not develop into a fire).

In 16 incidents the cause was not thought to be the PV system and in 6 incidents, there was insufficient information to arrive at a reliable conclusion, so classified as ‘cause unknown’.

In general therefore, PV fires have caused damage to PV installations themselves and sometimes to the buildings on which they are mounted. Fortunately, injuries appear to be mostly minor to date: 6 cases of smoke inhalation (treated at scene), 1 minor burn, 1 case of shock and 1 minor knee injury.

There are 3 fatalities recorded in the database, but the fire has not been as a result of the PV system.

The building types involved break down as follows:

- Domestic buildings 37 incidents
- Non-domestic buildings 37 incidents
- Solar farms 6 incidents

However, we strongly suspect a degree of under-reporting, especially amongst solar farms and domestic thermal events that were resolved by a solar installer/ maintenance engineer.

The review of international literature conducted under this project in 2015 [4], concluded that:

Where PV systems have been the cause of fires, some themes emerge. Much attention is paid to the phenomenon of electrical arcing, where a current flows across an air gap by ionising the air. High voltage arcs are extremely hot and can cause combustion of surrounding materials in less than a second. Arcing can occur where conducting parts become physically separated by mechanical movement or mis-alignment. Also, a build-up of contaminants (e.g. oxide) on electrical contacts can cause resistive heating, resulting in the breakdown of materials and subsequent arcing.

Certain components, if incorrectly specified, poorly installed or contain manufacturing faults, are typical locations of electrical arcs:

- *DC connectors*
- *DC isolators*
- *Inverters*
- *PV modules, including by-pass diodes and junction boxes*

The experience of investigating 47 recent incidents in the UK has resulted in very similar findings. The analysis of our database of incidents shows that the PV components most likely to develop faults that lead to a fire incident are as follows:

- DC isolators 26 - 28 incidents
- DC connectors 5 - 12 incidents
- Inverters 6 - 9 incidents
- DC cables 1 - 5 incidents
- PV modules 2 - 5 incidents
- DC combiner box 1 incident

In 4 cases, the origin of the fire was not traced to any particular component.

Approximately 36% of incidents recorded that were caused by PV systems were attributed to poor installation practices. 5% were attributed to faulty products and 10% to system design errors. The causes of the remainder were unknown.

A summarised, anonymised listing of the database records can be seen in Appendix B.

There are anecdotal reports of power diverters presenting new fire and safety risks. These devices divert excess electricity generated by solar panels to a specific load, such as an immersion heater. However, within this project, we have yet to encounter a fire that appears to have been caused by one of these devices, so the results so far do not support this assertion.

8.4 Challenges

Once the team has been made aware of a live or recent incident, an assessment is made as to whether the site should be visited, based upon the apparent involvement of the PV system. In cases where a site visit is indicated, the next step is to gain permission at access the site. This can be problematic as the owner of the building may not be identified - the FRS cannot pass on contact details without permission. In some cases, this can cause a delay of days or even weeks before we can speak with the owner and seek permission to visit. However, as the project progressed, the FRS generally obtained permission on site and passed on contact details in a timely manner, allowing us to complete more on site investigations.

A second challenge can be discovering who is investigating the scene on behalf of the building owner's insurance company. In each case we make efforts to determine the identity of the relevant fire investigator in order to coordinate the site visit, support each other's investigation and, ideally, to share resulting information. Our project colleagues at Fire Investigations UK have excellent contacts and relationships with all of the main forensic investigation companies, so this is of great assistance. However, the team has been denied access to one site by the insurance company's loss adjuster, so careful handling of this situation is called for.

Responding to incidents with little notice can be a challenge. Both personal and professional plans may need to be changed. However, the team accepts this as part of the project requirements and we can normally respond within 24 hours.

The database in its current form is rather rudimentary, making it time consuming to extract data and perform analysis. Some relatively minor upgrades to the functionality of the database would allow more efficient processing and analysis of incident characteristics. We have recently introduced an anonymising print-out function that is useful for reporting.

References

[1] IET, “Code of Practice for Grid Connected Solar Photovoltaic Systems,” IET Standards, London, 2015.

[2] Microgeneration Certification Scheme, “Guide to the installation of photovoltaic systems,” Electrical Contractor's Association, London, 2012.

[3] “National Operational Guidance Programme,” London Fire Brigade, [Online]. Available: http://www.ukfrs.com/. [Accessed 02 02 2017].

[4] S. Pester and S. Woodman, “Fire and Solar PV Systems. Literature Review, Standards and Training,” BRE National Solar Centre, Watford, 2017.

[5] S. Pester and C. Coonick, “Fire and Solar PV Systems. Recommendations for the PV industry,” BRE National Solar Centre, Watford, 2017.

[6] S. Pester, C. Holland and C. Coonick, “Fire and Solar PV Systems. Recommendations for fire and rescue services,” BRE National Solar Centre, Watford, 2017.

[7] S. Pester, “DC isolators for photovoltaic systems - a good practice guide,” IHS BRE Press, Bracknell, 2014.

[8] S. Pester, “Fire and Solar PV Systems. Investigations and evidence,” BRE National Solar Centre, Watford, 2017.

Appendix A Database description

Database fields

The database consists of a set of some 73 fields per record. Each record pertains to one incident and is given a unique reference number, of the form PVFxxxx, where xxxx is a serial number.

The field headings for each incident record are as follows:

Site Owner / occupier
Address
How did you become aware of this incident?
Date of incident
Time of incident (hh:mm)
Thought to be caused by PV, or PV just present?
Type of installation (Domestic/Non-domestic/Solar farm)
Was the local FRS called?
If no, how was the fire dealt with?
Severity of incident
Type of building
No. of storeys
Type of construction (if known)
Type of roof
If Other, please specify
Age of property
Location of PV array
Location of inverter
Location of isolation switches
General conditions
Wind speed
Wind direction
Precipitation (mm rain)
Irradiance (if known)
Was the property occupied at the time of the fire?
No. of evacuations (if any)
How were the occupants alerted to the fire?
Nature, extent and number of any injuries as a result of the fire?
Extent of fire spread/damage
Any issues with building performance (e.g. collapse, issues with compartmentation, etc.)
Provisional or recorded cause of fire
If PV system, components thought to be involved
Evidence to support likely cause
Any other comments on cause
Date system commissioned
Records of any maintenance (When and type of maintenance)

Is this a BIPV (built-in PV) system
Any comments on DC connectors and cabling (e.g. condition, damage away from fire)

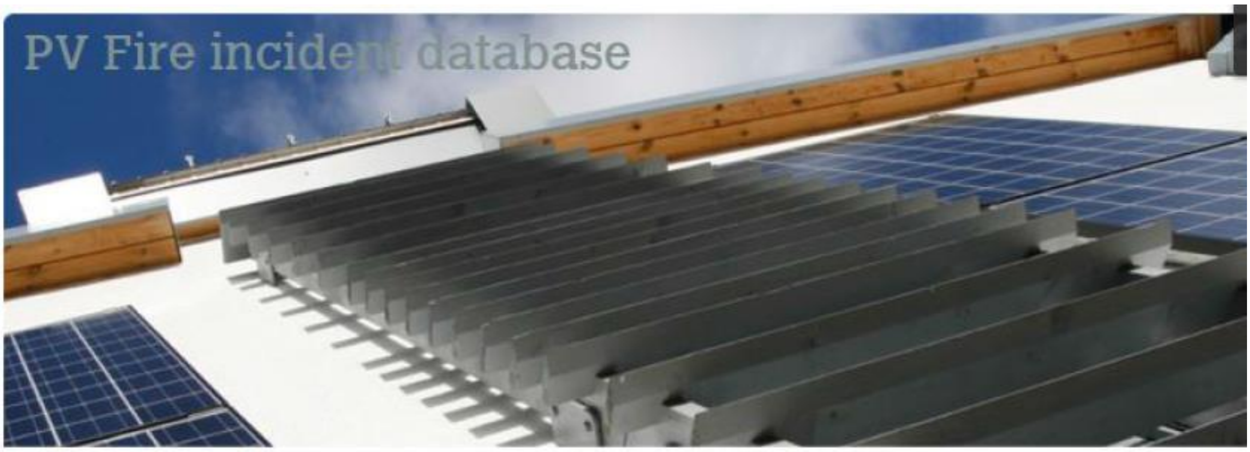
System components	Make	Model
Modules		
Mounting		
Inverter(s)		
DC isolator		
Remote DC switches		
DC connectors		
DC Cable		
DC overcurrent protective devices		
AC cable		
AC protective devices		
Surge protection		
Other		

Type of fire alarm system installed (if any)
Detector fitted specifically for PV system?
If yes, please select type of detector installed
Was the detector linked to the main alarm system?
Location of detector for PV system
Any other active fire protection systems installed (e.g. suppression systems)
If yes, please provide details of other fire protection systems
Remote DC switching device involved
Arc fault detection involved
Earth fault (insulation fault) alarm involved
Did any of the systems mentioned in this section operate?
If yes, please specify
Was there a Solar PV on roof label in place near the main consumer unit/distribution board?
Were the crews aware of the presence of the PV system on arrival?
Did crews notice a Solar PV on roof label near the main electrical intake?
If yes, did this change tactics for fighting the fire?
If yes, how were the tactics changed?
Did crews take any action(s) to make the PV system safe?
If yes, please specify:
Did the PV system cause any particular hazards for fire crews?
If yes, please specify:
Does your service have a Standard Operating Procedure or use any other guidance for dealing with fires involving PVs?
Did the presence of the PV system exacerbate the fire in any way?

Appendix B shows an anonymised summary of the current data set.

User interface

The first screen encountered when entering the portal is the listing. This shows a summary of all database records in short form. The screen shot below shows the listing page with sensitive data redacted.



List of reports

Logout

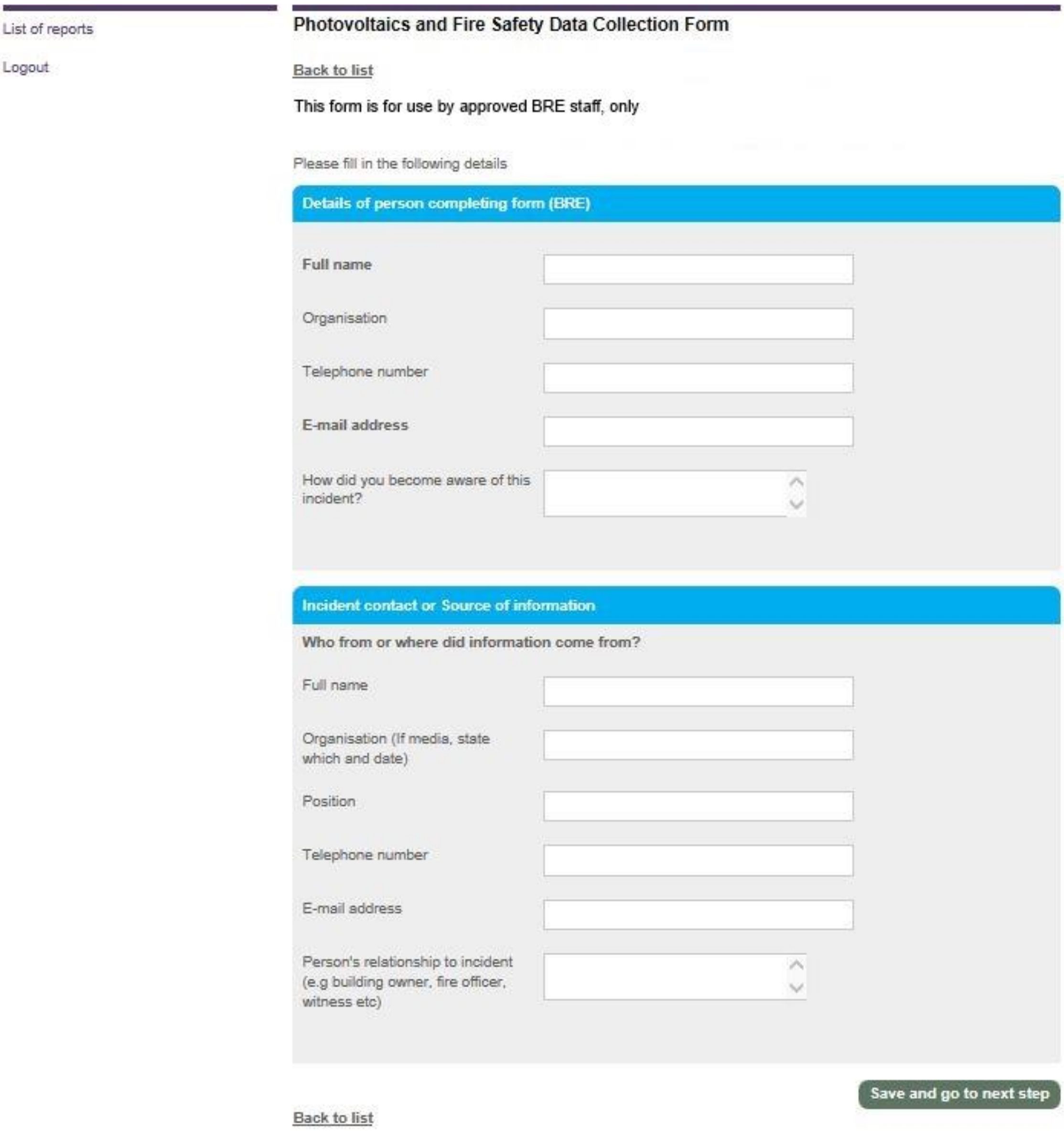
Fire reports on Solar panels

Full name	ID	Organisation	Email address	Phone number	Date of incident	Address of incident	
Steve Pester	PVF0041	BRE National Solar Centre	steve.pester@bre.co.uk	01923 664 729	[redacted]		view
Steve Pester	PVF0040	BRE-NSC	steve.pester@bre.co.uk	01923 664 729			view
Steve Pester	PVF0039	BRE-NSC	steve.pester@bre.co.uk	01923 664 729			view
Steve Pester	PVF0038	BRE National Solar Centre	steve.pester@bre.co.uk	01923664729			view
Chris Coonick	PVF0037	BRE	coonickc@bre.co.uk	07890256131			view

Each record is automatically assigned the unique identifier ("ID" column). The 'view' link on the right hand side provides access to the full record for each incident.

After the listing page, the user can opt to enter a new record, the first page of which is shown in the next screen shot:

Page 1:


List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Back to list

This form is for use by approved BRE staff, only

Please fill in the following details

Details of person completing form (BRE)

Full name

Organisation

Telephone number

E-mail address

How did you become aware of this incident?

Incident contact or Source of information

Who from or where did information come from?

Full name

Organisation (If media, state which and date)

Position

Telephone number

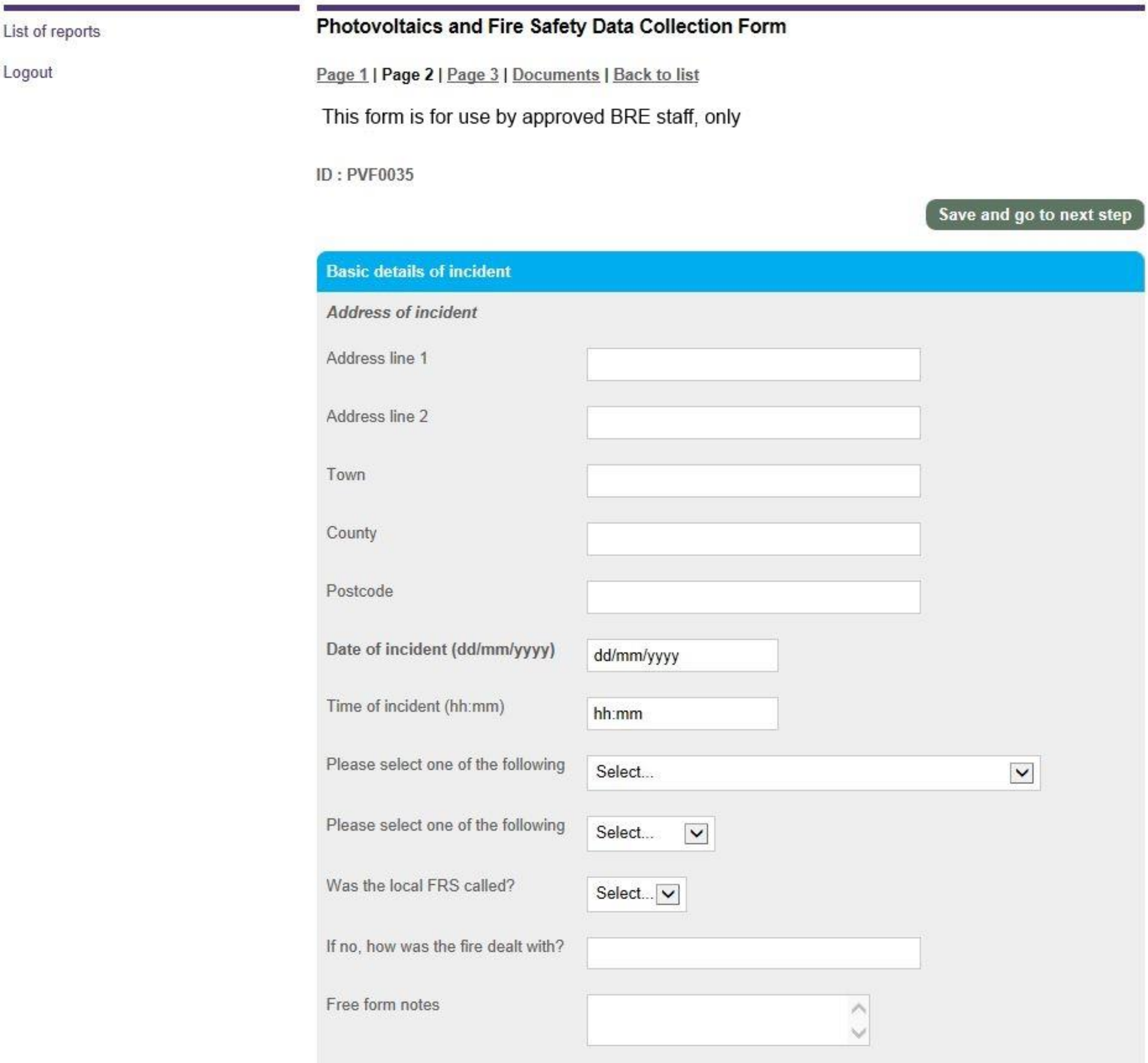
E-mail address

Person's relationship to incident (e.g building owner, fire officer, witness etc)

Save and go to next step

Back to list

The remaining incident data is input on pages 2 and 3, as shown in the following screen shots:



List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Page 1 | **Page 2** | Page 3 | Documents | Back to list

This form is for use by approved BRE staff, only

ID : PVF0035

Save and go to next step

Basic details of incident

Address of incident

Address line 1

Address line 2

Town

County

Postcode

Date of incident (dd/mm/yyyy) dd/mm/yyyy

Time of incident (hh:mm) hh:mm

Please select one of the following Select...

Please select one of the following Select...

Was the local FRS called? Select...

If no, how was the fire dealt with?

Free form notes

Fire and Rescue Service intervention

FRS in attendance (Name of Fire and Rescue Service)	
FRS Incident No. (if known)	

Details of Officer in Charge of incident (either during the incident or lead fire investigator)

Full name	
Role in relation to the incident	

Detailed information on the incident

Type of incident (please select)	Select...

Building description (where a building is involved)

Type of building	Select...
No. of storeys	0
Height of building	Select...
Type of construction (if known)	Select...
Type of roof	Select...
If Other, please specify	
Age of property	
Location of PV array	
Location of inverter	
Location of isolation switches	

Weather at time of incident

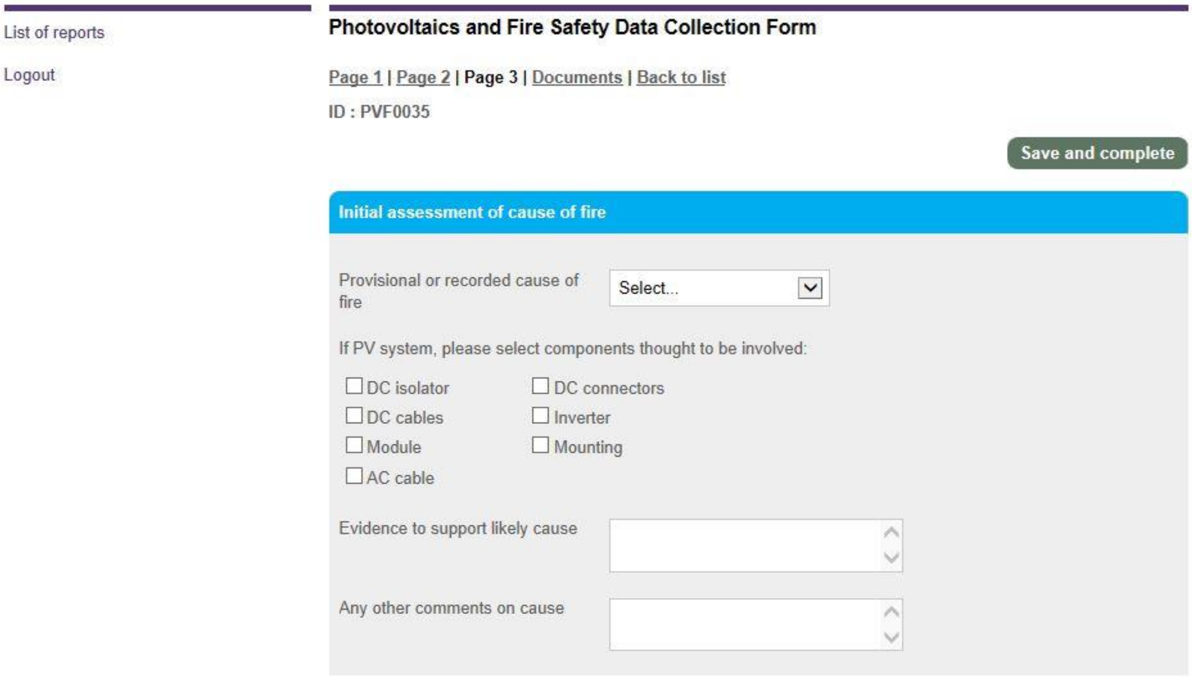
General conditions		
Wind speed	0.0	m/s
Wind direction		
Precipitation	0.0	mm rain
Irradiance (if known)	0.0	W/m²

Description of the fire

Was the property occupied at the time of the fire?	Select...
No. of evacuations (if any)	
How were the occupants alerted to the fire?	
Nature, extent and number of any injuries as a result of the fire?	
Extent of fire spread/damage	
Any issues with building performance (e.g. collapse, issues with compartmentation, etc.)	

Save and go to next step

Page 1 | **Page 2** | Page 3 | Documents | Back to list



List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Page 1 | Page 2 | **Page 3** | Documents | Back to list

ID : PVF0035

Save and complete

Initial assessment of cause of fire

Provisional or recorded cause of fire: Select...

If PV system, please select components thought to be involved:

- ☐ DC isolator
- ☐ DC connectors
- ☐ DC cables
- ☐ Inverter
- ☐ Module
- ☐ Mounting
- ☐ AC cable

Evidence to support likely cause

Any other comments on cause

System description

Date system commissioned (dd/mm/yyyy)	dd/mm/yyyy
System installer	
Records of any maintenance (When and type of maintenance)	
Is this a BIPV (built-in PV) system	Select...
Any comments on DC connectors and cabling (e.g. condition, damage away from fire)	

System components	Make	Model
Modules		
Mounting		
Inverter(s)		
DC isolator		
Remote DC switches		
DC connectors		
DC Cable		
DC overcurrent protective devices		
AC cable		
AC protective devices		
Surge protection		
Other		

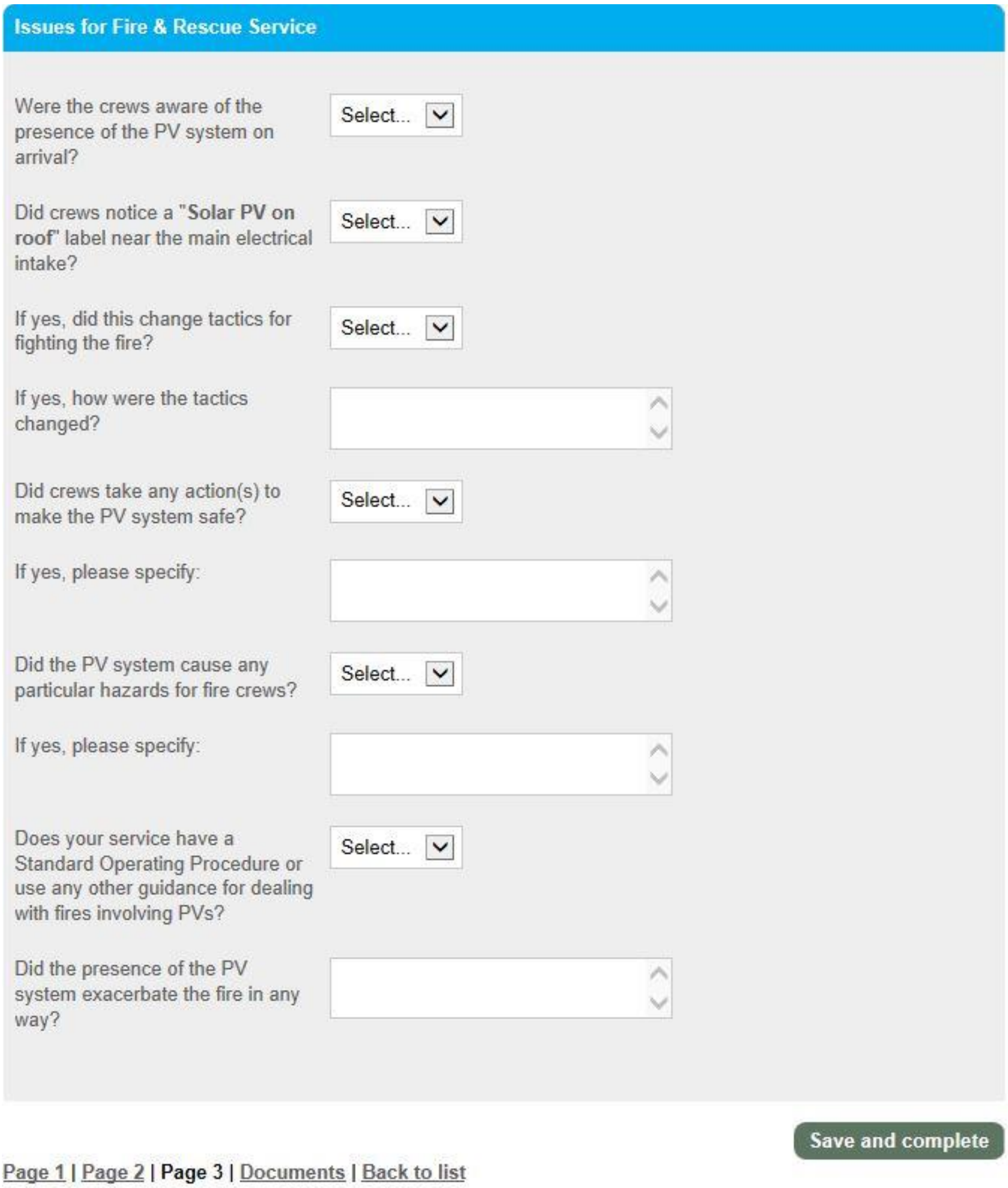
Fire protection equipment

Type of fire alarm system installed (if any)	
Detector fitted specifically for PV system? -1	Select...
If yes, please select type of detector installed	Select...
Was the detector linked to the main alarm system?	Select...
Location of detector for PV system	
Any other active fire protection systems installed (e.g. suppression systems)	Select...
If yes, please provide details of other fire protection systems	

Were any of the following installed (please tick all that apply):

- ☐ Remote DC switching device
- ☐ Arc fault detection
- ☐ Earth fault (insulation fault) alarm

Did any of the systems mentioned in this section operate?	Select...
If yes, please specify:	
Did the fire protection systems installed operate as expected/designed?	Select...
If no, please specify why:	
Was there a "**Solar PV on roof**" label in place near the main consumer unit/distribution board?	Select...



Issues for Fire & Rescue Service

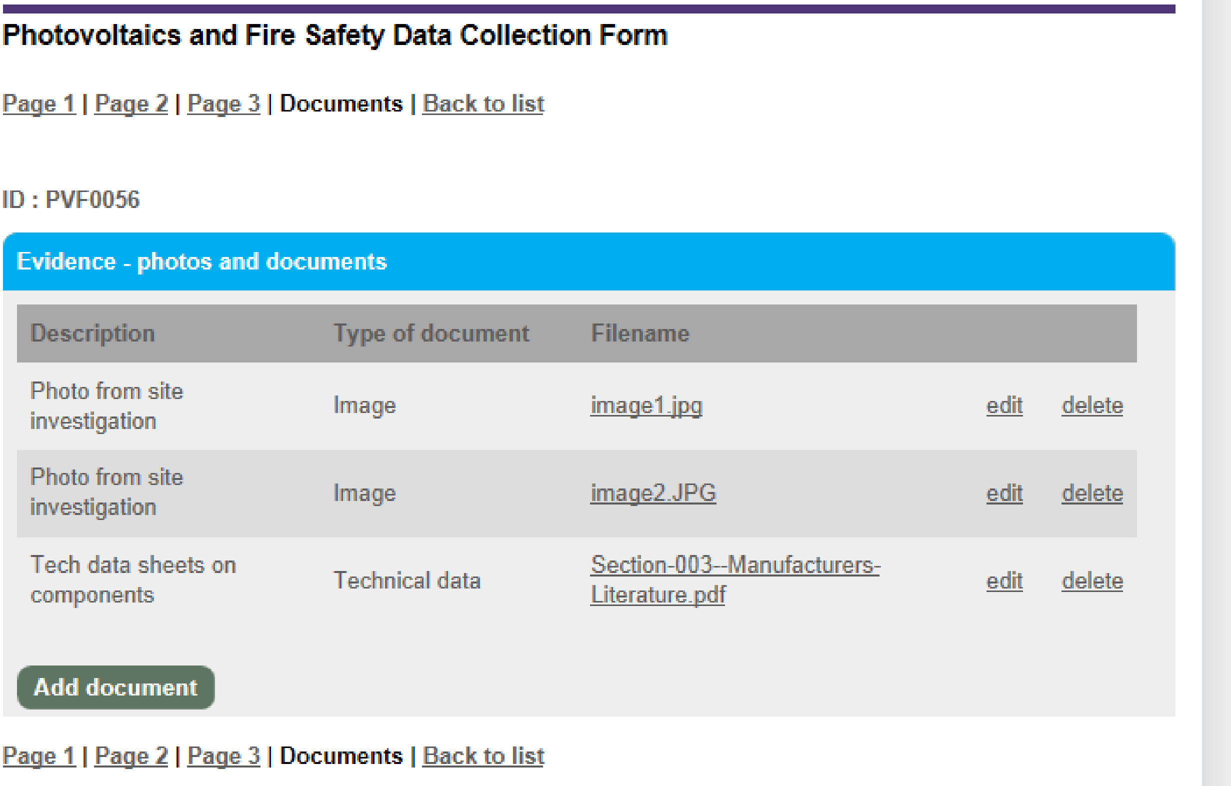
Were the crews aware of the presence of the PV system on arrival?	Select...
Did crews notice a "**Solar PV on roof**" label near the main electrical intake?	Select...
If yes, did this change tactics for fighting the fire?	Select...
If yes, how were the tactics changed?	
Did crews take any action(s) to make the PV system safe?	Select...
If yes, please specify:	
Did the PV system cause any particular hazards for fire crews?	Select...
If yes, please specify:	
Does your service have a Standard Operating Procedure or use any other guidance for dealing with fires involving PVs?	Select...
Did the presence of the PV system exacerbate the fire in any way?	

Save and complete

Page 1 | Page 2 | **Page 3** | Documents | Back to list

After this final screen of input data, the user may also attach related documents, e.g. reports, photographs, witness statements, etc.

The screen for attaching documents is shown in the next screen shot with example documents loaded.



Photovoltaics and Fire Safety Data Collection Form

Page 1 | Page 2 | Page 3 | **Documents** | Back to list

ID : PVF0056

Evidence - photos and documents

Description	Type of document	Filename		
Photo from site investigation	Image	image1.jpg	edit	delete
Photo from site investigation	Image	image2.JPG	edit	delete
Tech data sheets on components	Technical data	Section-003--Manufacturers-Literature.pdf	edit	delete

Add document

Page 1 | Page 2 | Page 3 | **Documents** | Back to list

Please note that in some cases not all of the database fields can be populated since the information is not always available. However, the team attempts to gather as much information on each incident as possible.

Appendix B Summary listing of records (anonymised)

Incident Ref	Site Visit	Desk Study	Lab bench exam	Incident cause attributed to PV system?	Site Type	Severity	If PV system, components thought to be involved	Most likely root cause
PVF0001	Y			Y	Commercial	Serious	DC connectors, Module, Mounting	Faulty product
PVF0002				Y	Domestic	Localised	Unknown	Unknown
PVF0003				Y	School	Localised	DC isolator	Poor installation
PVF0004				N	Domestic	Serious	N/A	N/A
PVF0005	Y		Y	Y	Domestic	Thermal event	DC isolator	Poor installation
PVF0006				Y	Commercial	Thermal event	DC isolator	Unknown
PVF0007				Y	Domestic	Serious	DC isolator	Unknown
PVF0008				Y	Domestic	Serious	Unknown	Unknown
PVF0009				Y	Commercial	Thermal event	DC isolator, Inverter	Unknown
PVF0010				Y	Domestic	Thermal event	Unknown	Unknown
PVF0011				N	Domestic	Serious	N/A	N/A
PVF0012				N	Domestic	Serious	N/A	N/A
PVF0013				Y	Commercial	Localised	DC isolator	Unknown
PVF0014				N	Domestic	Serious	N/A	N/A
PVF0015				N	School	Serious	N/A	N/A
PVF0016				N	Commercial	Serious	N/A	N/A
PVF0017				Unknown	Domestic	Localised	Unknown	Unknown
PVF0018				Y	Solar farm	Localised	Unknown	Unknown
PVF0019				Y	School	Serious	Unknown	Unknown
PVF0020				Unknown	Solar farm	Localised	Unknown	Unknown
PVF0021				Y	Domestic	Serious	DC isolator	Unknown
PVF0022				Unknown	Domestic	Serious	Inverter	Unknown
PVF0023				Y	Domestic	Serious	Unknown	Unknown
PVF0024				Unknown	Commercial	Localised	Unknown	Unknown
PVF0025				N	Domestic	Serious	N/A	N/A
PVF0026				N	School	Serious	N/A	N/A
PVF0027				N	Domestic	Serious	N/A	N/A
PVF0028				Y	School	Localised	DC cables	Unknown

PVF0029 Record deleted								
PVF0030				Y	Solar farm	Localised	Inverter	Unknown
PVF0031				Y	Solar farm	Localised	Inverter	Faulty product
PVF0032				Y	Domestic	Serious	Inverter	Unknown
PVF0033				Unknown	Commercial	Localised	Unknown	Unknown
PVF0034				Unknown	Domestic	Localised	Unknown	Unknown
PVF0035		Y	Y	Y	Commercial	Thermal event	DC isolator	Poor installation
PVF0036				Y	Domestic	Serious	DC isolator	Unknown
PVF0037		Y		Y	Commercial	Localised	DC isolator	System design issue
PVF0038				Y	School	Serious	DC connectors, Mounting	Unknown
PVF0039	Y		Y	Y	Commercial	Localised	DC isolator	Poor installation
PVF0040		Y		Y	Commercial	Localised	Unknown	Unknown
PVF0041	Y		Y	Y	Commercial	Localised	DC isolator	Poor installation
PVF0042		Y		Y	Hospital	Localised	DC connectors, DC cables	Poor installation
PVF0043		Y		N	School	Serious	N/A	N/A
PVF0044		Y		Y	Domestic	Serious	DC connectors, Inverter	Unknown
PVF0045		Y		Y	School	Localised	DC isolator	Unknown
PVF0046		Y		Y	Domestic	Thermal event	Module	Faulty product
PVF0047		Y	Y	Y	Domestic	Thermal event	DC isolator	Faulty product
PVF0048		Y		Y	Commercial	Thermal event	DC connectors	Poor installation
PVF0049		Y		Y	Commercial	Localised	DC isolator	System design issue
PVF0050		Y		Y	Solar farm	Thermal event	DC connectors	Poor installation
PVF0051	Y			Y	Domestic	Serious	DC isolator	Unknown
PVF0052	Y			Y	Domestic	Serious	Inverter	Faulty product
PVF0053	Y		Y	Y	Commercial	Localised	DC isolator, DC connectors	Poor installation
PVF0054	Y			Y	Domestic	Serious	DC connectors	Poor installation
PVF0055	Y			Y	Domestic	Serious	DC connectors, DC cables	Poor installation
PVF0056	Y			Y	Commercial	Serious	DC connectors	Poor installation
PVF0057	Y			Y	Domestic	Serious	DC connectors, DC cables	Unknown
PVF0058	Y		Y	Y	School	Localised	DC isolator	Poor installation
PVF0059		Y		Y	Domestic	Serious	Inverter	Unknown

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PVF0060	Y			N	Domestic	Localised	N/A	N/A
PVF0061		Y		Y	Domestic	Serious	DC isolator, AC isolator, inverter	Unknown
PVF0062	Y			N	Residential home	Serious	N/A	N/A
PVF0063		Y		Y	Solar farm	Localised	DC combiner box	Poor installation
PVF0064		Y		Y	Domestic	Serious	Unknown	Unknown
PVF0065	Y			Y	Domestic	Serious	DC isolator, DC connectors	Unknown
PVF0066	Y			Y	Domestic	Serious	DC connectors, Module, Mounting	Unknown
PVF0067	Y			N	Domestic	Serious	N/A	N/A
PVF0068		Y		Y	Industrial	Localised	Module	System design issue, faulty product
PVF0069		Y		Y	School	Localised	DC isolator	N/A
PVF0070		Y		N	Domestic	Serious	N/A	N/A
PVF0071	Y			Y	Leisure centre	Localised	DC isolator	Poor installation, faulty product
PVF0072	Y			Y	Leisure centre	Localised	DC isolator	Poor installation, faulty product
PVF0073		Y		Y	School	Localised	DC isolator	Poor installation, faulty product
PVF0074		Y		Y	Residential home	Localised	DC isolator	Poor installation, faulty product
PVF0075	Y			Y	Residential home	Localised	DC isolator	Poor installation, faulty product
PVF0076	Y			N	Industrial	Serious	N/A	N/A
PVF0077		Y		Y	Domestic	Serious	DC isolator, inverter	System design issue, poor installation
PVF0078		Y		Y	Commercial	Localised	DC isolator	Poor installation, faulty product
PVF0079		Y		Y	Commercial	Localised	DC isolator, DC cable	Poor installation, system design issue
PVF0080		Y		N	Domestic	Serious	N/A	N/A
PVF0081		Y		Y	Domestic	Thermal event	DC isolator	Poor installation, faulty product

Appendix C Laboratory examination report - example 1

CASE No: [redacted]-BRE Solar Project
BRE Ref:

Scene Examination Report

1. Synopsis

1.1. **FIUK Case No.** [redacted] BRE Solar Project - [redacted] – Laboratory Examination.

1.2. **Address of fire:** [redacted].

1.3. **Date and time of incident:** 10 February 20[redacted] at 10:54.

1.4. **Date and time investigation commenced:** 1 March 20[redacted] at 09:00.

1.5. **Fire Investigator:** [redacted].

1.6. **Client:** [redacted] BRE Solar.

1.7. **Reason for instruction:** To determine the origin and cause of a fire involving a photovoltaic installation. This report should be read in conjunction with the scene examination report.

1.8. **Equipment description:** the equipment subjected to forensic examination consisted of three DC isolators identified as RHB 1, RHB 2 (collected from the premises of the PV system installers and labelled as exhibit [redacted]) and LHB 1 (collected from the fire scene and labelled as exhibit [redacted]). A third exhibit (collected from the fire scene and labelled as [redacted]) consisted of DC isolator remains found on the ground below the original positions of DC isolators RHB 1 and RHB 2.

1.9. **Summary:** This report determines that the damage to the DC isolators examined is consistent with abnormal electrical activity occurring within the DC isolator enclosures generating sufficient heat energy to cause ignition of adjacent materials.

1.10. **Photographs:** Those photographs mentioned in the text of this report are enclosed in this report. Photographs were taken using a Pentax WGIII digital camera.

2. Sequence of events

2.1. On the 10 February 2016 at approximately 10:50, a delivery lorry was driving along the road outside the [redacted] site, toward the entrance, when the driver noted a fire on the outside wall of the [redacted]. The driver alerted members of the public who were outside the entrance to the [redacted] to the situation. The members of the public then notified a [redacted] staff member.

2.2. The staff member attended the scene with Carbon Dioxide and Dry Powder fire extinguishers that were used to extinguish the fire. Other members of [redacted] staff also attended the scene and the [redacted] Fire and Rescue Service [redacted]) were called.

1

2.3. The [redacted] arrived at the scene at 11:16 and as the fire had been extinguished they carried out checks using a thermal imaging camera (TIC), established a cordon around the scene and turned all the isolators to the 'OFF' position. They also sent a message to their mobilising control reporting that the fire was due to "water ingress at the inverter isolation points".

2.4. The [redacted] staff contacted the installers of the system, [redacted], who attended the scene later that afternoon and removed the affected DC isolators, the inverter located above and they also cut and taped a number of DC conductors that had been attached to the affected isolators.

2.5. Following a visit to the installers, [redacted], and a scene examination at [redacted], a number of exhibits (detailed above) were retained for a laboratory forensic examination.

3. Laboratory examination

3.1. **Exhibit [redacted]**

3.2. This exhibit packaging contained the remains of DC isolators RHB 1 and RHB 2.

3.3. The remains of RHB 1 consisted of a small section of a light coloured plastic, identified as the rear of the enclosure, with a mounting screw. This particular exhibit was unremarkable.

3.4. An examination was carried out of RHB 2. This DC isolator had been located to the immediate right of RHB 1. The enclosure had sustained fire damage and melting of the plastic to the left hand side and top sections. The pattern of fire damage to RHB 2 was consistent with fire spread from RHB 1 (see Figures 1 & 2).

3.5. **Exhibit [redacted]**

3.6. This exhibit consisted of debris collected from the ground below the original location of DC isolators RHB 1 and RHB 2 (see Photograph 3). Within this debris, amongst the sections of burnt and melted plastic, were metal screw terminals. It was determined that these had most probably been originally associated with DC isolator RHB 1 as the enclosure of RHB 2 had retained much of its integrity.

3.7. The screw terminal remains examined exhibited metallic deposits in the area of the terminal screw. This is indicative of abnormal electrical activity (see Figure 4).

3.8. The remains of a further metallic component, possibly a terminal connection, were noted to be heavily oxidised. However consideration must be given to the fact that this item had remained exposed to the elements prior to collection (see Figure 5).

3.9. Other items examined from this debris included short lengths of DC conductor. One of the short lengths of conductor displayed evidence of arcing.

3.10. **Exhibit [redacted]/3**

3.11. This exhibit consisted of the fire damaged DC isolator that was responsible for the third fire event identified during the scene examination.

2

3.12. Once opened the internal surfaces of the enclosure were found severely contaminated with the products of combustion. The internal switching unit was removed for examination (see Figures 6 & 7).

3.13. The 'jumper links' were fitted to the top connections of L1 and L2 and of L3 and N. These connections were found tight and relatively undamaged (see Figure 8).

3.14. The lower connections were identified as T1 (positive out), T2 (positive in), T3 (negative in) and N (negative out).

3.15. The cables from the array feeding the DC isolator had entered from the bottom glands with the feed out exiting from the top to connect to the inverter.

3.16. Examination of the damage to the external switching unit revealed the greatest damage, causing melting and burning to the plastic, in the vicinity of T2 and T3, the permanently live conductors (see Figures 9 & 10).

4. Conclusion

4.1. Based on the findings of the scene examination carried out at [redacted] and the forensic laboratory examination of the exhibits, I am of the opinion that the three fire events, affecting the PV installation, were as a result of water ingress into the enclosure of the DC isolators.

4.2 Once the water has entered the enclosure a conductive path was established between the positive and negative conductor terminals causing arcing and generating heat. The heat would have degraded the plastic materials adjacent to the arcing event, which have subsequently ignited.

Report prepared by:

[redacted]
Fire Investigations (UK) LLP

[redacted]

3

 Figure 1	 Figure 2
 Figure 3	 Figure 4
 Figure 5	 Figure 6
 Figure 7	 Figure 8

4


Figure 9


Figure 10

5

Appendix D Laboratory examination report - example 2

CASE [redacted]

Bench Top Examination Report

1. Synopsis

1.1. **Address of fire:** [redacted].

1.2. **Date and time of call:** [redacted] shortly before 09:00.

1.3. **Date and time investigation commenced:** [redacted]

1.4. **Fire Investigator:** [redacted]

1.5. **Information from the fire & rescue service:** [redacted] FRS attended (three appliances). No further details have currently been provided.

2. PV Installation

2.1. The array was installed on [redacted] [redacted] 2011, by [redacted] MCS Installer Certificate Ref: [redacted]. The array had a declared capacity of 3.42 kW comprising 18 [redacted] 190W [redacted] modules and a [redacted] Invertor. System details provided with my instructions show that the array was arranged with two strings, each containing nine modules.

2.2. Photographs provided with my instructions show that the [redacted] Invertor, AC Isolator, two DC Isolators and the Generation Meter were all mounted within a metal electrical cabinet that was attached to the exterior of the property (see Figures 1 and 2). The DC cables were routed on the exterior of the property within protective conduit (this appears to be metal but cannot confirmed).

2.3. Photographs taken of the fire damaged installation show localised fire damage to one of the two DC Isolators, mounted in the bottom left hand corner of the cabinet. Both DC Isolators have been submitted for examination.

3. Key observations

3.1. The DC isolators were identified as the [redacted] Enclosed DC rated switch disconnector manufactured by [redacted]. The two DC isolators are both rated at 16 Amps and 500 Volts DC (Model [redacted]) (see Figures 3 and 4). The switching mechanism is a 4-pole isolator that utilises a contact bridge mechanism. The isolator was originally manufactured for use in AC systems (identified by the terminal labelling designations namely L1, L2, L3 & N), however, it has been rated and certified for use in DC systems by the manufacturer [redacted] by pairing the switching contacts.

3.2. The array fitted was 18 [redacted] 190W modules arranged into two strings. Information with my instructions details that the modules had a rated output of $V_{oc\,(STC)}$ 45.6 Volts and an $I_{sc\,(STC)}$ 5.8 Amps.

1

Therefore, the maximum voltage and current generation can be calculated using the following formulas:

PV String Switch Disconnector – Current Rating:

String Short-Circuit Current x 1.25

5.8 x 1.25 = **7.25 Amps**

PV String Switch Disconnector – Voltage Rating:

String Open-Circuit Voltage x 1.15

(9 x 45.6) x 1.15 = **472 Volts**

The [redacted] DC Isolator was operating within its design specification (16 Amps and 500 Volts).

3.3. The DC isolators had been installed within the electrical cabinet using the intended fixing points which did not compromise the weather proof rating of the switch enclosure.

3.4. The four DC cables (4mm^2 core diameter) were routed through a single M25x1.15 gland, secured to the top of the isolator enclosure (see Figure 5).

3.5. Within the enclosure 3-poles from the switch mechanism had been wired in series using two insulated link cables. The isolator had been wired so that 3-poles were used to switch the positive and 1-pole was used to switch the negative (see Figure 6). Both the fire damaged isolator (exhibit [redacted]) and the exemplar (exhibit [redacted]) were wired identically in terms of terminal configuration and gland position.

3.6. The fire damaged isolator enclosure (exhibit [redacted]) showed localised damage to the top right-hand corner, affecting the top, right-hand side and rear of the enclosure. The front of the enclosure was mostly undamaged. The four DC cables had been severed by electrical arcing activity within the enclosure. The switch mechanism showed the greatest fire damage to the bottom right-hand corner (highlighted in pink on Image 1).

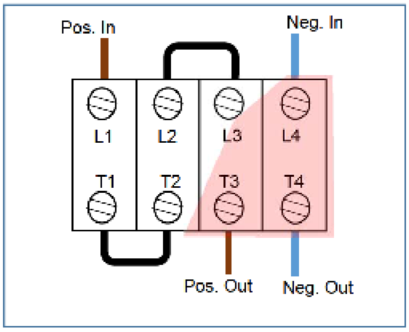

Image 1: Schematic showing the configuration and terminal designation of the switch mechanism inside the DC Isolator.

2

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3.7. The head of the screw terminal L4 showed metallic deposits where it had melted from erroneous electrical arcing activity that had occurred between the L3 link cable and L4 cable (see Figure 7). The terminal clamp from L4 was less damaged and showed that there had been no excess heat generated at the point of connection; there was extensive melting to the L4 terminal switch contact (see Figure 8). The contact bridge from poles three and four had not been recovered or had been destroyed due to electrical arcing activity inside the switch mechanism. There was evidence of further melting and erroneous electrical activity to terminal T4, again the damage was far more extensive to the switching contact rather the connection between the cable and clamp (see Figure 9).

3.8. The second DC isolator (exhibit [redacted]) mounted on the right-hand side of the fire damaged isolator, showed minor fire damage to the exterior of the left-hand side of the enclosure. There was evidence of corrosion from water ingress inside the four DC cable terminals, this was most extensive in terminals L4 and T4 (see Figure 10). This may be a consequence of fire-fighting activities rather than weather exposure; it is not possible to exclude that the water ingress resulted from weather exposure, however the weatherproof enclosure and the use of conduit around the DC cables suggest this is less likely.

3.9. Inside the switch mechanism of exhibit [redacted], there was evidence of heat discolouration to both the fixed switching contacts from each terminal and the movable switching bridge contacts (see Figure 11). There was also evidence of minor scorching to the plastic bridge mechanism (see Figure 12).

3.10. There was also evidence of minor pitting to the contact pads on each of the switch terminals, this was consistent with the formation of a switching arc during opening and closing. The switching contact in terminal L2 appeared to show greater damage than the other neighbouring contacts. The non-movable switching terminal L2 appeared to be set slightly higher than terminals L1 and L3 this could cause this pole within the switch mechanism to make and break the full voltage fractionally before the other contacts, this could accelerate the rate of wear within the contact.

4. Conclusion

4.1. The fire has originated inside the switching mechanism for this DC isolator, the greatest damage has occurred within the mechanism used to switch the negative. Excessive heat has been generated at the switching contact point. The damage to the terminals is not consistent with the effects of restive heating having occurred between the terminal connection and the DC cable. Electrical activity within the negative switching pole has likely charred the plastic casing separating the poles within the switching mechanism. Arcing between the negative and neighbouring positive pole has then occurred within the switching mechanism. As the fire has developed further arcing between positive and negative cables outside of the switching mechanism but within the DC enclosure has occurred.

4.2 [redacted] product data sheet for the [redacted] isolator includes a circuit diagram showing the isolator wired in a balanced configuration using two poles to switch the positive and two poles to switch the negative. The actual installation appears to differ from the manufacturer's guidance, this could have a detrimental effect on the switching capabilities of the isolator.

3

4.3 There was evidence of water ingress inside the exemplar switching mechanism, however it is not possible to confirm if this was present before the fire occurred. The exemplar isolator shows excess heat has been generated around each of the switching contacts this has caused discolouration to the metal terminals, scorched the plastic bridging mechanism and evidence of minor pitting to the switching contacts. This heat discolouration appears to be a consequence of general use given that the [redacted] isolator was appropriately rated for this array.

Report prepared by: [redacted]
Fire Investigations (UK) LLP

Signature: [redacted]

4

 Figure 1	 Figure 2
 Figure 3	 Figure 4
 Figure 5	 Figure 6

5

 Figure 7	 Figure 8
 Figure 9	 Figure 10
 Figure 11	 Figure 12

6

Report Ends