Photovoltaic Module and System Fault Analysis

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Photovoltaic Module and System Fault Analysis

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A thesis project submitted to Murdoch University School of Engineering and Information Technology to fulfil the requirements for the degree of Honour Bachelor of Engineering in the discipline of Instrumentation and Control Engineering and Renewable Energy Engineering.

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Submission Date: 04 December 2017
Photovoltaic Module and System Fault Analysis
Author’s Declaration

I declare that this thesis is my own account of my research and contains as its significant content work which has not previously been submitted for a degree at any tertiary education institution.

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Abstract

Photovoltaic (PV) systems have a total installed capacity of 6 GW in Australia at the end of 2016 according to International Energy Agency (IEA). Despite this, there are PV systems and system components that are suboptimal. The weather and different climate zones affect the performance of PV solar system, and it could cause degradation and reduction in performance. Because of this, an online questionnaire called the Photovoltaic Module and System Fault Reporting Portal (PVFRP) was established. This project was funded by the Australian Renewable Energy Agency (ARENA) and coordinated by the School of Engineering and Information Technology at Murdoch University in cooperation with the Clean Energy Council (CEC), the Australian PV Institute (APVI), UNSW, and Ekistica (Project Participants). This portal covers five main sections: Module, Installation, Inverter, Other Equipment and General Issues. The PVFRP is aimed to gather data a section of a PV system that has a failure and further details about the defective components. Due to the issues found in the original version a revised version of PVFRP was developed. The revised version was approved by the Murdoch University Human Research Ethics Committee, and it has been in operation since October 2017. This thesis project intend to analyse the obtained data from PVFRP and summarise the recently published findings associated with operational failure in PV systems including their main driving factors. In general, the findings from both versions of the PVFRP are also recognised in the literature findings of similar area studies performed in nationally and/or internationally. The reported failure types vary over the five sections. Some safety problems issues were also reported through PVFRP such as incorrect wiring of polarised DC circuit breakers, and exposed live conduct.
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## List of Abbreviations

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<td>APVI</td>
<td>Australian PV Institute</td>
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<td>ARENA</td>
<td>Australian Renewable Energy Agency</td>
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<tr>
<td>CEC</td>
<td>Clean Energy Council</td>
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<tr>
<td>EVA</td>
<td>Ethylene vinyl acetate</td>
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<tr>
<td>IEA PVPS</td>
<td>International Energy Agency Photovoltaic Power Systems Programme</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electro technical Commission</td>
</tr>
<tr>
<td>IITB</td>
<td>Indian Institute of Technology Bombay.</td>
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<tr>
<td>NCPRE</td>
<td>National Centre for Photovoltaic Research and Education</td>
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<tr>
<td>NISE</td>
<td>National Institute of Solar Energy</td>
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<tr>
<td>PID</td>
<td>Potential induced degradation</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
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<tr>
<td>PVFRP</td>
<td>Photovoltaic Module and System Fault Reporting Portal</td>
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<tr>
<td>$W_p$</td>
<td>Watt peak capacity, or nominal power, or the nameplate capacity</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
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<td>GW</td>
<td>Gigawatt</td>
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List of Definitions

In this research, several terms with the following definitions or short explanations are used.

All India Survey of Photovoltaic Module Degradation in India performed by the National Centre for Photovoltaic Research and Education (NCPRE) twice:

1. The first time in 2013 (Dubey et al. 2014).
2. Repeated in 2014 (Chattopadhyay et al. 2015).

The primary objectives of these two surveys were to assess the effect of climatic zones on the PV modules while considering the age of the PV systems.

Cell cracks are splits or cracks in the silicon wafer of the PV cells that regularly cannot be observed by the naked eye.

International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) Task 13 is an international programme and partners of this programme were from 18 different countries. This programme focuses on developing the reliability of photovoltaic systems as well as the subsystems by gathering, analysing, publishing the data on their technical performance as well as failures and providing a basis for their assessment has a group of studies investigating include the following two published reports:

2. (Köntges et al. 2017) “Assessment of Photovoltaic Module Failures in the Field”.

Operation faults in the PV system are those that are developed through the operation of PV system, as well as those that could start developing before installation (through manufacturing processes or transportation). The latter failures develop further during operation of PV system such as cell cracks. It is also named as PV faults or PV failures.
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Power loss determination (definition) is done in different ways. The participants in the surveys usually estimate the power loss with respect to the nameplate power rating. This method is considered as one of the market’s accepted methods which are usually used for the manufacturer’s warranty purpose. Sometimes the initial power of Photovoltaic modules is available. In this situation, one can clarify the power loss relative to the initial measurement (the scientific approach).

Project Participants of Photovoltaic Module and System Fault Reporting Portal (PVFRP) which funded by the Australian Renewable Energy Agency (ARENA) are the Clean Energy Council (CEC), the Australian PV Institute (APVI), UNSW, and Ekistica.

PV specialists (experts) are manufactures, inspectors, auditors, and technical staff from research organisation.

PV non-specialists are installers, distributors, system owners and end users of PV system.

Quick connector is an essential element for the reliable power generation as well as the safety of the system. It is used to connect solar modules to each other, to extension cables, combiner boxes, to fuse boxes, and to the inverter

Unscheduled maintenance is maintenance due to a failure that develops during the operation of the PV system

Nominal service life and the technical lifetime of PV module are terms used to describe the estimated period of operation of a PV module which is expected to be between 20 to 25 years.

Service life of PV module is the real period where a PV module is utilised in a PV system, which could vary from 0 up to 50 years.
1. Chapter 1 - Introduction

1.1 Background

With the depletion of fossil fuel-based energy resources, globally, there is an urgent need to find alternative resources. The investments and subsequent studies in the field of renewable energy such as solar, thermal and wind started during the oil crises in the 1970s (Laird and Stefes 2009), but the high cost associated with the renewable energy technologies thwarted the widescale realisation of these technologies. The advent of more cost-effective technologies coupled with sustained higher oil prices in the last decade, for example, fuelled a rapid growth in this field. Governments in different countries support renewable energy in the form of tax breaks or subsidies, which in turn further reduce the retail price of renewable energy products such as solar panels. Renewable energy sources are easily available almost everywhere on this planet, environmentally safe, and highly sustainable. However, investment in renewable energy increasingly faces some challenges, which include the initial high cost (installation plus the components’ costs), a utility of power and its round-the-clock availability. Standalone systems need storage facilities, which makes them very expensive systems. The other challenge is the fluctuation of the generated power, for example, when the sky is fully cloudy, there will not be any power produced by the solar panels, and wind turbine will not produce power in the absence of sufficient wind. Moreover, there is an added uncertainty associated with these systems as no one can accurately predict the climatic condition which affects the power generation (PVPS 2016).

Despite these challenges, the future depends on developing reliable alternative energy sources and solar has the greatest potential.

Therefore, this project is interested in the solar energy particularly PV solar. There has been rapid development in PV solar in term of technologies, and equipment selection (e.g. inverters),
especially in China, America and India. This contributes to the total cost reduction of PV installation and increases the total solar capacity in the world. By the end of 2016, around 75 gigawatts (GW) of PV capacity was installed world widely. The 25 International Energy Agency Photovoltaic Power Systems (IEA PVPS) countries installed a total of 265 GW of cumulative PV installations and other countries installed at least 35.7 additional GW(Fig2x). Therefore, the global total installed PV solar capacity was at least 303 GW (Jäger-Waldau 2017).

Figure 1 shows that the top 10 leading countries with cumulative installed solar photovoltaic capacity at the end of 2016: China (78.0 GW) is the top country, followed by Japan (42.8 GW), followed by Germany (41.2 GW) and then the USA (40.3 GW).

In fact, four Europe counties are among the top 10 countries in cumulative installed solar photovoltaic capacity: Germany (41.2 GW) France (7.1 GW), Spain (5.4 GW) and Italy (19.3 GW). Australia’s the total installed capacity was around 6 GW at the end of 2016 (Jäger-Waldau 2017).
At the end of 2016, the 25 International Energy Agency Photovoltaic Power Systems Programmes (IEA PVPS) countries represented 265 GW of cumulative PV installations together, mostly grid-connected. Additional countries that are not part of the PVPS programme represent at least additional 35,7 GW, mostly in Europe; the UK with 11,6 GW, The Czech Republic with 2,1 GW (stable in 2016), Greece with 2,6 GW (stable in 2016), Romania with 1,3 GW and Bulgaria with 1 GW (stable in 2016). Following these countries, India has installed more than 9 GW and Taiwan more than 1 GW. Many other countries have installed PV systems but none have reached the GW scale. While other countries around the world have reached various PV installation levels, the total of these remains hard to quantify with certainty. At present, it appears that 298,6 GW represents the minimum installed by end 2016 with a firm level of certainty. Remaining installations account for some additional 4,5 GW installed in the rest of world (non-reporting countries, and off-grid installations) that could bring the overall
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installed capacity to around 303.1 GW in total. Today, PV drive at least 0.1% of total international electricity generation (Jäger-Waldau 2017).

Figure 2: Evolution of PV Installations (GW-DC) (Jäger-Waldau 2017)

Despite the growth and the development of high quality, reliable solar energy, a high number of low-cost and low-quality PV modules has been entering the Australia market since 2008. There are process approval procedures, installation guidelines and standards which are made to protect the quality of the services and products. Despite this, there are PV installations and system components that are suboptimal. Consequently, these issues could lead to production lost or additional cost due to maintenance and subsequently could also long-term degradation lead to safety issues and fire hazards. For these reasons, different studies were attained in relation to the PV system reliability and fault analysis, for example, the Photovoltaic (PV) Module and System Fault Reporting Portal (PVFRP).

PVFRP is an online survey questionnaire (operating since 2014) designed to gather localised failure information of PV systems for different climate zones in Australia. This questionnaire is an activity run by the School of Engineering and Information Technology at Murdoch
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University. PVFRP has been established as part of the project ‘Data Collation & Analysis for Development of a Climate-based PV Module Rating Scheme’. PVFRP was funded by the Australian Renewable Energy Agency (ARENA). This survey is supported by the Clean Energy Council (CEC), the Australian PV Institute (APVI), UNSW, and Ekistica (Project Participants). This project contributed to international PV Module Quality Assurance Task Force and International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS ) Task 13. IEA PVPS Task 13 is explained in section 2.2.2. PVFRP can be accessed through Clean Energy Council (CEC) and the Australian PV Institute (APVI) webpages. PVFRP is intended to collect information from PV non-specialists (e.g. end users of PV systems, installers, and distributors) and PV specialists (e.g. inspectors, auditors, technical staff from research organisations, and manufacturers). The PVFRP is mainly aimed at gathering data about which section of a PV system has a fault, and further details about the defective equipment which mainly based on visual inspection only. The PVFRP is also aimed at gathering data from warranty returns (data) form module manufacturers. The survey covers five main sections: Module, Installation, Inverter, Other Equipment and General Issues. However, the respondent can add any additional comments before completing the survey. The obtained data will help with identifying issues with PV systems and assist in avoiding these in the future, enhancing solar system design, solar production, and components selection. The original version of PVFRP had operated from April 2014 until October 2017. The original version of the PVFRP, in operation for 41 months, is generally simple to access for respondents around the world. However, during the operation of the original version of PVFRP, it came apparent that there are issues and shortcomings include:

➢ Although accessible, the original survey was time-consuming to fill out and took an unnecessary effort as the respondent had to go through all the five sections till the end
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of the survey even though if the user needs to report only a failure under one section only as can be seen in Figure 7.

- Many respondents did not provide the location of installation of PV system and essential system descriptions (e.g. the PV array capacity (kW), and postcode) because of these details are not compulsory. Consequently, it makes hard to analyse the data in relation to location or temperature zone.

For these reasons, a revised version was considered in order to improve this specific web-based survey. These changes are essential to satisfy the needs of respondents by simplifying their experience of the PVFRP and make the survey shorter. These changes are aimed to make it easier for the respondent to attempt the PVFRP questionnaire; however, the content of the survey questions has kept the same as explained in the next section (2.3).

There was a process that needs to be followed to approve the revised version by the Murdoch University Human Research Ethics Committee, and the Project Participants mentioned earlier.

The steps of this approval process involve:

- The revision of the original survey and the development of the new survey.
- Approval from the Project Participants.
- Refinement based on feedback.
- Approval by the Murdoch University Human Research Ethics Committee.
- Documentation and assistance with launching the new survey.

The revised version of the PVFRP has been granted by the Murdoch University Human Research Ethics Committee, and the Project Participants. The revised version of the PVFRP become publically available in October 2017. CEC change over to the new survey version on Thursday the 26th of October 2017, and APVI changed over on the 19th of October 2017. More
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details about the data collection of both versions are described in section 3.2. This thesis project is related to assess collected data from both versions of the PVFRP.

1.1.1 Previous Work on The Original Version of the PVFRP

The following brief description summarises two theses and two reports that illustrate the primary findings from Website (PVFRP):

1. A report by Zaman et al. (2014) illustrates the major findings from the PVFRP up to 2014. They compared results of the PVFRP with similar studies. The report also shows background information about the PVFRP project, its aims and development.

2. The thesis by Mahajan (2014) analysed and compared the PVFRP data with All Indian Survey (2013). All Indian Survey (2013) is described in section 2.2.1. Mahajan analysed the data in different climate zones including environmental conditions on the operation, and reliability of the PV systems and the paper states that failures in inverters dominate the reported failures in the PVFRP.

3. A report by Zaman, Parlevliet, and Calais (2014) illustrates the main findings from the PVFRP up to February 2015. They analysed PVFRP data, and the findings are filtered and expressed graphically and/or through tables which can be used for publishing or statistical purposes.

4. The thesis by Hairudin in (2016). He summarized the main findings from the PVFRP up to December 2015 and the findings obtained in the previous three papers.
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Overall, the results from these four papers show that the module faults, inverter faults and installation faults are considered the highest number of the reported faults compared to other reported failures and can be seen in Figure 3.

![Figure 3: PVFRP Survey Faults by Type (Zaman, Parlevliet, and Calais 2015)](image)

1.2 Description of the Project

This thesis project consists mainly of two parts. The first part is associated with the assessment of the gathered data from the Photovoltaic Module and System Fault Reporting Portal (PVFRP) surveys, while the second part is the literature review regarding the previous data collection of PV system faults and issues and their findings.
1.3 Aim of the Project

The overall aim of this thesis project is to investigate the different failure types that are developed in PV systems (during the operation). Some of those failures could start developing before installation (through manufacturing processes or transportation).

The main purpose of the thesis project is to analyses the system faults obtained mainly from an electronic survey which is called the PV module and System Fault Reporting Portal (PVFRP).

An essential aim of this project is also to contribute to the development and improvement of the PVFRP, and compare the revised version findings versus the original version findings.

Another significant main aim of this project is to compare the findings from the PVFRP with literature review findings of similar reports, electronic websites, surveys, and other scientific papers. In addition, the thesis focuses on assessing the survey results of the PV system according to climate zones or system different locations. This is only possible if a certain amount of survey responders were collected.

1.4 Significance of the Project

There is an interest among stakeholders, include PV system organisations, research institutes, and consumers to provide a study of the developed faults in the PV systems in order to improve the future designs for such systems. There will be a review of current literature in the following chapter. This research aims to design a study that highlights the most common operational faults in PV systems in Australia.

1.5 Project Thesis Outline

This thesis is structured into six chapters. The contents of each chapter are described as follows:

- Chapter 1 provides an introduction about this research. Beginning by highlighting the background information about this thesis project, followed by a description of the project, then the aim of the project and its significance.
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- Chapter 2 provides the literature review on the thesis topic.
- Chapter 3 describes the method of data collections in the original and revised versions of PVFRP as well as thesis methodology.
- Chapter 4 provides the evaluation of the original version of PVFRP. It is also discussed compare the main finding with those obtained by other authors.
- Chapter 5 provides the evaluation of the revised version of PVFRP. It is also discussed compare the main finding with those obtained by other authors.
- Chapter 6 provide the conclusion and suggest some recommendations for future work which can be done in order to improve the PVFRP.

2. Chapter 2 - Literature Review

2.1 Introduction

Although the literature covers different aspects of faults observed regarding PV system, it is difficult for investors to analyse these faults since there are few studies highlighting how often specific failure occurs, and how much impact those failures have on the PV system (Köntges et al. 2017). This review concentrates on summarising the previous studies that have been performed by other authors in relation to the development of operational faults, including their main driving factors. Module and inverter qualification test sequences have been extremely effective in distinguishing design faults that are likely to lead to early field failures; however, there are still many faults developed through the operation of the PV systems. The exponential growth of the PV industry could result in tremendous financial losses occurring due to operational faults. As the industry is searching for approaches to decrease cost and enhance the
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performance of PV system, PV system components need to be examined. Fortunately, there are some maintained PV solar systems which have been in the field for more than 20 years. Those systems allowed (other) researchers to obtain a limited evaluation of the PV systems performance during the operation of the PV system. Many of these studies include identification of failure mechanisms, estimation of the system lifetime and predict the degradation rate. Clearly, study of the faults that are developed during the PV operation will assist to improve the future design (Kurtz, Granata, and Quintana 2009).

This chapter summarises the literature in the following two sections: The first section (2.2) groups the literature into two different groups. The second section (2.3) presents the detailed findings from the studies. The third section (2.4) describes the Australian climate zones based on a modified Köppen classification system.

2.2 Previous Data Collections Groups on PV System Faults and Issues

In this section, the previous studies are categorised into three groups: Group 1 includes surveys or studies where the information acquisition is conducted by specialists or experts, Group 2 includes surveys or studies where data collection is done through individual voluntary reporting which includes non-specialists, and Group 3 is based on other studies which do not fall under the previous two groups.

2.2.1 Group 1: Expert Data Acquisition

This group of studies is performed by experts or (technical staff from) industry organisations where experts collect information through site visits and/or laboratory test ‘component test’. Experts use different methods to characterise, analyse and determine the faults in PV systems in the laboratory and in the field. For instance, it is observed that infrared images and I-V characteristics were utilised as a diagnostic tool in the laboratory and in the field. Visual inspection was also used for fault finding (Köntges et al. 2017). The significant advantage of
these studies is that they can provide technical details and provide a comprehensive description of the mechanisms of PV systems or modules flaws.

An example of this group of studies is the All India Survey of Photovoltaic Module Degradation which was performed twice in India in 2013 (Dubey et al. 2014) and in 2014 (Chattopadhyay et al. 2015) in PV systems in operation for 3 to 30 years. The main objectives of these studies are to assess the effect of climatic zones on the PV modules while considering the age of the PV systems. In these surveys, specialists went into the field and reviewed the state of PV systems. The gathered information, which involved both visual inspection and methods which identify electrical parameters of the PV systems. In fact, experts used a portable IV curve tracer and an infra-red camera (being used few times) in the 2013 survey. On the other hand, in the 2014 survey, different characterisation tools were brought to the field in order to obtain further detailed inspection of the PV modules. As they reached the site, initially dust samples were collected from the top of a number of modules in order to be analysed later for module soiling studies in the laboratory. Then spraying water was used to clean the module surfaces. Before the current-voltage (I-V) characterization was obtained, these modules surfaces were wiped dry (since the module performance could be affected by the water film on the module surface).

During the day, the following tests were performed: Visual inspection, insulation resistance test, interconnect failure test, illuminated I-V, and infrared (IR) thermography.

In the late evening, electro luminescence testing was executed. Then dark I-V and dark IR experiments on a chosen number of PV modules based on the daylight test results were performed.
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The surveys were carried out by the National Centre for Photovoltaic Research and Education (NCPRE) at the National Institute of Solar Energy (NISE) and the Indian Institute of Technology Bombay (IITB).

The first (2013) survey found that the corrosion tended to correlate with hot and humid zones, whereas discoloured modules were regularly found in hot and dry climates (Dubey et al. 2014, Köntges et al. 2017).

The second survey correlated data obtained between September and December in 2014. 1080 modules with various photovoltaic technologies were inspected from 45 areas over six climatic zones of India.

The second survey (2014) indicated the following:

1) The degradation develops faster in many modules in PV system in the first five years of operation and the causes could be associated with any of the following:
   a) High temperatures in India.
   b) Poor installation practices.
   c) Poor or inappropriate quality of modules.

2) The ‘Hot’ climatic zones of India – ‘Hot & Dry’, ‘Warm & Humid’ and ‘Composite’, where most of the installations are likely to take place, present a challenging environment for PV modules. Failures encountered in Hot & Dry, ‘Warm & Humid’ and ‘Composite’ zones include interconnect breakage, higher annual degradation rates, discolouration, delamination, greater incidence of hot cells, and higher metal corrosion (Chattopadhyay et al. 2015).

3) Inappropriate orientation, poor support structure, inappropriate tilt angle, shading soiling, are some of the issues in the field which potentially increase the likelihood to develop a degradation and failure of PV systems.
Photovoltaic Module and System Fault Analysis

4) PV modules installed in heavily soiled sites have a higher degradation rate than those modules that are regularly cleaned.

5) Scratches on the front glass, backsheet, and frame are more often found in small PV systems owned by local people. These failures developed as a result of inappropriate handling during installation.

6) Module installed in small systems (size less than 100 kW) are degraded at a much higher rate than those modules installed in a large system of size more than 100 kW (~ 1%/year).

According to Chattopadhyay et al. (2015), the performance of PV systems seems to rely upon both installation and the PV system components quality.

Another example of this group is associated with PVResQ! It is a research activity (field survey), which is mainly aimed to establish a practical maintenance approach for PV systems based on an evaluation of the inspected roof-top PV systems. It is also aimed to assist the design of reliable, sustainable, and safe quality PV systems in future. PVResQ! was performed by Kato (2012) in Japan. The study involved field visits and status checks of the roof-top PV systems as well as a collection of users reports on the inspected PV systems utilised for this study. Visual inspection, an infrared camera (IR), I-V measurements were utilised in this survey. These PV modules have been repeatedly inspected over five years (2006-2011). The study found the following:

- The condition of PV system installed by large commercial PV utilities and research organisations are much better than small PV systems which are maintained by local owners. The reason is that large commercial PV utilities are occasionally inspected, and maintained their PV systems for warranty purposes.

- Hot spots caused by disconnected interconnection, soldering degradation, overheated bypass diodes.

- Several burn marks on the backsheet.
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- Extremely hot spots were identified by an infrared camera.
- Some bypass diodes did not perform at all (I-V curves were measured with and without partial shade).

The results of testing bypass diodes in 1272 modules of a single type (crystalline PV modules) obtained within PVResQ! can be seen in Figure 4. The study found that a total of 47% (around half) of the modules had faulty bypass diodes, which did not work at all. The testing has been performed over car parks in a PV solar system at the National Institute of Advanced Industrial Science and Technology in Japan (Kato 2011, Köntges et al. 2014).

Figure 4: Result of Bypass Diode Testing for 1272 180 Wp PV Modules of a Single Type (Köntges et al. 2014)

The PV System Safety audit of 20 public school installations in Perth in 2011 also fall into this category. In this audit, two specialists went to these schools in order to assess the installation practices and reviewed the state of PV modules.
They found safety issues include the following (Calais, Ruscoe, and Glenister 2011):

- Voltage rating of some switching devices does not match the voltage of PV Array.
- Exposed live contacts.
- AC and DC wiring inadequately segregated.
- Incorrect wiring of polarised DC circuit breaker.
- Inadequate cable protection.
- Inappropriate or incorrect labelling.
- Inadequate or missing documentation.

Another example of this group is associated with a visual inspection depict in (Köntges et al. 2014) “Review of Failures of Photovoltaic Modules”. (Köntges et al. 2014) is one of the groups of studies performed by the International Energy Agency Photovoltaic Power Systems (IEA PVPS) Programme’s Task 13. The visual inspection in accordance with the International Electrotechnical Commission (IEC) PV standards which present in (Köntges et al. 2014) was performed as follows:

Initially an international approach, also known as the “Documentation of visual failures in the field”, collected visual inspection data which had been introduced and utilised. Visual inspection of PV modules was executed twice before and after the module had been exposed

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1 IEA PVPS Task 13 is an international programme and partners of this programme were from 18 different countries. This programme and those institutes articles focus on developing the reliability of photovoltaic systems as well as the subsystems by gathering, analysing, publishing the data on their technical performance as well as failures and providing a basis for their assessment. The IEA PVPS Task 13 published articles showed statistical studies of the PV fault types from accelerating ageing tests and in the field (Woyte et al. 2013).
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to electrical, environmental, or mechanical stress testing in the laboratory. The problems reported include the following: delamination, bubbling, burnt diodes, and loose contacts within the junction box.

The most common failure types of PV system and components, as well as the different methods used to detect failures in the field and laboratory have also been addressed well in (Köntges et al. 2014). This article indicated that defective frames in Si modules are a noticeable fault in cold & snow climates while Snail tracks and moisture ingress are dominant in the dataset of PV failures for a moderate climate.
2.2.2 Group 2: Voluntary Reporting

The data collected by voluntary reporting is typically provided by non-experts such as owners or end users of the PV systems. The gathered information in this group is usually based on visual inspection only, but may also incorporate infrared or IV tests in a few circumstances (which is provided by experts).

The main advantage of voluntary reporting data is that it is possible to get higher number of respondents from a wide geographic locale. Nevertheless, the collected information requires further validation or filtration. Examples of this group of studies include the previous work on the PV Module and System Fault Reporting Portal (PVFRP), (which is explained early in section 1.1) and the survey, which is presented in (Köntges et al. 2017).

Recently, a survey was designed and run via the IEA PVPS Task 13 and the article which describe the result of this survey was published in May 2017 “Assessment of Photovoltaic Module Failures in the Field”. The survey was initially designed to gather failure information of PV systems for different climate zones. This survey is aimed to gather data from PV experts, installers and PV system owners installed in different part of the world. This international survey is aimed to assess the various impacts of the failures for Köppen-Geiger climate zones which are described in (Kottek et al. 2006) and to provide recommendations for test approaches based on the results of the climate zone analysis. For example, Köntges et al. (2017) recommended the PV plant designer to obtain additional tests such as extended UV-degradation with the new IEC 61215:2016, PID (IEC/TS 62804), and bypass diode test (IEC 62979, IEC/TS 62916). Köntges et al. (2017) have developed a method to assess the failures data from the field. This method enables them to analyse the number of failures in the PV systems with respect to the power loss.
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This research has obtained the following findings:

- Hot and dry climates as well as moderates climate record the highest degradation rate caused by bypass diodes defects.

- The degradation rate caused by cell cracks is higher in the cold and snow climatic zones.

- The discolouring of encapsulating fault is found in three climatic zones: the hot and humid, hot and dry, and in the moderate climate zone.

Additionally, a data collection tool was designed, which can be downloaded from the IEA PVPS Task 13 website. Visual data collection from the field is reported via IEA PVPS Task 13 in (Köntges et al. 2017). A total of 1211 PV module dataset from seven countries have been gathered and evaluated. A large portion of the reported PV modules is installed in Europe. The cold & snow climate, and moderate climate record the highest percentage of the database with 74% and 24% respectively. In the hot & dry climate, there is only 2% PV module dataset, and in hot & humid climate, there is no data available.

The visual inspection of the PV modules was done for PV installations which were in operation for more than a year and the total distribution of the fault types over the period between installation and inspection for PV modules is classified into two periods: The first seven years and the first three years after installation. Then the collected data was analysed as follows:

The first study shows a cumulative distribution of occurrence of the failures over periods between installation and inspection dates for silicon PV modules in the field. The result of this study shows that delamination over the cell cracks and snail tracks dominate the fault types in the initial three years (170 modules inspected) period, whereas for the first seven
years (395 modules inspected): snail tracks, and defect frames are the dominant fault types. Consequently, it seems that snail tracks appear to show up in the initial three years after installation, whereas the defect frame develops over a longer period. It is observed that there is a notable increment of faults due to the moisture ingress and defect frame during the operation of the PV system. Moreover, moisture ingress usually occurs because of other faults, for example, as a consequence of defect frame and glass breakage. Köntges et al. (2017) noted that the ageing of the PV modules is also a critical factor.

The second study illustrates the total distribution of the fault types for cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) modules. In the first three years (150 modules inspected), is only one fault type developed mainly delamination (5%). The total distribution of this fault type rises dramatically (more than three times) for seven years after installation (505 modules inspected). Delamination (17%) dominates the failure types in CdTe, followed by defective frames (6%).

2.3 Developed Operational Faults in PV Systems

The field failures of PV components are regularly developed mainly due to varied environmental conditions, components failures, and improper installation. These failures are contributors to reduced availability and reliability of PV systems (Köntges et al. 2014). Several terms are used to describe the expected usage periods. The nominal service life and the technical lifetime of PV module are terms used to describe the estimated period of operation of a PV module which is expected to be between 20 to 25 years. The service life of PV module is the real period where a PV module is utilised in a PV system, which could vary from 0 up to 50 years. According to Köntges and et al. (2014), the service life of a PV system usually ends if a safety issue develops, or the power of PV system falls below a
specific percentage, which is normally specified between 80% and 70% of the initial power rating. Power loss determination is done in different ways. The participants in the surveys usually estimate the power loss with respect to the nameplate power rating. This method is considered as one of the market’s accepted methods which are usually used for the manufacturer’s warranty purpose. Sometimes the initial power of Photovoltaic modules is available. In this situation, one can clarify the power loss relative to the initial measurement (the scientific approach). The different common failures are described in the following subsections.

2.3.1 Modules

There are several common faults of PV modules which were found in the field such as degradation, back sheet adhesion loss, delamination, ethylene vinyl acetate (EVA) discolouration, frame breakage, cell cracks, interconnect ribbons, burn marks, snail tracks, and defective bypass diodes.

2.3.1.1 Degradation

Modules are generally seen to degrade gradually in the field. The degradation is produced because of a drop of short-circuit current. The literature suggests that this reduction in short-circuit current is related to delamination and discolouration of the encapsulated material. Systems with potential induced degradation (PID) faults are mostly reported in year 3 to 4 year and degradation rates tend to be higher in hotter climates. Even though the degradation modes based on the components and materials that are unique to each single PV module brand and model, there are usually several degradation modes which make it hard to correlate observed effects with single mechanisms or processes (Köntges et al. 2014). Module installers and manufacturers should put more attention while packaging and
handling of the modules during transportation because improper handling can develop cell cracks and subsequently long-term degradation.

### 2.3.1.2 Glass Breakage

Glass breakage of frameless PV modules in the field is often a result of poor clamp geometry design or excessively-tightened screws. Glass breakage causes a drop in the performance because of electrical circuit corrosion which is developed as a result of the penetration of water vapour and oxygen into the PV module. Hot spots in PV modules may lead to glass breakage because of the extreme heat produced at a specific spot in the PV module. Hot spots develop when the operating current of the module exceeds the reduced short-circuit current of the shaded cells within the PV module (Molenbroek, Waddington et al. 1991). Most of the issues which are developed as a result of glass breakage are considered electrical safety issues. The reason behind this is that the protection of the modules’ insulation can never again be guaranteed (Köntges et al. 2014).

### 2.3.1.3 Cell Cracks

During many types of failure analyses or studies in PV system, it is noted that cell crack faults are regularly reported during the first two years after installation in 2014. Cell cracking could develop through the manufacturing process, or while transportation, or during operation of PV.

Cell cracks that are related to the cell production, wafer slicing, stringing and the embedding procedure (Köntges et al. 2014):

- Cracks can develop initially as a result of stress initiated by the soldering process in the cell interconnect ribbon. These cracks are often situated towards the end or beginning of the connector since this is the area with most elevated stress.
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- One type of crack is called a cross crack. During the production, cross cracks are developed because of needles pressing on the wafer substrate.

- Cracks beginning from the edge of the cell can develop as a result of moving the cell against a hard item.

- Intrinsic manufacturing process variation during manufacture process of the module, for example, the stringing process is a potential source of developing cell cracks.

- Cell cracks can develop also while reloading, transport and packaging of the modules is a great source for cell cracks.

- At the installation of PV modules such as if somebody steps on the PV module or the module falls, cell cracks may develop.

When cell cracks are present in a PV module, there is the possibility for further degradation: short cell cracks can develop into wider or longer cracks during the operation of the PV module. The reasons behind this are mechanical stress (snow or wind) and thermo mechanical stress on the PV modules because of changes in temperature as a result of passing clouds and climate variations.

2.3.1.4 Defective Bypass Diode

If a cell is reversed with a voltage that is higher than it is intended for the cell could create hotspots which could cause subsequent failures such as burn marks, browning, or even a fire (Köntges et al. 2014). Defective bypass diodes are reported in the first ten years after installation (Köntges et al. 2017).
2.3.1.5 Quick Connector

Quick connector is an essential element for the reliable power generation as well as the safety of the system. It is used to connect solar modules to each other, to extension cables, combiner boxes, to fuse boxes, and to the inverter. A study of causes of fire in 75 PV systems states that the opportunity of the quick connector developing the fire is potentially high, but some PV module and inverters faults could have also led to the fire.

2.3.1.6 Junction Box

Following are examples of junction box failures in the field (Köntges et al. 2014):

- Bad wiring leads to internal arcing in the junction box as can be seen in Figure 5. Arcing can create fire.
- Poor fixing of the back sheet to the junction box.
- Opened or poor design junction boxes.
- Moisture ingress which could produce corrosion of the connections.

Figure 5 demonstrates three junction box failures: the right one illustrates poor wiring, the middle shows a poorly bonded junction box to the back sheet, the left one demonstrates an open junction box.
2.3.1.7 Corrosion

Corrosion can occur as a result of delamination, but some corrosion develops without delamination.

The review also proves that the appropriate combination of the backsheet film and an encapsulant could reduce the PV module failures. However, the studies also stated that there are no common rules that could generally be applied for all PV modules (Köntges et al. 2014).
2.3.2 Inverter

Failure in inverters dominate all the reported faults in the PV Module and System Fault Reporting Portal (PVFRP) up to 2014 and various other surveys. Fault in inverter issued usually lead to a total or partial reduction in the performance of PV system (Mahajan 2014, Zaman et al. 2014). The cost of rectifying the fault in a PV system depends on the type of the fault. For example, an inverter fault could be very costly (UMR 2017).

2.3.3 Installation

Certifications and indoor accelerated tests enhance the confidence in the warranty. Regardless of the development in the performance and the design of numerous PV solar system components, these components still tend to undergo PV-system maintenance costs and some faults could be solved by the user while other defects in the solar system required professional assistance (Silverman et al. 2015). Improper installation is one of the major Factors contributing to developing the operational failures in PV systems (Kurtz, Granata, and Quintana 2009). Previously, many cases of improper installations which did not follow the regulations were found, for example, the findings from the PV System Safety audit of 20 public school installations in Perth in 2011. Installation issues sometimes are considered as a safety issue, especially that failure which leads to fires, for example, in The West Australian the government made a statement that faulty panels and a fault in the inverters or incorrect installed PV solar systems is considered the major cause of fires developed in more than 20 properties in Western Australia during the past two years. Figures obtained from the electricity safety watchdog show that in two years to 30 June 2017, there were 24 incidents developed due to installation, module, and inverters faults (Mercer 2017).
2.3.4 Other Failures

2.3.4.1 Lightning

Depending on the location on the earth or temperature zones, there is a possibility that lightning strike can occur, for example, in tropical and subtropical regions, lightning strikes occur from 30 to 70 times yearly (Häberlin 2012). The PV modules are not designed to handle a direct hit by a lightning strike. The induced faults caused by a direct hit by a lightning strike are usually a mechanically broken PV module and open-circuit bypass diodes damaged through induced voltages and currents (Köntges et al. 2017). PV systems are not only affected by direct lightning strikes on the PV system itself. The effect of nearby lightning strikes, for example, a lightning strike in a nearby area or next to a building is more common. However, the cost of improving the design in order to prevent damage from nearby strikes is far lower compared to the effort required to protect against the damage from direct strikes. Therefore, all PV systems designs should protect against damage from any nearby lightning strikes. Nearby lightning strikes can damage the bypass diodes in a PV system. All the failure types caused by lightning strike could lead to hot spots as subsequent technical or safety faults (Häberlin 2012).

Häberlin (2012) described the effect of a direct and indirect strike and explained designs that could be implemented in order to protect against direct and nearby lightning strike in more detail. Häberlin conducted several tests to study the effect of lightning strikes. For example, for the tests with three-cell mini-modules and individual cells, the simulated lightning current induced through a wire, which was places 1-4mm from the edge of the tested mini-modules or cells. The lightning currents passing through a module frame resulted in a gradual drop in the I–V characteristic curve fill factor of the relevant module.
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This developed due to a rapid change in the lighting current’s electromagnetic field which can lead to damages in the back and front contacts and with that increased series resistance as well as semiconductor material defects. The experiments also showed that under the same conditions, framed modules suffer less damage than laminates. Lightning-current-induced damage is related to module wiring. Lightning current induces more critical damage when the module or cell is operating under open circuit condition (Häberlin 2012).

2.4 Climate Zone in Australia

![Map of Australia with climate zones](image)

Figure 6: The Key Climate Groups Based on a Modified Köppen Classification System (METEOROLOGY 2014).

The Köppen-Geiger system used globally for analysis and define the operational faults in the PV systems with respect to climate zones (Köntges et al. 2017).

There are six climate zones in Australia based on a modified Köppen classification system (METEOROLOGY 2014). The physical location of the six climate zones in Australia can
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be seen in Figure 6. The six climate groups are: Equatorial, Tropical, Subtropical, Dessert, Grassland, and Temperate climatic zones.

Köppen classification System covered temperature and humidity stress. Therefore, relating failures and degradation to climate zones is inconclusive at this time because there are other factors such as UV, soiling, irradiance, wind are stress factors that need to be considered and can be very different within one climate zone (Köntges et al. 2017).
3. Chapter 3 - Methodology

3.1 Survey Methodology

3.1.1 Introduction

This section describes the methods of data collections obtained in two versions of the PV Module and System Fault Reporting Portal (PVFRP): original and revised versions. Background information about the PVFRP and a summary of the previous work obtained on this survey is described in section 1.1.

The processes of data collection of original can be seen in Figure 7 while screenshots of the questions of the revised version of PVFRP and shown and described in Appendix.

Both versions of the PVFRP have common features:

The PVFRP starts with providing the following information: the project background, disclaimer, survey participants, rights of participants, use of the information, privacy policy, and the safety instructions. The user must declare that he or she read and understood the safety instructions, for example, in the revised version, the declaration icon can be seen in Figure 25 (Error! Reference source not found.).

The respondent can report failures in PV systems in each of five sections: Module, Installation, Inverter, Other Equipment and General Issues. The process is under the control of logic that defines subsequent stages based on reports failure types. The user is offered a list of failure types which could be experienced with Module or Inverters sections but only one failure type at a time can be chosen. The respondent has to provide further details of each reported failure. The reported failures in the Other Equipment section include failures in batteries, charge controller, datalogger, and circuit breakers.
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In the Other equipment and Installation sections, the user is offered a list of failure types which could be experienced, but multiple failure types at one time can be chosen as applicable and the survey does not return to these lists.

In the General Issues section, the respondent allows adding any failure type which cannot be reported under other four sections.

The user is able to exit the survey at any stage from the icon located on the top right side if he or she would like to for any reason.

The respondent is also able to go back to previous sections or previous stages in order to edit the reported data by clicking on the icon located at the bottom left side. For example, in the revised version these icons can be seen in Figures 26 to 51 in Appendix.

3.1.2 The Original Version of the PV Module and System Fault Reporting Portal

The original version was operated from April 2014 until October 2017. The structure of the original version and how the data was collected through the survey are shown in Figure 7 and is explained below.

Initially, the user has to go to the introduction section and declare that he or she read and understood the safety instructions.

After that, the respondent must specify whether or not there are any faults that need to be reported. If there is no failure, the user exits the survey. Otherwise, he or she will proceed to further stages.

Next, the user has the opportunity to provide personal details, installation details, and system description. At this stage, the user may also specify if he or she is an end user or a specialist. However, providing all these details and descriptions is not compulsory.
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After that, the respondent has to go through all the five sections in the following order: Module, Inverter, Other Equipment, Installation and General Issues. In the Module section, the respondent may report any failures associated with the module. The user has to provide further details on each reported failure as shown in Figure 7 and summarised in Note 3 (Page 35). Then the user is offered a chance to go back and report any other failures related to the module. When all the PV modules failures are added, the respondent has the opportunity to report module certification and/or labelling issues encountered. If there is no module certification and/or labelling issues to report, then the user has to go through the other four sections. The user is also able to go back to add new failures or edit previous entries.

After completing all the required details of all five sections, the user could add further information such as photographs, and a means of communication (an email or phone number) if the respondent did not do that previously.

Finally, the respondents can submit the survey.
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Figure 7: The Original Version of PVFRP Methodology

Notes:

Note 1: In the Module and Inverter sections, only one failure at a time can be reported.

Note 2: For the Certification and/ or Labelling issues, Other Equipment, Installation, and General Issue sections, the user can report multiple failures at a time.

Note 3: The respondent provides further detail on:

- the type of problem;
- how many of the selected components had this problem;
- if the system performance has reduced because of this problem and a quantification of the reduction (%);
- how long the system has been operating, and
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➢ if the issue has been resolved or not, by whom and how it was resolved, and how long the problem lasted before it was fixed.

3.1.3 The Revised Version of The PV Module and System Fault Reporting Portal

The structure of the revised version and how the data is collected is explained below and screenshots of the questions of the revised version of PVFRP and shown and described in Error! Reference source not found..

Initially, the user has to go to the introduction section and declare that he or she read and understood the safety instructions as shown in Figure 25 and Figure 26 in Error! Reference source not found..

After that, the user has to provide personal details, installation details, and system description. The user is encouraged to provide a means of communication; however, it not compulsory to provide a means of communication. Providing postcode is made compulsory in the revised version as can be seen in Figure 27 and Figure 28 (Error! Reference source not found.).

In this stage, the user may specify if he or she is an end user of PV system or a specialist of PV system.

Next, the respondent is asked to choose any one of five different sections: Module, Inverter, Other Equipment, Installation and General Issues section (Figure 29 in Error! Reference source not found.).

After that, the survey takes the user to the selected section and the respondent has to report the failure and provide further details on each reported failure. When all the selected section failures are added, the user returned to the section list, albeit reduced as explained in
Photovoltaic Module and System Fault Analysis

**Error! Reference source not found.** and can be seen in Figure 29 and Figure 36 and Figure 42 and Figure 45

If the user chooses the PV Module section, he or she will be first able to report any failures associated with the module and provide further details of each reported failure. Then the respondent is offered an opportunity to choose any module certification and/or labelling issues encountered.

Then the user is also able to go back to add new failures or edit previous entries.

After completing all the required details of all reported failures, the user could add further information such as photographs, and a means of communication (an email or phone number) if the respondent did not supply that previously.

Finally, the user will be able to submit the survey.

With, the revised version of PVFRP is more efficient because providing postcode is made compulsory, and the user is more encouraged to offer a means of communication in order to clarify any of the details the user has provided. Therefore, the data could be analysed for different climate zones or locations if a sufficient number of responses are received. The user could consume less time using the revised version of this survey due to the following two changes:

- Providing information such as country and street number (installation details), and organisation (personal information) was removed from the revised version of this survey,
- The user has a chance to select the section that fits the failure that needs to be reported, and he or she can skip unnecessary parts.

Overall, the revised version of this survey is considered more efficient, preferable, and more user-friendly.
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3.2 Thesis Methodology

In this section, the methods used to complete the project objectives are outlined. An overview of the methodology used for this thesis project is shown in the block diagram in Figure 8. This thesis project is aimed to evaluate the information about the failure associated with the PV systems specifically in Australia, potential causes which accelerate those failures to occur or develop further. In order to address this, the following procedures were obtained:

- Background research about the PVFRP and failures in PV systems was obtained.
- Data from both versions of PVFRP was downloaded and filtered
  1. International entries removed.
  2. Entries with no useful details were removed.
  3. Entries with insufficient or misguided descriptions were removed.
- The literature review findings in this field of study were summarised.

The methodologies used and findings of (Köntges et al. 2017), (Köntges et al. 2014), and (Zaman, Parlevliet, and Calais 2015) contribute to the design of this thesis.

- Then the data in each of the five sections (Module, Inverter, Other Equipment, Installation, and General Issues) was analysed and compared with the findings from the literature.
- Finally, the findings are summarised, and suggestions to improve the survey were provided.
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Figure 8: Thesis Methodology
4. Chapter 4 - The Result and Evaluation of the Original Version of PVFRP

4.1 Introduction

In the following subsections, the data after 41 months of operation of the original version of the PVFRP is evaluated, presented and compared with the findings from the literature review.

4.2 General Findings

The composition of the original version of PVFRP is presented in Figures 9 to 13 in order to check the representativeness of the data with respect to the most essential PV system characteristics.

During the operation of the original version of the survey (41 months), a total of 124 respondents have reported issues associated with PV system components and installation in Australia. Figure 9 demonstrates the type of respondents reported using this online questionnaire. The majority of failures have been reported by the owner/operator (57 users) and 20 installers. For this reason, the data had been filtered, validated. Inconclusive entries were verified through follow up where a means of communication had been obtained.

![Figure 9: Respondents by Types](image)
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Figure 10 shows the geographical distribution of the respondents. While one report had been recorded from Australian Capital Territory, Three from South Australia, most of the other States recorded between eight to thirteen reports. However, there had not been any reports from the Northern Territory and Tasmania.

![Figure 10: PV Systems by Locations](image-url)

More than the half the respondents (76 out of 124) did not provide the postcode (entry was not compulsory in the original version of the PVFRP).

The sizes of PV systems reported vary broadly, with most of the reports lodged for systems of 1.1kW to 5kW (42 systems) as can be seen in Figure 11. 45 respondents did not report the type of PV systems. Most of the PV systems reported are grid-connected PV systems without batteries (66 out of 123). There are also 3 PV systems are grid connected with batteries and 6 PV systems are standalone/Off-grid (Figure 12).
Figure 11: PV Systems by Size

Figure 12: PV Systems by Type

Figure 13 indicates the number of entries for each of the different sections.
4.3 PV Module Section

4.3.1 Module Failure Types

The reported failure types vary broadly, and are fairly evenly distributed over the different types (84 entries). Glass breakage (13 entries), and backsheet issues (9 entries) were found to be slightly more common as can be seen in Figure 14 and Error! Reference source not found.. Glass breakage issue discussed in section 2.3.1.2.
The other failures found within the PV module reported failures included: Water ingress encapsulant discolouration issues, and loose connection in the junction box which can create a spark that could cause subsequent arcing and/or fire. The problems reported in the module section are similar to those failures found during a visual inspection (Kontges et al., 2014) and the IEA survey (Köntges et al. 2017). For example, delamination, bubbling, burnt diodes, and loose contacts within junction box are found in all these three studies. In general, the PV module failures reported up to October 2017 through the PVFRP are similar to those found in other papers which analysed the development of operational failure in PV modules.

4.3.2 Module Certification and/or Labelling Issues

There are 19 entries with the certification and/or labelling of PV modules which can be seen in Table 1. The system with non-certified components used in modules, and modules that are not correctly labelled are found to be the top three issues.
## Table 1: Certification Issues of PV Modules

<table>
<thead>
<tr>
<th>Failure Types</th>
<th>No of Failures Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor quality modules are being sold as top quality products</td>
<td>1</td>
</tr>
<tr>
<td>Non-certified components used in modules</td>
<td>4</td>
</tr>
<tr>
<td>Modules are not CEC approved</td>
<td>2</td>
</tr>
<tr>
<td>Modules are not correctly labelled</td>
<td>4</td>
</tr>
<tr>
<td>Modules have lower power ratings than the nameplate ratings</td>
<td>1</td>
</tr>
<tr>
<td>Modules do not have manufacturer's warranty</td>
<td>3</td>
</tr>
<tr>
<td>Have but not identify</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
</tr>
</tbody>
</table>

### 4.4 Inverters

Failures in inverter (90 entries) are categories as: complete failures, partial failures, safety issues, unknown, and other inverter issues (Table 2). Inverters suffered complete failures and partial failures dominate the total reported failures with 40 reported failures and 17 reported failures respectively (Figure 15). Only 6 out of 40 inverters with complete failures had been fixed, and 7 out of 17 inverters with partial failures had been fixed. Participants also reported some customer support issues associated with inverter failures: Getting a defective inverter fixed take quite a while, with one of the reported inverters taking 3 months in order to be replaced.
The other failures found within the PV inverter reported failures included: Safety issues, and unknown failure and other inverter issues. Respondents also commented on inverter safety and performance failures. Three of the inverter reported failures only affected system performance and did not make major failure in the PV system. These three failures are:

- Overheating because of leaf develop in the heat-sink,
Photovoltaic Module and System Fault Analysis

- The inverter is turning off because of grid frequency variation outside its operating range,
- Faults with inverter control programming,

There are fewer studies that concentrate on the failures in relation to inverters compared to those studies obtained associated with failures in modules. The findings within the inverter section confirm the general trend in the literature that inverter is important category of PV system failures (Kurtz, Granata, and Quintana 2009). Therefore, there is an urgent need to identify and eliminate unreliable inverters.

4.5 Other Equipment

Other than failures in modules and inverters, failures in other PV system components can lead to safety fault or a reduction in PV system performance. There are 74 entries in Other Equipment section (Table 3) which include: 16 failures with the PV array isolator, 14 failures with rooftop isolators, 13 failures with the mounting structure, 9 failures with the main DC cable, 7 failures with the battery and 6 failures with the optimiser.

Failures in the battery are also recognised in the “All India Survey of Photovoltaic Module Degradation” in 2014 (Chattopadhyay et al. 2015).

<table>
<thead>
<tr>
<th>Other Equipment Issues</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framing/mounting structure</td>
<td>13</td>
</tr>
<tr>
<td>Rooftop isolator</td>
<td>14</td>
</tr>
<tr>
<td>PV array isolator</td>
<td>16</td>
</tr>
<tr>
<td>Battery</td>
<td>7</td>
</tr>
<tr>
<td>Optimiser</td>
<td>6</td>
</tr>
<tr>
<td>Main DC cable</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>74</td>
</tr>
</tbody>
</table>

Table 3: Other Equipment Issues
Photovoltaic Module and System Fault Analysis

4.6 Installation Issues

Even though installation has been done based on Australian standards, there are reported failures associated with improper installation.

<table>
<thead>
<tr>
<th>Installation issues</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate cable protection</td>
<td>17</td>
</tr>
<tr>
<td>Water ingress into component enclosures</td>
<td>11</td>
</tr>
<tr>
<td>Inappropriate array location</td>
<td>10</td>
</tr>
<tr>
<td>Use of standard multicore TPS cable for DC</td>
<td>10</td>
</tr>
<tr>
<td>Incorrect rating of components (please specify which component, i.e. cable, isolator, fuse etc)</td>
<td>10</td>
</tr>
<tr>
<td>Insufficient array fixing</td>
<td>9</td>
</tr>
<tr>
<td>PV system not allowing roof self-cleaning i.e. build-up of leaves etc.</td>
<td>8</td>
</tr>
<tr>
<td>DC and AC wiring inadequately segregated</td>
<td>8</td>
</tr>
<tr>
<td>Inadequate sealing of roof penetrations (i.e. roof leaking)</td>
<td>7</td>
</tr>
<tr>
<td>Inappropriate location for inverter (i.e. poor access, poor ventilation, exposed to direct sunlight, etc)</td>
<td>6</td>
</tr>
<tr>
<td>Inadequate earthing of module frames</td>
<td>7</td>
</tr>
<tr>
<td>Missing or inadequate documentation</td>
<td>6</td>
</tr>
<tr>
<td>Incorrect wiring of polarised DC circuit breaker</td>
<td>5</td>
</tr>
<tr>
<td>Exposed live conductor</td>
<td>4</td>
</tr>
<tr>
<td>Insufficient ventilation limiting airflow around modules</td>
<td>4</td>
</tr>
<tr>
<td>Incorrect or inappropriate labelling</td>
<td>4</td>
</tr>
<tr>
<td>Incorrect functional earthing</td>
<td>3</td>
</tr>
<tr>
<td>Parallel strings with different number of modules connected in series to the same MPPT or charge controller</td>
<td>3</td>
</tr>
<tr>
<td>Corrosion of equipment due to contact between dissimilar metals</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>134</td>
</tr>
</tbody>
</table>

There are 134 entries to the original version of PVFRP associated with installation in PV systems and components which dominate all the reported failures to this particular survey. An inadequate cable protection and water ingress into component enclosures are two major problems identified (Even though installation has been done based on Australian standards, there are reported failures associated with improper installation.

Table 4 and Figure 16).
Some safety problems were also reported such as incorrect wiring of polarised DC circuit breakers, inadequate earthing of module frames, inadequate sealing of roof penetrations, water ingress into component enclosures, exposed live conductor, missing or inadequate documentation, incorrect wiring of polarised DC circuit breaker and incorrect rating of components (e.g. isolators, fuses, and cable).

Installation reported failures have also been recognised by different other studies such as the PV System Safety Audit of 20 Public School Installations in Perth in 2011 and All India Survey of Photovoltaic Module Degradation in 2014. Those two studies are summarized in section 2.2.1. For instance, the PVFRP up to October 2017 and the school audit obtained the following similar findings: inadequate cable protection, inadequate or missing...
Photovoltaic Module and System Fault Analysis

documentation, inappropriate or incorrect labelling, an inadequate or incorrect rating of the component, and use of standard multi-core TPS cable for DC.

All India Survey of Photovoltaic Module Degradation in 2014 identified similar findings such as over-rating of modules and Fault of PV systems, and water ingress into component enclosures.
Chapter 5 - The Result and Evaluation of the Revised Version of PVFRP

5.1 Introduction
In the following subsections, the data after two months of operation of the revised version of the PVFRP is evaluated, presented and compared with the findings from the literature review.

5.2 General Findings
The composition of the revised version of PVFRP is presented in Figures 17 to 21 in order to check the representativeness of the data with respect to the most essential PV system characteristics.

During the first two months of operation of the revised version of the survey, a total of 38 respondents have reported issues associated with PV system components and installation in Australia. Figure 17 demonstrates the type of respondents reported using the revised version of PVFRP. The majority of failures have been reported by the owner/operator (27 users).
Figure 18 demonstrates the geographical distribution of the respondents. While one report had been recorded from Tasmania, most of the other States recorded between two to ten reports. However, there had not been any reports from the Northern Territory.
The sizes of systems reported vary broadly, with most of the reports lodged for systems of 1.1kW to 5kW (28 systems) as can be seen in Figure 19. Most of the PV systems reported are grid-connected PV systems without batteries (21 out of 38). There are also 7 PV systems are grid connected with batteries Figure 20.
Figure 19: Systems by Size

Figure 20: System by Types

Figure 21 illustrates the number of entries for each of the different sections.
5.3 PV Module Section

5.3.1 Module Failure Types

The reported failure types vary broadly (26 entries). Glass breakage (5 entries) was found to be slightly more common as can be seen in Figure 22 and .
The other failures found within the PV module reported failures included: Framing issues, encapsulant discolouration issues, and cell interconnect. The problems reported in the Module section are similar to those failures found during a visual inspection (Kontges et al., 2014) and the IEA survey (Köntges et al. 2017). For example, delamination, bubbling, burnt diodes, and loose contacts within junction box are found in all these four studies. Cell discolouration issues including cracks or snail trails were not reported in the revised version. In general, the PV module failures reported through the revised version of PVFRP are similar to those found in the original version of the PVFRP.

### 5.3.2 Module Certification and/or Labelling Issues

There are 11 entries with the certification and/or labelling of PV modules which can be seen in
Photovoltaic Module and System Fault Analysis

Table 5. The modules that are not CEC approved, and modules that do not have manufacturer's warranty are found to be the top three issues.

<table>
<thead>
<tr>
<th>Failure Types</th>
<th>No of Failures Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-certified components used in modules</td>
<td>1</td>
</tr>
<tr>
<td>Modules are not CEC approved</td>
<td>3</td>
</tr>
<tr>
<td>Modules are not correctly labelled</td>
<td>1</td>
</tr>
<tr>
<td>Modules do not have manufacturer's warranty have but not identify</td>
<td>2</td>
</tr>
<tr>
<td>total</td>
<td>11</td>
</tr>
</tbody>
</table>

5.4 Inverters

There are 24 entries associated with failures in inverters (Table 6). In the revised version of PVFRP inverters suffered complete failures and partial failures also dominate the total reported failures with 9 reported failures and 6 reported failures respectively (Figure 23). Only 7 out of 9 inverters with complete failures had been fixed, and 2 out of 6 inverters with partial failures had been fixed. Participants also reported some customer support issues associated with inverter failures: Getting defective inverters fixed take quite a while, with four of the reported inverters taking 3 months in order to be replaced. The other failures found within the PV inverter reported failures included: Safety issues, and unknown failure and other inverter issues. In general, the findings within the Inverter section in up to 30 of November 2017 through the revised version of the PVFRP are similar to those found in the original version of the PVFRP.
Table 6: Inverter Failure Types

<table>
<thead>
<tr>
<th>Failure Types</th>
<th>No of Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete failure</td>
<td>9</td>
</tr>
<tr>
<td>Partial failure</td>
<td>6</td>
</tr>
<tr>
<td>Other (specify by users)</td>
<td>6</td>
</tr>
<tr>
<td>Safety issue</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
</tr>
</tbody>
</table>

5.5 Other Equipment

There are 23 entries in Other Equipment section (Error! Reference source not found.) which include: 5 failures with rooftop isolators, 4 failures with the framing/mounting structure, 4 failures with the main DC cable, 3 failures with the PV array isolator, 3 failures in the battery, and 2 failures with the optimiser. Failures in the battery are also recognised in the “All India Survey of Photovoltaic Module Degradation” in 2014 (Chattopadhyay et al. 2015) and revised version of PVFRP. In general, the findings within
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this section in up to 30 of November 2017 through the revised version of the PVFRP are similar to those found in the original version of the PVFRP.

5.6 Installation Issues

There are 33 entries to the revised version of PVFRP associated with installation in PV systems and components which dominate all the reported failures (Table 7 and Figure 24).

<table>
<thead>
<tr>
<th>Installation issues</th>
<th>No of Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate cable protection</td>
<td>3</td>
</tr>
<tr>
<td>Missing or inadequate documentation</td>
<td>3</td>
</tr>
<tr>
<td>PV system not allowing roof self-cleaning i.e. build-up of leaves etc.</td>
<td>3</td>
</tr>
<tr>
<td>Incorrect or inappropriate labelling</td>
<td>3</td>
</tr>
<tr>
<td>Inappropriate location for inverter (i.e. poor access, poor ventilation, exposed to direct sunlight, etc)</td>
<td>3</td>
</tr>
<tr>
<td>Corrosion of equipment due to contact between dissimilar metals</td>
<td>2</td>
</tr>
<tr>
<td>Incorrect rating of components (please specify which component, i.e. cable, isolator, fuse etc)</td>
<td>2</td>
</tr>
<tr>
<td>Insufficient ventilation limiting airflow around modules</td>
<td>2</td>
</tr>
<tr>
<td>Water ingress into component enclosures</td>
<td>2</td>
</tr>
<tr>
<td>Inadequate earthing of module frames</td>
<td>2</td>
</tr>
<tr>
<td>Inadequate sealing of roof penetrations (i.e. roof leaking)</td>
<td>2</td>
</tr>
<tr>
<td>DC and AC wiring inadequately segregated</td>
<td>2</td>
</tr>
<tr>
<td>Incorrect wiring of polarised DC circuit breaker</td>
<td>1</td>
</tr>
<tr>
<td>Insufficient array fixing</td>
<td>1</td>
</tr>
<tr>
<td>Exposed live conductor</td>
<td>1</td>
</tr>
<tr>
<td>Incorrect functional earthing</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
</tr>
</tbody>
</table>

In general, the reported failure types vary broadly, and are fairly evenly distributed over the different types. Installation reported failures have also been recognised by different studies such as the PV System Safety Audit of 20 Public School Installations in Perth in 2011 and All India Survey of Photovoltaic Module Degradation in 2014. For example, the revised version of PVFRP up to 30 of November 2017 and the school audit obtained the following similar findings: inadequate cable protection, inadequate or missing documentation,
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inappropriate or incorrect labelling, an inadequate or incorrect rating of the component, and use of standard multi-core TPS cable for DC.

The revised version of PVFRP up to 30 of November 2017 and All India Survey of Photovoltaic Module Degradation in 2014 identified similar findings such as over-rating of modules and Fault of PV systems, and water ingress into component enclosures.

Figure 24: Installation Issues Types

Some safety problems were also reported (Figure 24) such as incorrect wiring of polarised DC circuit breakers, inadequate earthing of module frames, water ingress into component enclosures.
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enclosures, exposed live conductor, missing or inadequate documentation, incorrect wiring of polarised DC circuit breaker and incorrect rating of components (e.g. isolators, fuses, and cable).

Installation reported failures through the revised version of the PVFRP have also been recognised by the original version of PVFRP mention early (section 4.6).

In general, the findings within the Inverter section in up to 30 of November 2017 through the revised version of the PVFRP are similar to those found in the original version of the PVFRP.

In general, the findings within this section in up to 30 of November 2017 through the revised version of the PVFRP are similar to those found in the original version of the PVFRP.
6. Chapter 6 - Conclusion and Future Work

6.1 Conclusion

To summarise, this thesis project has introduced two version of an online questionnaire called the Module and System Fault Reporting Portal (PVFRP): Original and revised versions. This thesis project also analysed the operational failures in the PV systems in Australia obtained from both versions. The findings from the PVFRP are compared with the literature review findings of similar area studies. The original version was in operation for 41 months, and a revised version is just published (2 months). Initially, the reported data during the operation of PVFRP are collected. The collected data was then filtered, validated, evaluated, and compared with the findings from the literature. The number of entries is not sufficient to claims comprehensive conclusion with respect to climate zone or geographic regions. For example, in the original survey, many respondents (75 out of 122) did not report their postcodes or the name of places where the PV system installed. Moreover. In the revised version only one report had been recorded from Australian Capital Territory, three from South Australia and in the revised version only one report had been recorded from Tasmania.

The findings from the PVFRP data indicated problems related to PV system reliability and performance as there are different failures reported in modules, inverters, other equipment, installation and other general issues in PV systems. In General, the findings from the PVFRP are also recognised in the literature findings of similar area studies undertaken both internationally and nationally. It is also concluded that failures associated with installation in systems and components dominate all the reported failure to Portal in both versions of
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the survey. With Installation section, safety issues were also reported such as incorrect rating of components and Inadequate cable protection.

In the PV module section, glass breakage dominates all the reported failures in the original (13 out of 84 entries) and (5 out of 26 entries). Inverter suffered with complete failures dominate the reported failure in Inverter section. There are also several reported regarding the services: some users (49%) reported that their problems that had not yet addressed by the manufacturer or the supplier. Moreover, module installers and manufacturers should pay more attention while packaging and handling of the modules during transportation because improper handling can develop cell cracks and subsequently long-term degradation.

It is noticeable that with the time progresses, more respondents report failures in PV systems to PVFRP. Therefore, the PVFRP questionnaire is served its purpose even though there are few responses with differed locations and at this current stage. Beside that the revised version of this portal is less time-consuming to fill out. Additionally, the post code entry was made compulsory to allow for data analysis with respect to climate zones in Australia. Accordingly, the obtained data are predicted to be increased.

6.2 Future Work

1) Data from the revised PVFRP should be collected, filtered, validated, evaluated yearly.

    If it is too hard for the Project Participants to obtained that due to their other duties to make an annual report similar to previous two report ( (Zaman et al. 2014) and (Zaman, Parlevliet, and Calais 2015)), it can be done as thesis project. A regularly published report will help to identify any new entries failures areas in Australia.
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2) Currently, the PVFRP is advertised in APVI, and CEC and an article on the release of the new survey was recently published through Reneweconomy an article by Murdoch Media staff is currently being prepared. More advertising of the new survey can be done such as on TV channels and in different newspapers. Therefore, there will be more data available on failures in the PV systems.

3) Verification of inconclusive entries through follow up calls/emails where contact information has been provided to increase the number of responses

4) If a sufficient number of responses is obtained, the findings from PVFRP could assist in matching some degradation failures with climatic zones.

5) Further survey improvements: Currently, there are different failure types offered for the user to choose within each section. However, providing a photo for each failure type option would assist the user to report failure in the appropriate section.

6) In the future, if a sufficient number of responses can be obtained, the findings from PVFRP could assist in improving products, system design and installation practices. Targeted manufacture testing to overcome issues noted within specific climate zones can be developed. Some work is done in this area (Köntges et al. 2017).
7. Appendix

This section demonstrates screenshots of the questions of the revised version of Photovoltaic (PV) module and System Fault Reporting portal (PVFRP) and brief explanation provided for these questions. The total number of questions in the revised survey is 152.

Note: the revised survey methodology are described in section 3.1.3.

7.1 Description and General Details

Figure 25 and Figure 26 demonstrate the introduction of the revised survey. The user must declare that he or she read and understood the safety instructions as can be seen in Figure 25.
Photovoltaic Module and System Fault Analysis

Project background: This web-based survey is being used to collect information about faults, issues and problems associated with Solar Photovoltaic (PV) systems in Australia. It will assist in improving future PV system design, component selection and product development for Australian conditions. It is supported by the Australian Renewable Energy Agency (ARENA) and coordinated by the Australian PV Institute (APV), the Clean Energy Council (CEC), and partners UNSW, Murdoch University and CAT Projects.

Survey participants: This survey has been designed for anyone who owns, operates, installs or inspects a PV system and has detected a fault/problem with whole or part of the system. Module manufacturers are also encouraged to provide data collected from warranty returns. You can remain anonymous by not providing your contact details, however, we would prefer to be able to contact you if we need to clarify any of the information you have provided.

Safety Instructions: Users of the survey are advised that assessing some of the issues in PV installations should only be performed by a trained professional with appropriate safety equipment. We strongly recommend that only competent people with appropriate training and safety equipment climb on the roof to inspect the solar system. Only an accredited installer should touch the solar electrical wiring as dangerous voltages are present even when the system is turned off. Please engage a CEC Accredited Installer to inspect the system on your behalf and submit a written report to you with a photo of the module rating label if appropriate.

* Declaration

I have read and understood the safety instructions.

Disclaimer: This is a research project only. Problems will not be fixed as a result of reporting through this survey. Customers with a grievance should take up warranty issues with their installer, or the equipment manufacturer’s representative in Australia. If this is unsuccessful they may contact their state consumer affairs office for assistance. Complaints about accredited installers may be lodged with the accreditation body, the Clean Energy Council.

Use of the data/information: The aim of this survey is to increase the understanding of the PV industry about the types of problems that are found with different system components when they are exposed to the Australian environment. Summaries of this information will be presented in journals and will be made available on APVI, ARENA and CEC websites.

Rights of the participants: Although we appreciate as much information as you can provide, you do not need to answer all the questions.

Privacy policy: The information provided in this questionnaire will be used by the research team to improve the standard of PV systems. Information specific to a particular installation or system components may be provided to the relevant installer or manufacturer, but only with your written consent. However, your personal information will not be presented in any publications or disclosed to anyone outside the project team without your written permission/consent, unless required to do so by law. The raw data will not be available for the public to view.

Ethics Approval: This study has been approved by the Murdoch University Human Research Ethics Committee (Approval 2014/030). If you have any reservations or complaint about the ethical conduct of this research, and wish to talk with an independent person, you may contact Murdoch University’s Research Ethics Office (Tel. 08 9360 5677 or e-mail ethics@murdoch.edu.au). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

If you have any questions about this project, please feel free to contact us. Please note that we will not provide advice on system performance or on how to fix problems.

Dr. Martina Calata, Senior Lecturer, School of Engineering and Information Technology, Murdoch University, Murdoch WA 6150, Tel. 08 9360 7020, info@apvi.org.au
Robert Passey, Senior Research Associate, Centre for Energy and Environmental Markets, University of NSW, Sydney NSW 2052, info@apvi.org.au

Figure 25: PVFRP Survey - First Page
Photovoltaic Module and System Fault Analysis

Figure 26: Revised Version of PVFRP Survey - Overview

Figure 27 and Figure 28 illustrate the questions where the respondent is asked to provide personal details, installation details, and system description. The user may also specify if he or she is an end user or a specialist (e.g. inspector, auditor, and manufacturer). Personal information is not compulsory, but the respondents are encouraged to provide a means of communication.
You can remain anonymous by not providing your contact details, however, we will not be able to contact you if we need to clarify any of the information you have provided. To review the Privacy Policy associated with this survey please go back to the Introduction page.

2. Your personal details
Name
Phone
Email

3. Are you a PV system
- Owner/Operator
- Installer
- Inspector/Auditor
- Manufacturer/Distributor
- Other (please specify)

4. Location of installation
Postcode
Street name
City / Town
State

Figure 27: PVFRP Survey - Personal Details and System Description
According to the fault type encountered, the respondent is asked to choose one of five different sections: Module, Installation, Inverter, Other Equipment and General Issues as can be seen in Figure 29.
Photovoltaic Module and System Fault Analysis

The survey questionnaire has been divided into sections focusing on issues and problems associated with:

- Key Solar Photovoltaic System Components (solar modules and inverters)
- Other equipment - includes circuit breakers, switches, array mounting hardware and DC cabling. If any of the following are installed batteries, charge controllers and data loggers.
- System installation - addresses any issues that may have arisen from an improper or non-standard installation.
- Other issues - This will help to provide information that does not fit elsewhere.

* 7. What do you want to report about? (please select one item. You will be able to return to this section if you have other items to report on)
  
  - PV module
  - Inverter
  - Other equipment
  - Installation
  - Others (General)

After clicking one section, the survey will take the user to that section (e.g. PV module section).

7.2 PV Module Associated Faults

In the PV Module section, different failure types are offered to the user to select as can be seen in Figure 30. The user will be able to report one failure type at one time.
7.2.1 Glass Breakage Problem

The user has to select the failure type such as glass breakage. Glass breakage is the first option on the list provided (Figure 30).

The user will then have to provide further details regarding the glass breakage problem encountered as can be seen in Figure 31, Figure 32 and Figure 33. These detail questions are discussed in details in section (3.1.3).
Photovoltaic Module and System Fault Analysis

Figure 31: PVFRP Survey - Glass Breakage Problem Period

Figure 32: PVFRP Survey - Glass Breakage versus System performance (%)
7.2.2 Other Module Problems

After providing the required detail of the reported failure (glass breakage), the respondent has an opportunity to report another module problems encountered as can be seen in Figure 34.
If the respondent has another module failure, he or she will go back to the previous list options (Figure 30). The respondent will have a chance to select another issue and he or she will then have to provide further details for each failure similar to those details associated with glass breakage problem (Figure 31, Figure 32 and Figure 33).

7.2.3 Module Certification Issues

When all the PV module failures are added, the user can report certification and/or labelling issues as can be seen in Figure 35. The user can report multiple failures at a time.
* 14. Are you aware of any issues related to module certification and labelling?

○ No
○ Yes.

Figure 35: PVFRP Survey - Module Certification Issue

When all the certification and/or labelling issues are added, the user is returned to the section list, albeit reduced as can be seen in Figure 36.

* 16. Would you like to report about another component? Please select one item. You will be able to return to this section if you have other items to report on.

○ Inverter
○ Other equipment
○ Installation
○ Others (General)
○ No, I have finished reporting

Figure 36: PVFRP Survey - Module Certification Issues List

7.3 Inverter Associated Faults

In the Inverter section, five options are offered to user to choose (Figure 37).

Then the respondent has to provide further details regarding inverter problem as can be seen in Figure 38, Figure 39 and Figure 40. These details questions discussed in detail in section (3.1.3). The user will be able to report one failure type at one time.
7.3.1 Inverter Partial Failure
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Figure 39: PVFRP Survey - Inverter Problem versus Performance (%)
7.3.2 Other Inverter Problems

After providing the required detail of the reported failure, the respondent has an opportunity to report any other inverter problems (Figure 41).
When all the inverter failures are completed, the user is returned to the section list, albeit reduced as can be seen in Figure 42.

**Figure 41: PVFRP Survey - Identify Another Inverter Problem**
Figure 42: PVFRP Survey - Choice of Report

7.4 Other Equipment

The user will be able to select multiple failure types from the list of different options, and he or she will then have to provide further details at one time in the Other Equipment section as can be seen in Figure 43 and Figure 44.
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Figure 43: PVFRP Survey - Other Equipment Issue

* What issues or problems with equipment other than modules or inverters did you encounter? Tick as many as applicable.

- Framing/mounting structure
- Rooftop isolator
- PV array isolator
- Main DC cable
- Battery
- Optimiser
- Other (please specify)

* Have you noticed any reduction in system performance (kWh's of electricity produced) as a result of the problem?

- No
- Yes
- Not sure

Figure 44: PVFRP Survey - Other Equipment Issues Duration and Performance (%)

* Do you know how long had the system been operating at the time the problem was discovered?

- No
- Yes (please enter duration in months)

* Has the problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)
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When all the other equipment failures are completed, the user is returned to the section list, albeit reduced as can be seen in Figure 45.

7.4.1 Installation Issues

The user will be able to select multiple failure types from the list of different options, and he or she will then have to provide further details at one time in the Installation section as can be seen in Figure 46 and Figure 47.
* What type of installation issue have you noticed? Tick as many as applicable.

- Inappropriate array location
- Insufficient array fixing
- DC and AC wiring inadequately segregated
- Inadequate cable protection
- Use of standard multicore TPS cable for DC
- Exposed live conductor
- Incorrect wiring of polarised DC circuit breaker
- Inadequate earthing of module frames
- Incorrect functional earthing
- Water ingress into component enclosures
- Parallel strings with different number of modules connected in series to the same MPPT or charge controller
- Incorrect or inappropriate labelling
- Missing or inadequate documentation
- Inadequate sealing of roof penetrations (i.e. roof leaking)
- PV system not allowing roof self-cleaning (i.e. build up of leaves etc.)
- Corrosion of equipment due to contact between dissimilar metals
- Inappropriate location for inverter (i.e. poor access, poor ventilation, exposed to direct sunlight, etc.)
- Insufficient ventilation limiting airflow around modules
- Incorrect rating of components (please specify which component, i.e. cable, isolator, fuse etc.)

* Have you noticed any reduction in system performance (kWh’s of electricity produced) as a result of the problem?

- No
- Yes

Figure 46: PVFRP Survey - Installation Issue
When all the installation failures are completed, the survey takes the user to General Issue section.

7.5 General Issues

In General Issue section, the user has a chance to add any failure that cannot be reported in the other four sections. The user will then have to provide further details of the reported failure as can be seen in Figure 48 and Figure 49 and Figure 50.
Figure 48: PVFRP Survey - General Issue

Figure 49: PVFRP Survey - Additional Reporting
7.5 The Survey Completion

Finally, the user can provide further information such as photographs and a mean of communication and submit the survey as can be seen in Figure 51.
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