PV Module and SystemFault Analysis

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ABSTRACT

In the recent years, there is a noticeable escalation in the number of Photovoltaic module systems installed on the rooftops for the residential and small level commercial purposes. Lower consumer prices, government grants and increase in the awareness of environmental issues are some of the basic causes for this increase. Increase in the renewable energy production is a long term solution to the problems faced due to the fossil fuels energy production methods including the availability and cost of the fossil fuels and environmental pollution.

To keep the positive slope of the trend of accepting the Photovoltaic module systems on the residential basis by the common residential people and to encourage more general public to install the Photovoltaic module systems on their rooftops, it is very important to increase the reliability and durability of the Photovoltaic module systems. Photovoltaic module and system fault analysis is an ongoing assignment in order to increase the efficiency, safety,reliability and durability of the PV system. It is an essential requirement for the PV systems to operate continuously while providing the maximum output results.

This thesis project explains the causes and results of the noticeable faults occur during the operation of the Photovoltaic module systems. These faults include the visible changes in the appearance of the Photovoltaic modules, reduction in the system performance, faults in the other main components of the Photovoltaic module system i.e. inverters, batteries, junction box, etc.

For the purpose of analyzing the faults and its causes in the Photovoltaic module systems, this thesis project investigates and analyzes the survey data collected from the survey conducted by the Australian Photovoltaic Institute (APVI). This survey data provides the information about the faults experienced by the installers and the users of Photovoltaic module systems. Other surveys and reports such as Solar Business in Australia Survey, International Energy Agency Survey are also analyzed and their results have been compared in order to find any relevance of the specific faults to occur.

This thesis project moreover investigates the frequency of the faults occurs during the operation of the Photovoltaic module system. Effect of different climate zones and environmental conditions on the operation, reliability and durability of the Photovoltaic module system is also analyzed from the survey's results, reports and other thesis as a part of literature review for the research for this thesis.

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CONTENTS

FIGURES AND TABLES

ACRONYMS

PV- Photovoltaic

KW- Kilo Watt

MW- Mega Watt

DC- Direct Current

AC- Alternating Current

UV- Ultra Violet

PCU- Power Control Unit

EVA- Ethyl Vinyl Acetate

1. CHAPTER -1 INTRODUCTION

1.1. BACKGROUND

Today, in a world where everything is dependent on electricity as a major source of energy for everyday life and for the small to large scale industries. This causes the demand of electricity to rise and the demand for the power is significantly large at this time. By 2035, global energy demand is expected to rise by 50% in comparison with 2014. (Antoniazzo)

Fossil Fuels are the major source of electricity production worldwide. Figure 1 shows the share of fossil fuels which is 80.6% of the total energy consumption in the world in 2010. Modern renewable sources including solar, hydropower, wind and biofuels share 8.2% of the total world's energy consumption, shown in Figure 2. (Renewables 2012 Global Status Report, 2012)

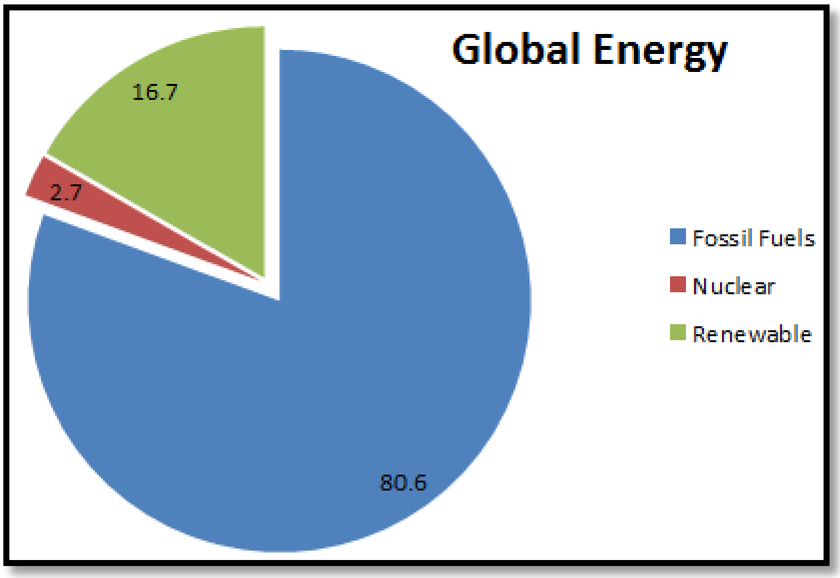

Figure 1: Energy Shares of Global Energy Consumption 2010 (Source: (Renewables 2012 Global Status Report, 2012))

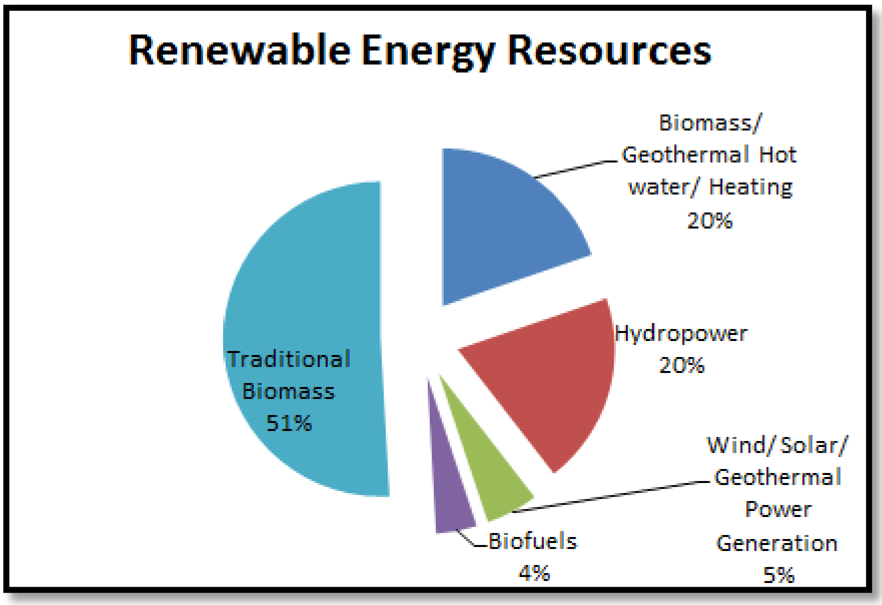

Figure 2: Renewable Energy Sources of Global Energy Consumption in 2010 (Source: Renewables 2012 Global Status Report, 2012))

The problem of fossil fuels running out will be faced soon. It is expected that the running out dates of oil is 2055, natural gas is 2072 and coal is 2128. (Antoniazzo). So, limited availability of the fossil fuels is a big concern at the moment and as the expected depletion date will keep on advancing, the prices of the fuel will keep increasing. Moreover, at some stage, it will be not affordable to generate power using the methods requires the consumption of fossil fuels.

Another issue which is been faced today is global warming and environmental pollution caused by the emission of the harmful gasses from the power plants using fossil fuels. A typical coal power station produces 3.5 million tons of carbon dioxide per year. It also produces other gasses includes sulphur dioxide, nitrogen dioxide, harmful particles and mercury. (Coal Power: air polution, 2011) (Clean Energy, 2013). All these gases are very harmful and perform a significant role in global warming and extinction of life on the planet Earth. (Tverberg).

In order to overcome the above problems, the power industry is concentrating more and more into the area of the development of the renewable sources of energy and to make them more efficient, cost effective and reliable.

Solar energy, wind energy and hydro energy are the major resources of energy in the field of renewable energy. (West, 2014). In 2013, over 38.4 GW of PV systems were installed all around the world. (Gaëtan Masson (iCARES Consulting), 2014). Considering the environmental conditions and the availability of solar energy in Australia, Australian continent records the highest solar radiation per square meter than any other continent. Figure 3 shows the mean annual availability of the solar energy in Australia. So, solar energy resource is very viable in Australia. Australia receives 10,000 times solar energy than its consumption therefore; solar energy is a great alternative form of energy. (Solar Energy, 2010). It is estimated that about 1 million houses in Australia would have PV solar panels by 2013. It is also mentioned that Australia targets on 20% sourcing from renewable energy by 2020 as shown in Figure 4. (Hannam, 2012) (Trabish, 2013). Figure 4 also represents the statistics of the rapid grown in the PV systems industry in Australia.

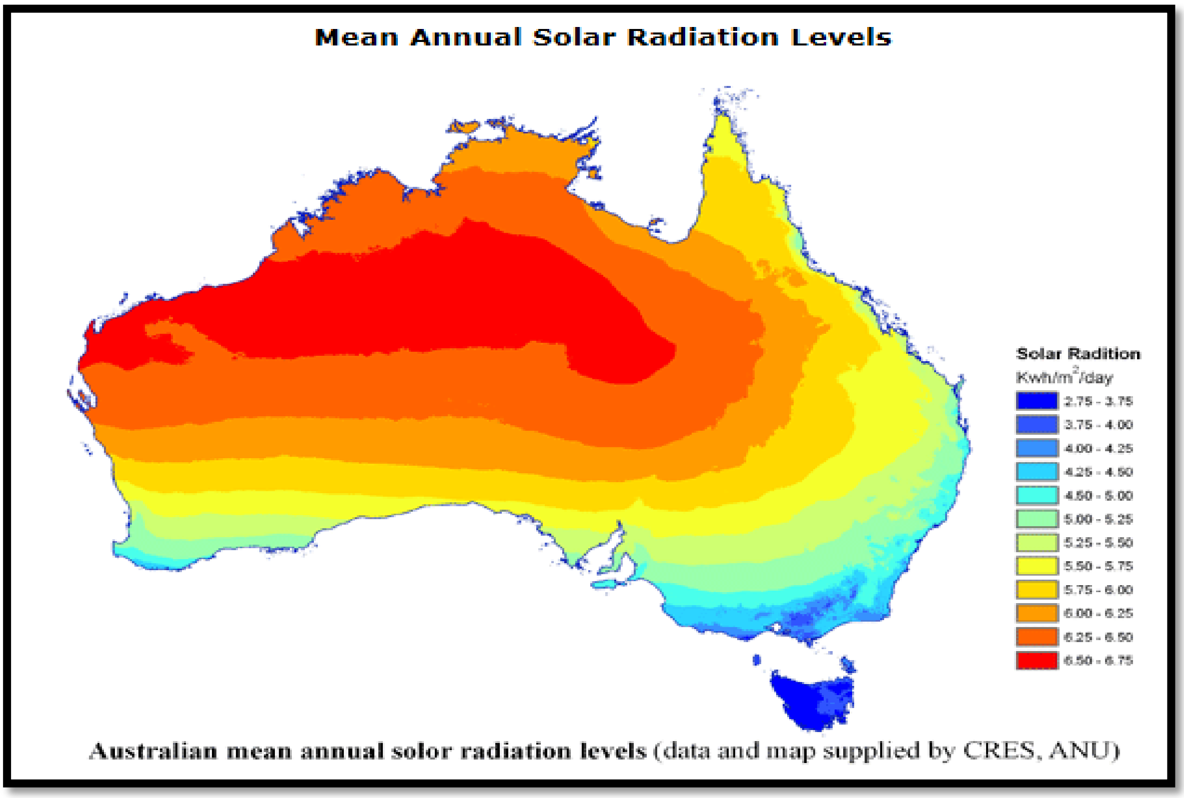

Figure 3: Annual mean solar radiation (in kWh/m2/day). (Source: (GENI, 2009))

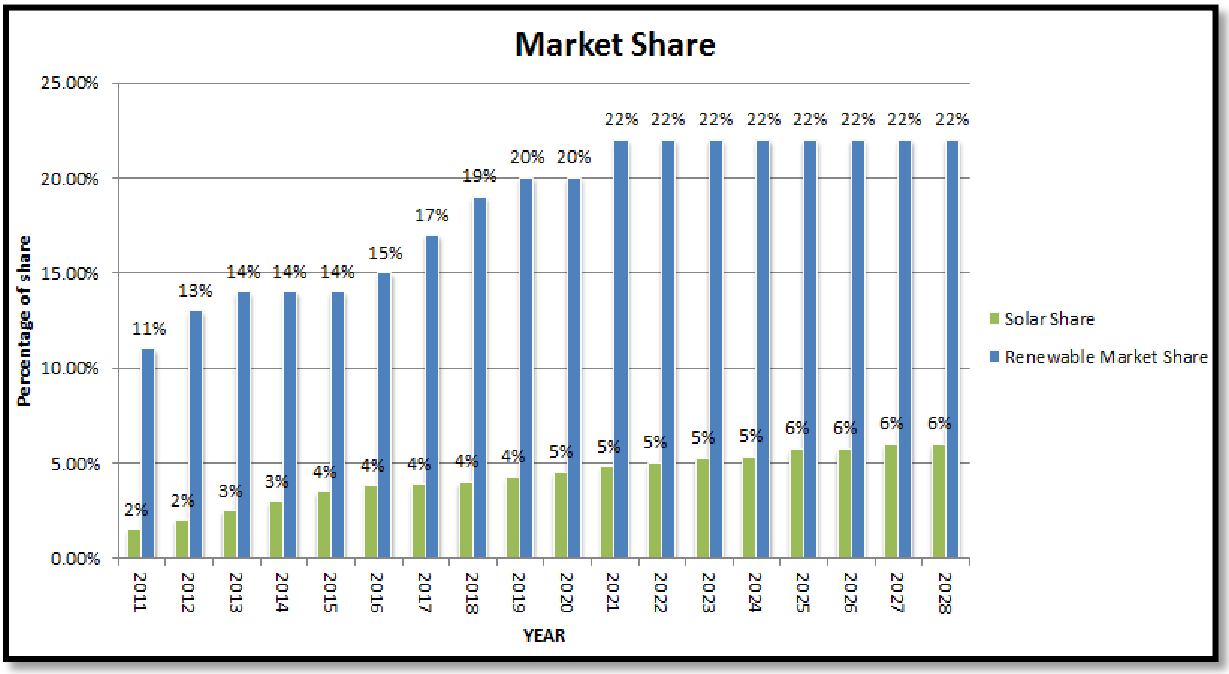

Figure 4: Australian renewable market share Target (Source: (Trabish, 2013))

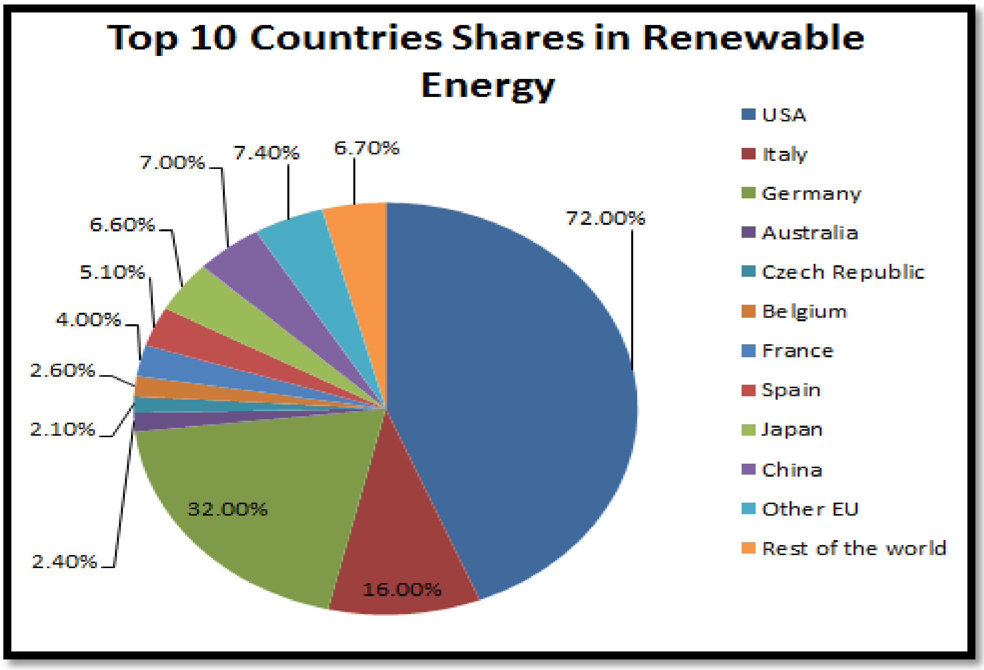

Figure 5: Solar PV Global Capacity, Shares of top 10 countries (Source: (Solar Energy, 2013))

In the year 2012, Australia is in the list of top 10 countries as shown in Figure 5which shows that Solar PV capacity of Australia is 2.4% of the Global PV capacity. Germany is the top producer of the solar power producing 32% of the Global PV solar capacity.

Photovoltaic module systems use solar cells to convert the solar energy into electricity and these systems are used for residential and commercial purposes. The typical system includes PV modules and the Inverter. In a typical household situation, PV systems are Grid connected systems as shown in Figure 6. Power is imported from the grid for the household use and also exported to the grid directly from the inverter when it is available in excess. (Canadian Mortgage and Housing Corporation, 2010)

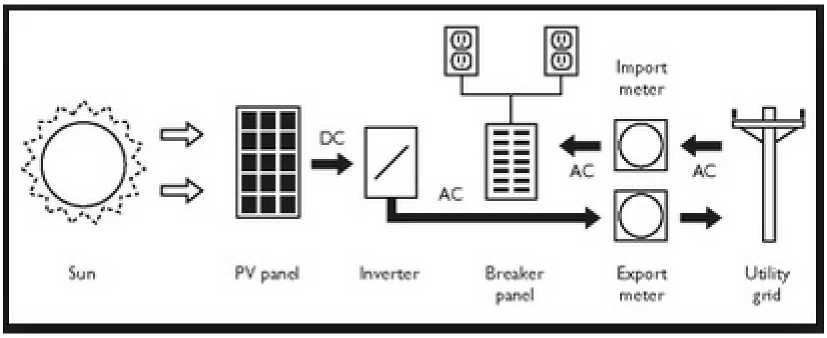

Figure 6: residential Photo- Voltaic Generated Electricity systems (Source: (Canadian Mortgage and Housing Corporation, 2010))

Photovoltaic cells are generally made up from modified silicon or other semi-conductor materials that absorb the solar energy and convert it into the power. PV system is made up of a number of PV modules which consists of a number of solar cells connected to each other. More than one PV module connect together to make an array of PV modules. Array generates DC which is converted into AC by an inverter. (Canadian Mortgage and Housing Corporation, 2010)

1.2. AIM OF THE THESIS PROJECT

The primary aim of the project is to research and analyse the faults that occur during the operations of the PV module and PV system. This work will assist other research projects to identify the causes of the faults and failure of the PV systems and to increase the reliability and efficiency of the PV systems. Analysing the faults occurring in the operation of the PV modules will help in understanding the issues and causes which results in the failure of the PV module systems.

The major focus of this project is to study the issues related to the environmental conditions at the site of the system. Environmental conditions in Australia are very harsh and do have potential to break the PV module or to affect the efficiency of the module. This project will try to correlate the faults at different locations, the frequency of the fault and their causes.

The projects uses data collected by the Australian PV Institute (APVI), Murdoch University, Clean Energy Council and Australian Renewable Energy Agency (ARENA) by conducting various surveys through their websites. (Clean Energy Council, 2014)

In order to increase the reliability and durability of the Photovoltaic (PV) system, APVI and other renewable energy supportive organizations are working in the direction to analyse and investigate the faults that usually occurs during the operation of the Photovoltaic (PV) module system. This includes collecting the information about the problems and the faults facing by the users and installers of Photovoltaic module systems through a survey. The survey requests the users and installers to fill out the questionnaire regarding the faults and problems that they detect during the installation and operation of the PV system. The survey provides the information about different types of faults occurs at the different locations around Australia. The common faults investigated by the survey and will be looked upon in this thesis are Glass Breakage, Delamination, Discolouration, Natural Impacts on the efficiency of the modules such as corrosion due to the salty and humid atmosphere along the coastal regions and high temperature in the dessert zones [11]. The survey information includes type of the system, size of the PV array and system, model and manufacturer of the PV module and the information about the inverter and other components of the system. The survey is designed to study the fault analysis of the PV systems across Australia to overcome the current issues with the PV systems.

In this thesis, relevant research and results from other reports and thesis projects are used to compare the faults and to find the trend, cause and relevance of the different faults and their frequency of occurrence during the operation of the Photovoltaic module system in the field.

This thesis project is a part of the on-going project which is being conducted at Murdoch University; an online survey which is designed for users and installers to provide the information about the various faults occurs in the operation of the PV module systems. The whole project has been carried out by Murdoch University in order to improve the design and the operations of the PV modules to achieve the high efficiency in different environmental conditions in Australia with low cost systems design and more reliability.

1.3. OUTLINE OF THE REPORT

Section 1 of this report provides the introduction and background information about this thesis project.

Section 2 of this report provides the information about the designing, construction and the working principle of the Photovoltaic module systems.

Section 3 of this report explains the information about different types of the major faults which usually occur in the PV module system during its operation in the field.

Section 4 provides the information about the climate conditions in Australia which may affect the performance and the durability of the PV module systems.

Section 5 of this report is the Literature review which explains the information gathered from the other reports and surveys related to the PV module systems and the faults associated with them.

Section 6 describes the information and results derived from the data provided by the Australian Photovoltaic Institute from the web based survey conducted by them in Australia.

Section 7 of this report includes the discussion of the results and the information collected from this thesis project.

Section 8 provides the conclusion of this thesis project and Section 9 provides the information about the potential future work which can use the information from this thesis report.

2. INTRODUCTION TO PV MODULE SYSTEM

2.1. PRINCIPLE AND DESIGNING OF PV MODULE SYSTEM

2.1.1. INTRODUCTION

This section describes the basic construction and design of a Photovoltaic system and its basic principle of working. This chapter provides the information about the working of a solar cell to utilize the sunlight to convert it into energy. This chapter also explains the construction of a PV module and PV array. Moreover, this chapter also includes the types of different basic Photovoltaic modules and other main components of a complete PV module system.

2.1.2. BASIC PRINCIPLE OF WORKING OF SOLAR CELL

Photovoltaic cell or solar cell converts the energy received from the sun into electricity. The concept on which the solar cell works is called **Photoelectric effect**.

The phenomenon which creates the voltage or electric current in the material when it is exposed to the solar energy is called **Photovoltaic effect.**

Photoelectric effect explains that under the right circumstances, light can be used to push the electrons and has an ability to emit electrons from the material. The material is called **photo emissive** and the phenomena is called the **photoelectric effect.** (Physics Info, 2014)

The main component of a solar cell is silicon. Silicon is a semiconductor which is extensively used in construction of Photovoltaic cells. As a semiconductor, silicon has half of the properties of metals and the other half of its properties belongs to the electric insulators.

Sunlight contains the particles called photons. When photons hits silicon atom, they loses its energy to the silicon atom and silicon atom loose its electron through that energy. To convert these free electrons into electric current, an imbalance is required to make free electrons flow.

By introducing some impurities into the silicon, two different types of silicon layers are created- n type and p-type. Usually n-type contains Phosphorous and p- type contains boron. (Contrata, Atlantech Solar Inc., 2009). The n- type has a spare electron and p- type misses an electron, leaving holes in their place. When (n-type) and (p-type) are placed together, electron from n-type moves towards the p-type to fill up the hole in the p-type.

This leads to the formation of an electric field across the cell. As silicon is semiconductor, it acts like an insulator and maintain the imbalance.Figure 7 shows the diagram of Photovoltaic effect. (physics.org, 2014)

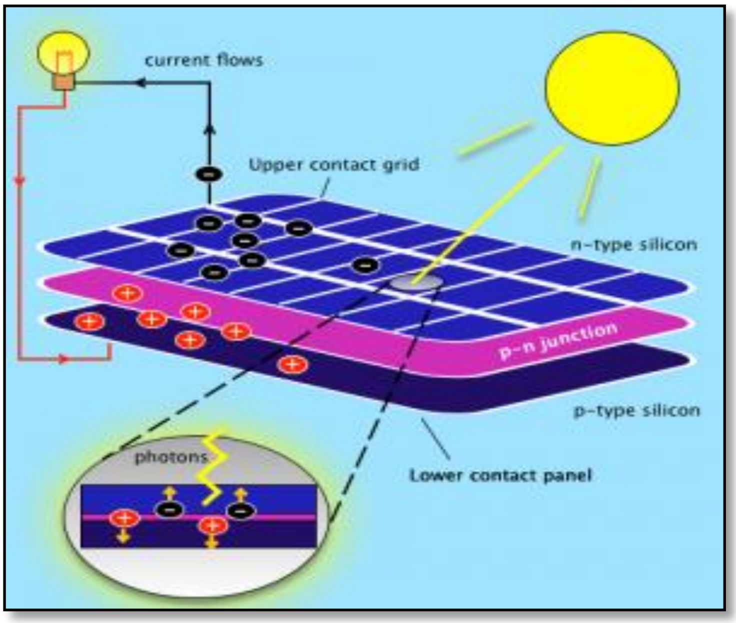

Figure 7: Photovoltaic Effect (Source: (Atlantecsolar, 2009))

2.1.3. ANATOMY/ CONSTRUCTION OF A PHOTOVOLTAIC MODULE

2.1.3.1. BASIC STRUCTURE OF PHOTOVOLTAIC MODULE

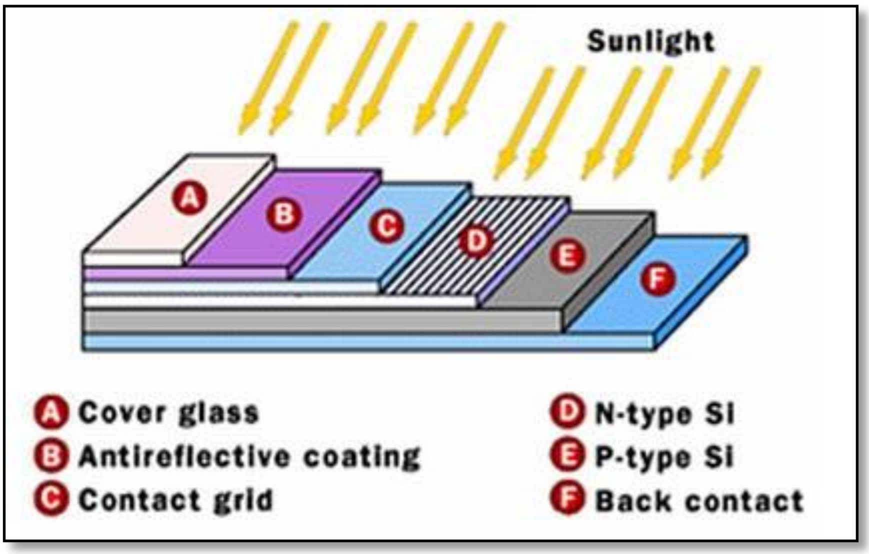

Figure 8- Structure of a basic Photovoltaic Module (Source: (Contrata, Atlantech Solar Inc., 2009))

In the Photovoltaic module as shown in Figure 8, a number of solar cell cores are connected in series with each other to form a solar panel. The panel contains multiple numbers of solar cells connected in series and is framed in a metal and covered with a clear glass and a backing support material.

The top cover layer (A, as shown in the figure above) of the solar cell is usually made up of clear glass and is a part of the enclosure. The sunlight penetrates through the glass to the cells. This layer protects the cells, adds rigidity and encased by a metal frame.

The antireflective coating (B, as shown in the figure above) preserves the sunlight to reflect back from the solar cell. It helps to keep up the efficiency level of the solar cell. This antireflective coating is placed by two different methods. One is by using a thin layer of silicon monoxide to cover the cells. Other is by using a chemical which forms the scathes to form pyramids and cones which help the sunlight to reflect back to the cell.

The contact grid (C, as shown in the figure above) is made up of conductive metals. The contact grid collects the electrons and passes them to an electronic device to the load as electrical voltage.

The n-type semiconductor silicon (D, as shown in the figure above) is doped with the impurities of phosphorous atoms. It produces the negatively charged electrons.

The p-type semiconductor silicon (E, as shown in the figure above) is doped with the impurities of boron atoms. This creates holes in the positive field.

The n-p junction acts like an absorber layer which is present between the N-type semiconductor and P-type semiconductor. At this junction, the negatively charger electrons and positively charged electrons meet and transfer of electricity takes place through the photovoltaic effect.

The back contact layer (F, as shown in the figure above) is a metal layer which protects the bottom of the cell and giving it an extra strength. Combined cells are connected in series and enclosed with the aluminum metal frame together and called module.

(Contrata, Atlantech Solar Inc., 2009)

2.1.3.2. COMBINATION OF SOLAR CELLS TO FORM AN ARRAY

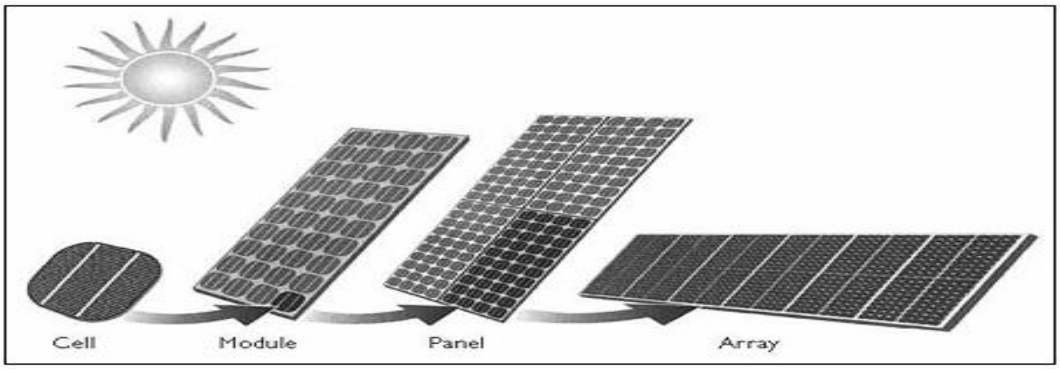

Figure 9: Components of a PV array (Source: (Canadian Mortgage and Housing Corporation, 2010))

The array is a complete power generating component of a PV module system comprising a number of PV modules connected in series or/ and parallel arrangement. The module is made up of a number of solar cells connected in series and then packed up in the encapsulant and backsheet layer of the PV module.

2.1.4. TYPES OF PHOTOVOLTAIC MODULES

2.1.4.1. MONOCRYSTALLINE PHOTOVOLTAIC SOLAR PANELS

Mono-crystalline solar panels are constructed with large crystal of silicon; cut from ingots. This makes the solar panel appears very uniform as shown in Figure 10. The corners of the cells are octagon shaped in the appearance due to the cutting of the wafer material from cylindrical ingots of silicon. These are the most efficient and most expensive type of solar panels as compare to the other types. The lab efficiency of these modules is up to 25%. (Contrata, atlantecsolar, 2009)

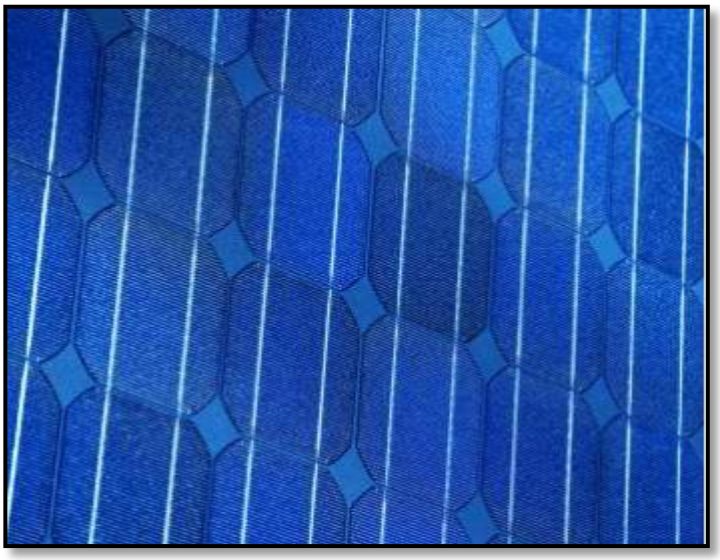

Figure 10: Mono-crystalline Solar Panel (Source: (fotovoltaicosulweb.it, 2014))

2.1.4.2. POLYCRYSTALLINE PHOTOVOLTAIC SOLAR PANELS

Polycrystalline Solar panels are made up of multiple silicon crystal as shown in Figure 11. Polycrystalline cells are made up from cast square ingots- in the process of its construction; large blocks of silicon metal are cooled and solidify. They are most common type of solar panels. These PV modules are less expensive and less efficient as compare to the mono-crystalline PV modules. (Contrata, Atlantech Solar Inc., 2009)

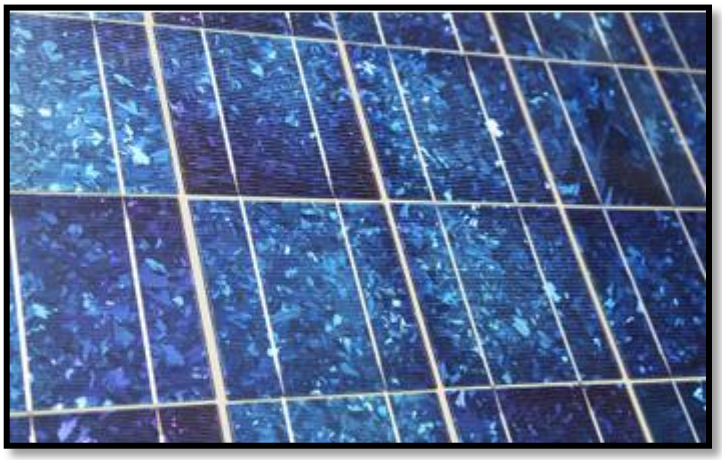

Figure 11: Polycrystalline Solar Panel (Source: (Direct Industry, 2014))

2.1.4.3. AMORPHOUS SILICON (THIN FILM) PHOTOVOLTAIC SOLAR PANELS

Figure 12: Thin Film Solar Panel (Source: (Ontario Solar Farms, 2008-2013))

Amorphous silicon/ thin film solar panels are flexible PV modules as shown in Figure 12. These are made up of a thin silicon material positioned between a laminated chemical or flexible glass. The efficiency of these types of panels is very low. Due to its thinner structure, less material is used so they are relatively cheaper to use. (Ontario Solar Farms, 2008-2013)

2.1.5. MAIN COMPONENTS OF PHOTOVOLTAIC SYSTEM

2.1.5.1. PHOTOVOLTAIC ARRAY

A photovoltaic array is made up of number of Photovoltaic modules connected together in series and/ or parallel arrangement. It can also be defined as the more than one string of series connected PV modules being connected in parallel to each other. It is a complete generator unit which converts the solar energy into the electric current and generates the DC voltage. The PV array is then connected to the inverter which receives DC voltage and converts it into AC voltage.

2.1.5.2. JUNCTION BOX

Figure 13: Junction Box in PV module (Photo taken at Renewable Lab, Murdoch University. November, 2014)

The Junction box is an important part of PV module system. Typical PV module Junction box consists of housing, cable and connector. It delivers electricity from the panels to the battery. It is a terminal storage box which protects the internal electrical wires and is a part of the PV module system where electrical connections are made. (Junction Box Trading, 2014)

In the PV module systems, the Junction box is divided into two different types. They are Generator Junction Box and Array Junction Box. A Generator junction box is the box where all the PV arrays are connected and Array junction box connects all the PV modules OF the Array. It is designed to contain the terminals, blocking diodes, fuses and DC switches. (PV Junction Box Research, 2012)

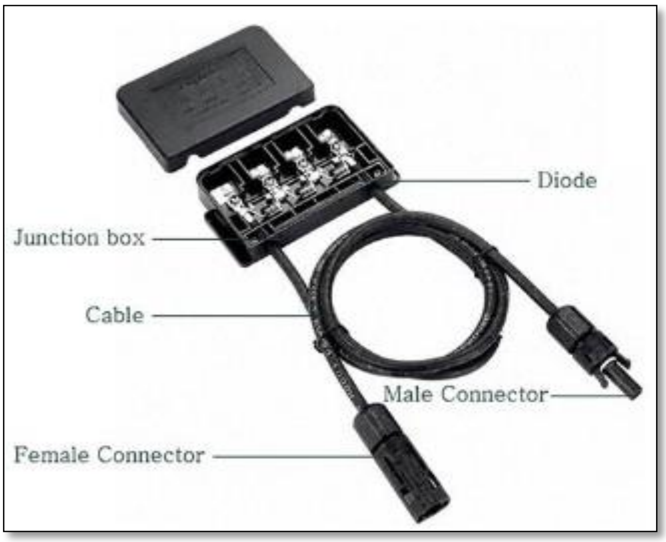

Figure 14- Structure of Junction Box (PV Junction Box Research, 2012)

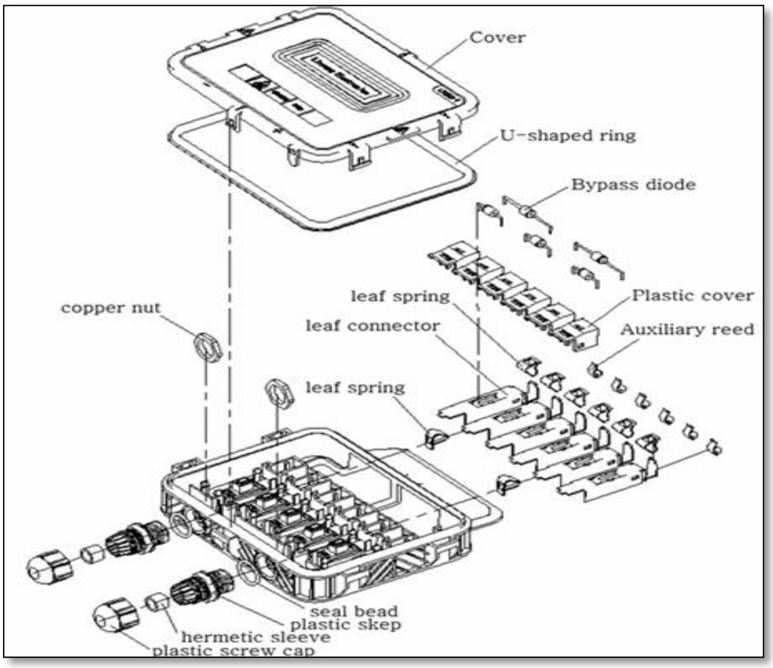

Figure 15- Components of the Junction Box (Junction Box Trading, 2014)

Junction box is usually located at the back of the PV modules as shown in Figure 13, so it is in direct contact with the environment such as rain and snow. As a result, electrical isolation is one of the risk factor needs to be considered. Circuit connectors are made up of copper or brass. Protection boxes of the junction boxes are attached by polymer materials such as silicon. Junction boxes are made up of stable material to withstand the harsh environmental conditions for long duration of time. Figure 14 shows the structure of a Junction Box. Figure 15 shows the components of the junction box.

2.1.5.3. SOLAR INVERTERS

2.1.5.3.1. INTRODUCTION TO THE PHOTOVOLTAIC SYSTEM INVERTERS

A PV inverter converts the direct current (DC) produced by the PV modules into Alternating current (AC) which can be fed into the main grid or can be used in the household electrical items. (National Solar schools Program, 2014)Figure 16 shows the block diagram of the position of the inverter in the PV module system.

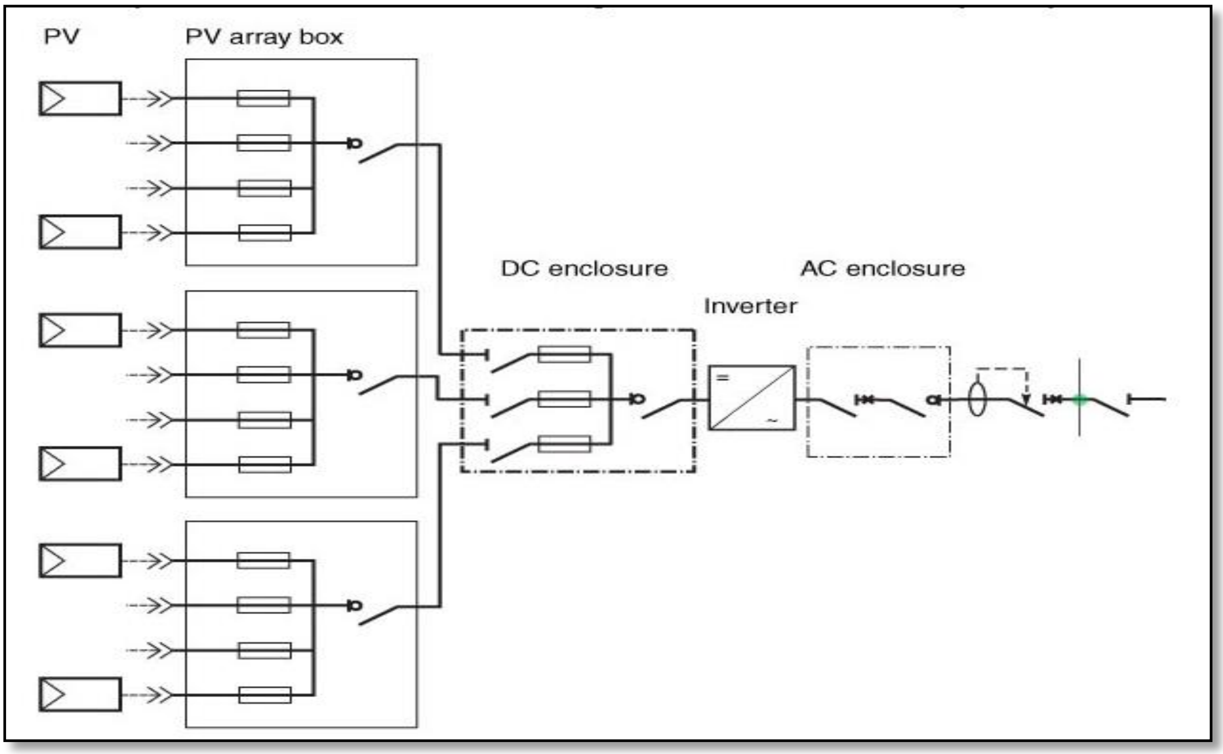

Figure 16: Block Diagram of PV System shows the inverter between AC and DC enclosures (Source: (Electrical- Installation, 2013))

2.1.5.3.2. FUNCTIONING OF THE INVERTER

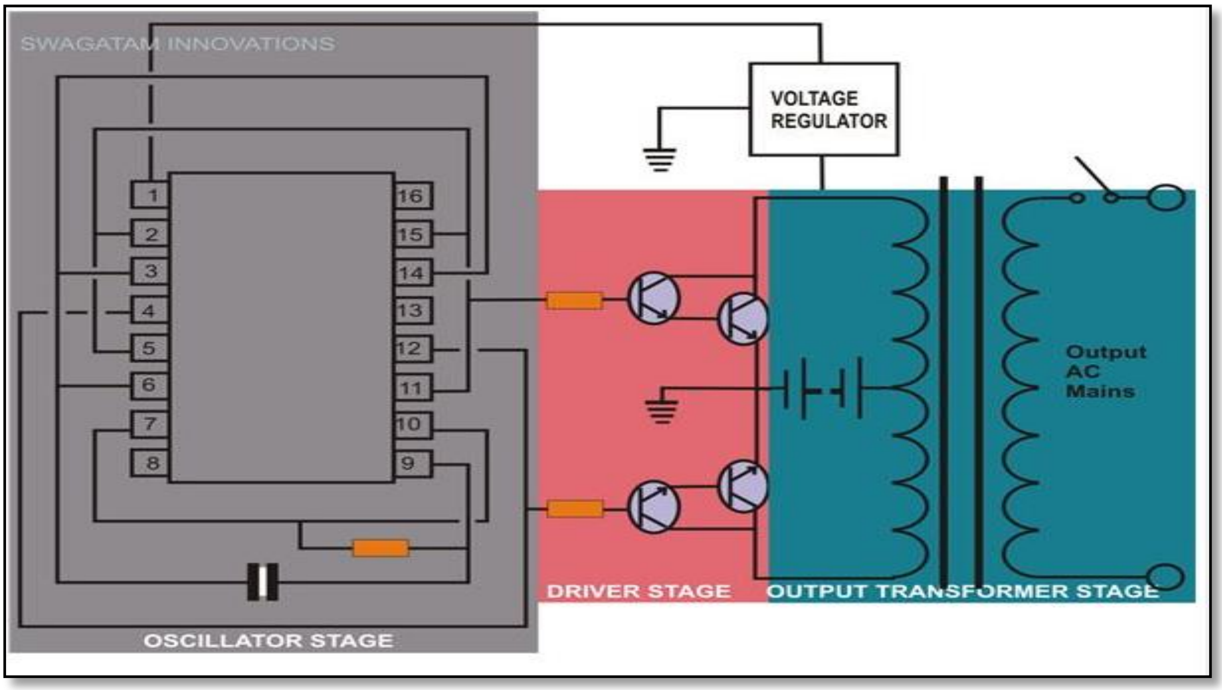

Figure 17: Block Diagram of Internal Circuitry of PV Inverter (Source: (Homemadecircuits and schematics, 2012))

The inverter converts DC into AC in three stages. Figure 17 shows the internal circuitry of the inverter. The DC fed into inverter is very low level current as compared to the desire output. To achieve the high output, the inverter functions through the three different stages:

1. Oscillator stage: In this stage, oscillating pulses are generated through an IC circuit or transistorized circuit. These oscillations are produced by alternate battery positive and negative voltage peaks with specified frequency. These square waves are too weak and cannot be utilized to feed into high current output transformer.
2. Driver stage: This stage is also known as booster or Amplifier. In this stage, the received oscillating frequency is amplified to the high current level by the transistors or MOSFETS. The boosted response is an AC response but the current level is still very low.
3. Output Transformer: The output transformer is step up transformer which converts the low level AC into the high level AC current. This is done by using the principle of magnetic induction of its two winding coils. (Homemadecircuits and schematics, 2012)

2.1.5.4. BATTERY

In a photovoltaic system, the battery stores the energy from the PV generator when the production is more than the consumption. Later on, the stored energy will be used when the consumption/ requirement is more than the current production of the energy. Below Figure 18 shows the Energy Demand and battery storage of a basic residential PV system and also shows the power generation and power consumption comparison of an average house on an average day.

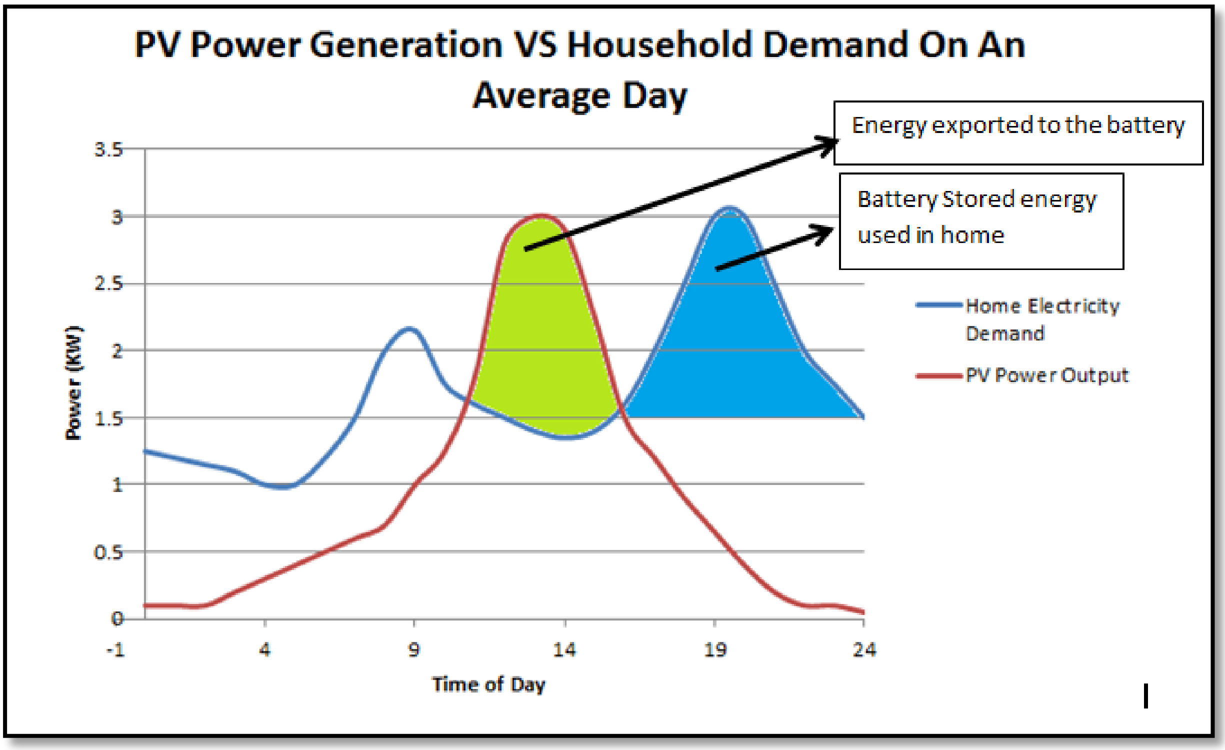

Figure 18: Battery Storage and Time of the day (Illustration: (PV Solar with Batery Storage, 2014))

2.1.5.5. *DIODES IN PHOTOVOLTAIC MODULES*

2.1.5.5.1. DFINITION OF DIODE

Diode is an electronic device made up of semiconductor material having two terminals. It allows current to pass through only in one direction.

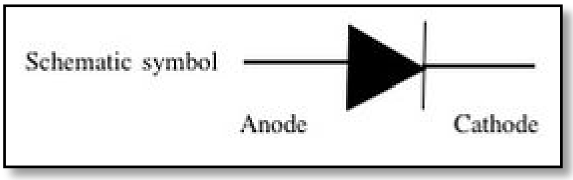

Figure 19: Symbol for Diode (Source: (Diodes, 2009))

2.1.5.5.2. DIODES IN PV MODULE SYSTEM

There are two types of Diodes usually used in a PV module system to keep the flow of the current in the right desired direction.

2.1.5.5.2.1. BLOCKING DIODES

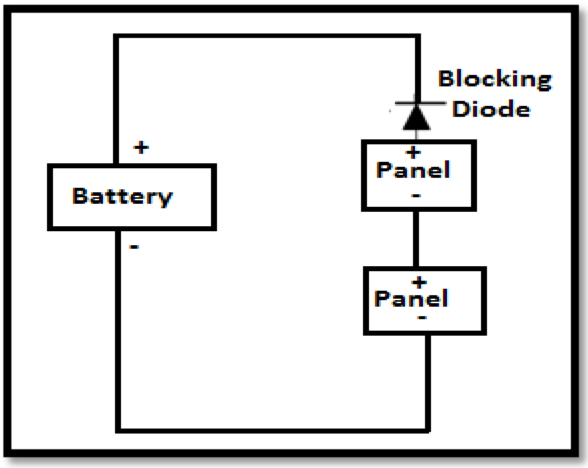

Figure 20: Simple Blocking Diode (Illustration: (Blocking and Bypass Diodes in Solar panels, 2014))

Figure 20 shows the simple diagram of the Blocking diode connected in series with two other solar panels connected in series with each other. When the sunlight is available to the panels and the panels produce a voltage greater than the voltage of the battery, the battery gets charges as the current flows from the panels to the battery. However, when the sunlight is not available, the panels do not produce any voltage; the voltage in the battery will source the current to flow in the opposite direction to discharge the battery.

At this stage, the blocking diodes prevent the current to flow in the reverse direction and it prevents the battery to discharge. The blocking diodes are a part of the module which is connected to the solar panel during the construction of the module. (Blocking and Bypass Diodes in Solar panels, 2014)

2.1.5.5.2.2. BYPASS DIODES

Figure 21 shows the panels connected in series and a Bypass diode connected in parallel to each panel. In the event of one panel being shaded and other producing higher voltage, the bypass diodes play a very significant role in the system as explained in Figure 22. The shaded panel is not only producing no voltage but also becomes a high resistance in the circuit. Therefore, the current choose to flow from the bypass diodes which are connected parallel to that of the panel, to avoid the high resistance of the panel. Each group of solar cells of its own built in bypass diode. (Blocking and Bypass Diodes in Solar panels, 2014)

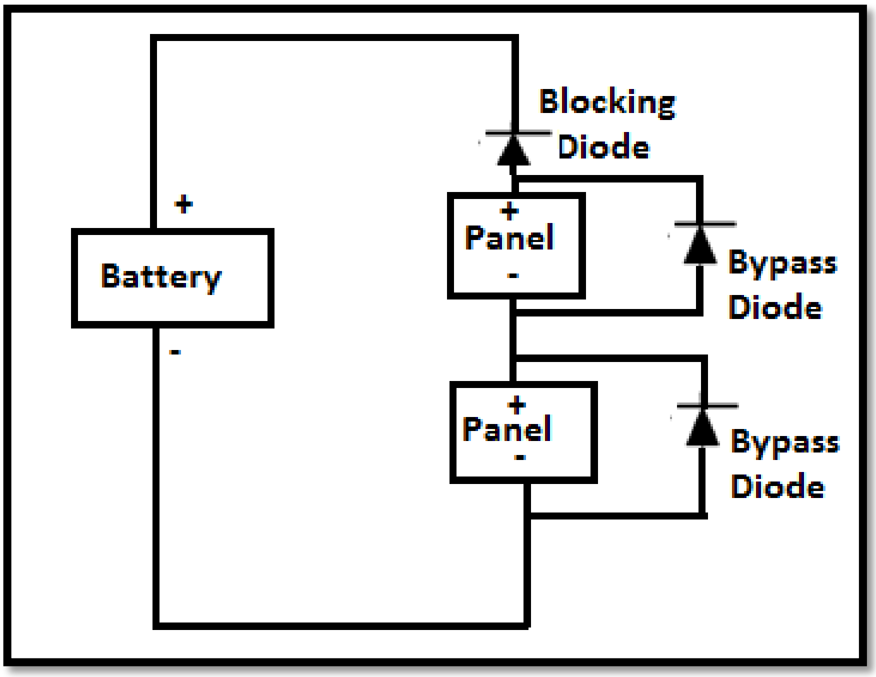

Figure 21: Simple Bypass Diode (Illustration: (Blocking and Bypass Diodes in Solar panels, 2014))

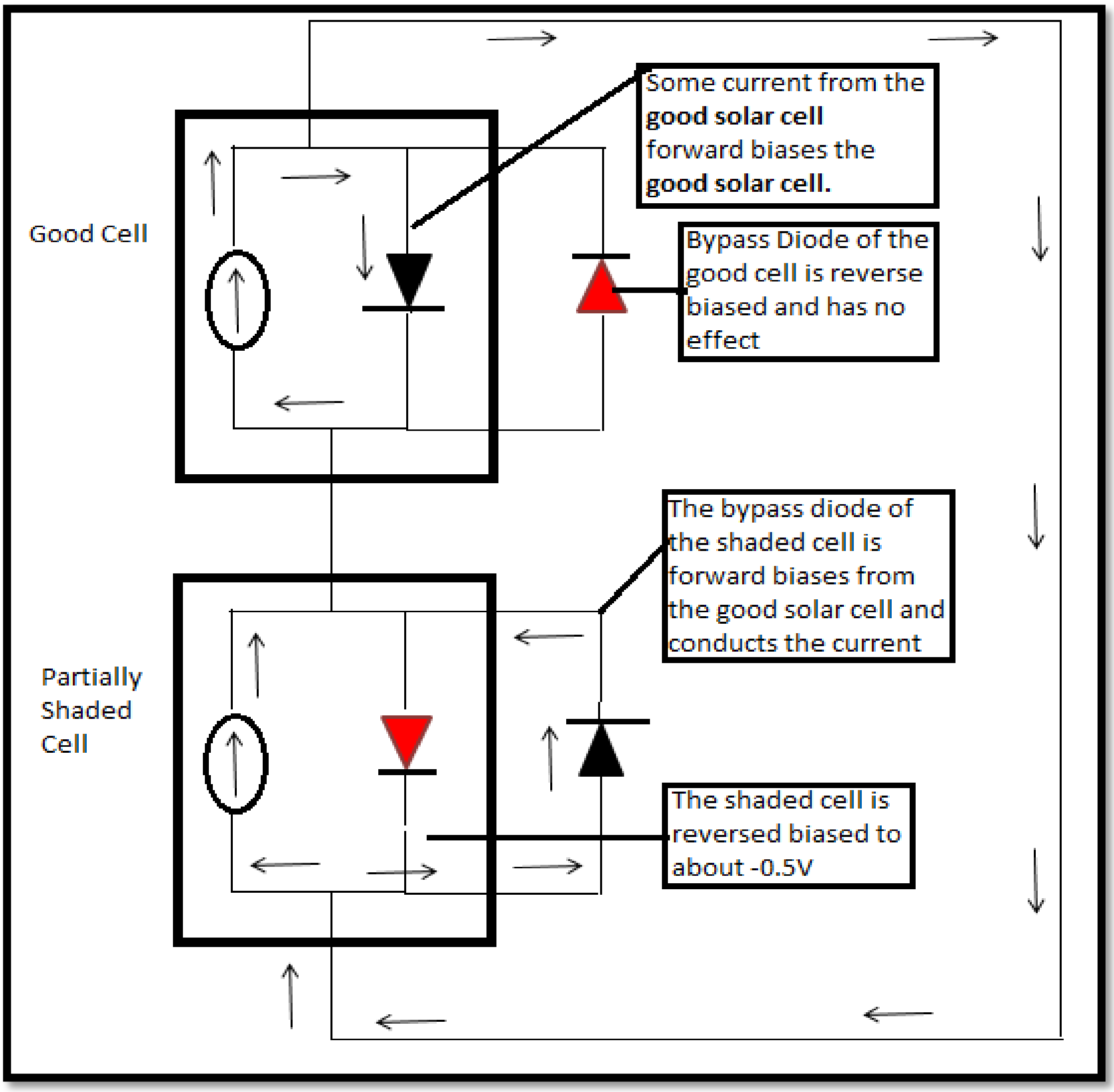

Figure 22: Operation of Module with Bypass Diode (Illustration: (Blocking and Bypass Diodes in Solar panels, 2014))

2.1.6. COMBINATION OF THE MAIN COMPONENTS TO FORM BASIC PHOTOVOLTAIC MODULE SYSTEM

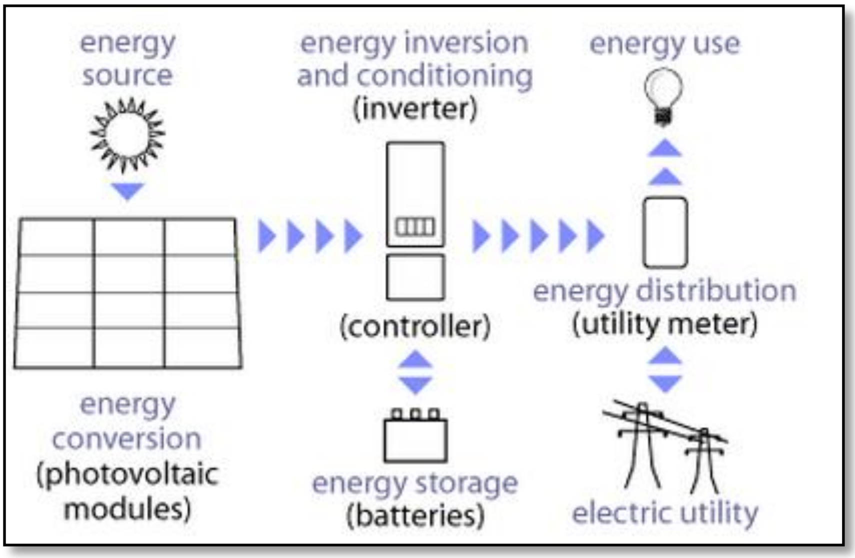

Figure 23: Complete Photovoltaic System (Source: (Solar Direct, 2014))

In a photovoltaic system, the PV modules convert the sunlight into DC electric power. The DC power is then supplied to the inverter which then converts DC into AC for consumption. A battery stores the extra energy coming in and provides that energy when demand exceeds supply from the PV modules. A controller controls the overcharging of the battery. It helps in keeping the battery life long. A utility meter provides electricity when demand exceeds supply from the PV modules. The utility meter moves in a backward direction when the supply from the PV module exceeds the demand and power is supplied into the grid.Figure 23 shows the combination of the main components which forms a PV module system. (Solar Direct, 2014)

2.1.7. TYPES OF PV SYSTEMS:

2.1.7.1. GRID CONNECTED PV SYSTEMS

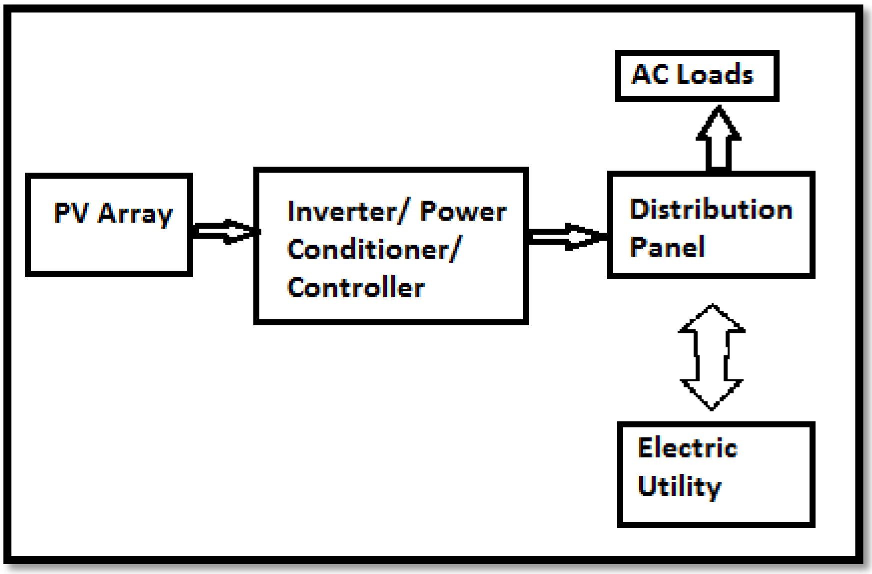

Figure 24: Block Diagram of Grid connected Photovoltaic System (Illustration: (Florida Solar Energy Center, 2007- 2014))

Grid connected PV systems works parallel and is inter- connected to the main grid as shown in Figure 24. In this system, the PV array supplies the generated power to the inverter or power controlling unit. PCU (Power Control Units) converts the generated DC into AC and provides AC to the load voltage and to the main grid when the power generated is more than the power required by the load. At the times, when the demand is more than the power generated by the PV system, the power is supplied back by the main grid. (Florida Solar Energy Center, 2007- 2014)

2.1.7.2. STAND ALONE PV SYSTEM

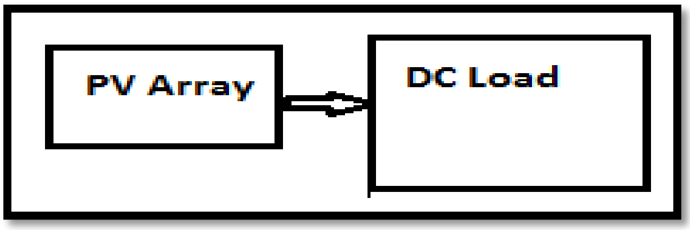

Figure 25: Block diagram of Stand Alone Photovoltaic System (Illustration: (Florida Solar Energy Center, 2007- 2014))

Stand-alone PV systems are the systems which are not connected to the main electricity grid and are neither connected to any other systems as shown in Figure 25. They are designed and sized to match up the requirements of DC load connected to the system.

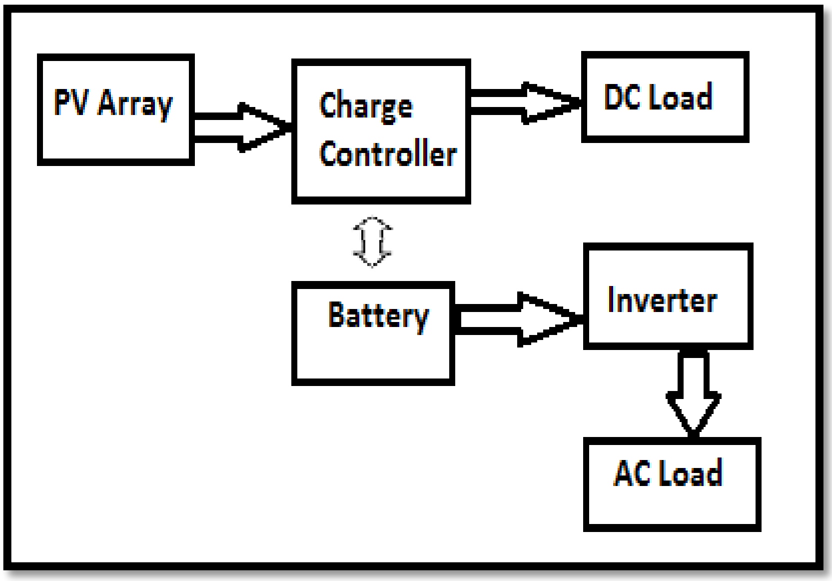

Figure 26: Block Diagram of Standalone Battery connected Photovoltaic System (Illustration: (Florida Solar Energy Center, 2007- 2014))

Normally such systems are connected with the battery, controller and inverter as shown in Figure 26. This enables the system to store the excess power generated and to be used later on for AC and DC loads. (Florida Solar Energy Center, 2007- 2014)

2.1.7.3. HYBRID PV SYSTEM

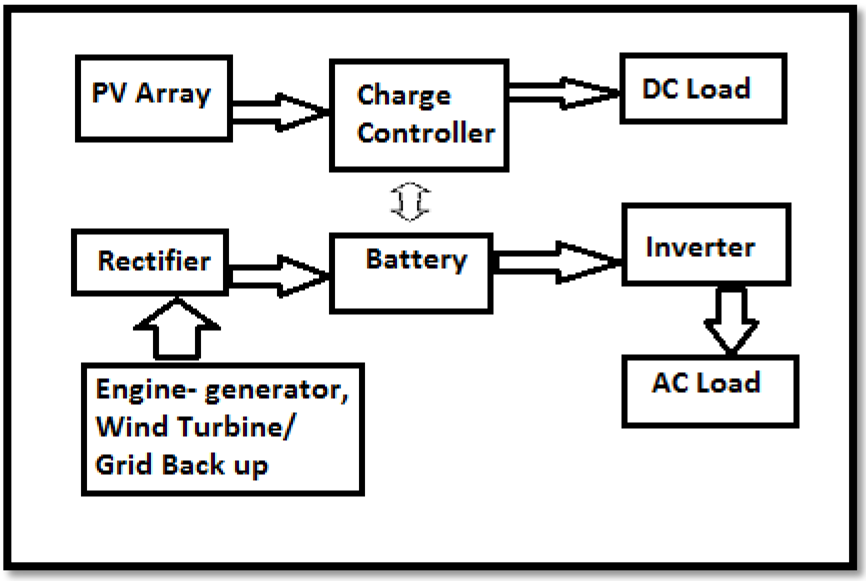

Figure 27: Block Diagram of Hybrid Photovoltaic System (Illustration: (Florida Solar Energy Center, 2007- 2014))

Hybrid PV systems are PV systems connected to other sources of power generation systems. Other systems are normally wind turbines, grid back up, diesel power generator, etc. An example is shown in the block diagram of Figure 27.

This type of system may use PV system as a primary source of power production and other sources can be used as a backup or to support the system in case of the power demand exceeding the PV power supply.

The system may contain one or more types of other systems to support the main system.

3. FAULTS/ ISSUES IN PV SYSTEMS DURING OPERATION

3.1. INTRODUCTION

This chapter of the report explains the common faults which occur in different components of the Photovoltaic module system during its operation in the field. This chapter also mentions the causes and its effects on the efficiency, durability and reliability of the system.

3.2. CORROSION

Corrosion in the Photovoltaic module system usually occurs due to the water ingression. Corrosion can be minimized by minimizing the ionic conductivity in the PV module encapsulant. In some cases, corrosion can result in the power loss, the total failure of the system.

For crystalline Si PV modules, corrosion of the front contact is dependent on both the metallization system and encapsulant system. (John Wohlgemuth, 2010)

Metallization refers to the fingers and bus bars that criss-crosses the surface of the solar cell and gather the charge carriers for exporting outside of the module. It occurs on the metal and other parts of the photovoltaic module, except the glass or the actual cell. Corrosion of metallization can be easily seen at the fingers, interconnects and at the bus bars as shown in Figure 28but sometimes it is not easily visible if the encapsulant is discoloured due to corrosion as well. (Rajiv Dubey, 2014).

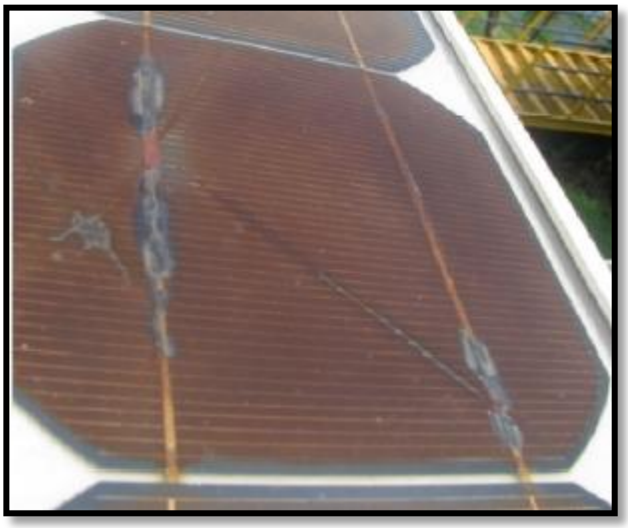

Figure 28: Corrosion marks on Bush bars and interconnects (Source: (Rajiv Dubey, 2014))

Damp heat test beyond 1000 hours gives a good indication of the extent to which the PV module can get corroded. During an experiment for corrosion in the thin film PV modules, it was found that the thin- film photovoltaic modules constructed on the glass substrate coated with a layer of transparent conductive oxides are likely to show signs of corrosion. The PV modules get corroded quickly when operating at high voltages, high temperature and highly moist regions. The current study in this document shows that the tin oxide contacts may delaminate from the glass due to the combination of sodium accumulation near the interface and the ingression of moisture into the PV module from the edges. (Corrosion Effects in Thin- Film PV Modules, 2003)

3.3. DISCOLORATION OF ENCAPSULANT OF PHOTOVOLTAIC MODULE

The encapsulant of photovoltaic module is the top surface part of the module which provides the physical strength to the module and protects the solar cell. It also provides electrical isolation between the solar cell and the glass. Now a days, EVA (Ethyl- Vinyl Acetate) is widely used as the encapsulant in the PV modules. In the field, discoloration of encapsulant is caused by the discoloration in EVA over the long period of time during the operation of the PV module. The brownish appearance of the encapsulant is usually visible due to this cause. This browning is believed to be due to the generation of long- chain polygenes in EVA due to the exposure to the ultra violet rays from the sun. Hot and Humid Climate is highly suitable for this fault in photovoltaic modules. Figure 29 shows the discoloration of the photovoltaic modules.

Figure 29: Discoloration shown in the solar cell of the PV module. (Source: Photo taken at Murdoch University, Perth on October 2014)

3.4. DELAMINATION OF PHOTOVOLTAIC MODULE

Delamination is the detachment of the layer of a PV module from its panel. It is mainly caused by humidity and moisture ingression. (Roest, Top 3 quality issues in solar panels, 2013)

In a PV module, the solar cells are coated and sealed with a layer of Ethylene Vinyl Acetate (EVA). It protects the cell from the harsh environmental conditions such as moisture, dirt, extreme temperature, UV radiations, etc. (Solar EVA, 2014)

During manufacturing, this process is to be done at its mentioned temperature and pressure conditions for specific time. If the process is not performed properly or in the case of cheap or unsuitable material being used for this process, EVA will delaminate later during the operation of the PV module in the field. The layer of EVA gets dissolved or reacted with moisture to form white milky colour.

This will affect the performance of the cell. If the cell is used continuously after its delamination, moisture may get into the cells causing corrosion and other on-going damage to the module. (Clean Energy Investment, 2014)

Figure 30 shows the structure of a PV module with an EVA layer. Figure 31 and Figure 32 show the delamination of the top layer of the PV module.

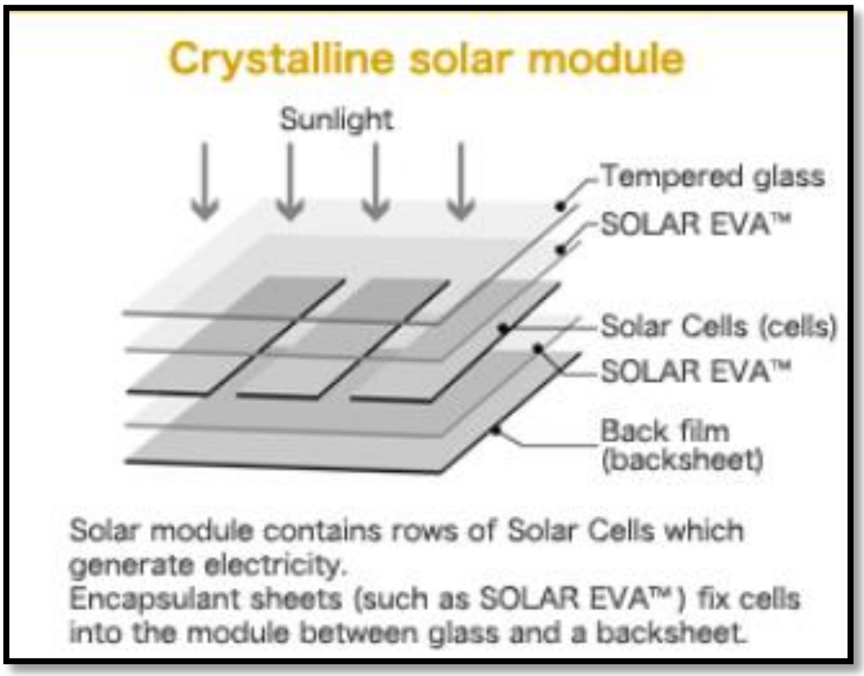

Figure 30: Structure of a PV module with EVA layer lamination (Source: (Solar EVA, 2014))

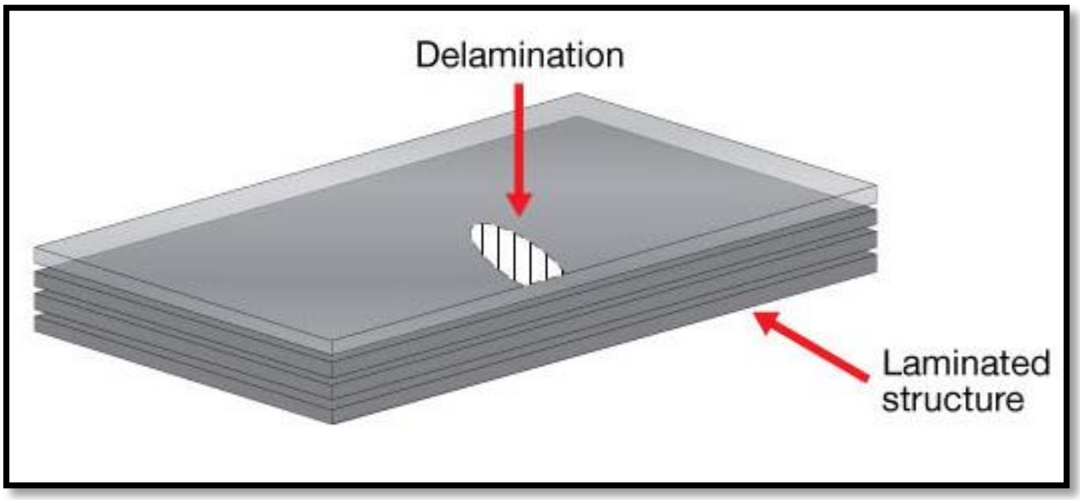

Figure 31: Delamination of PV module (Source: (Olympus, 2014))

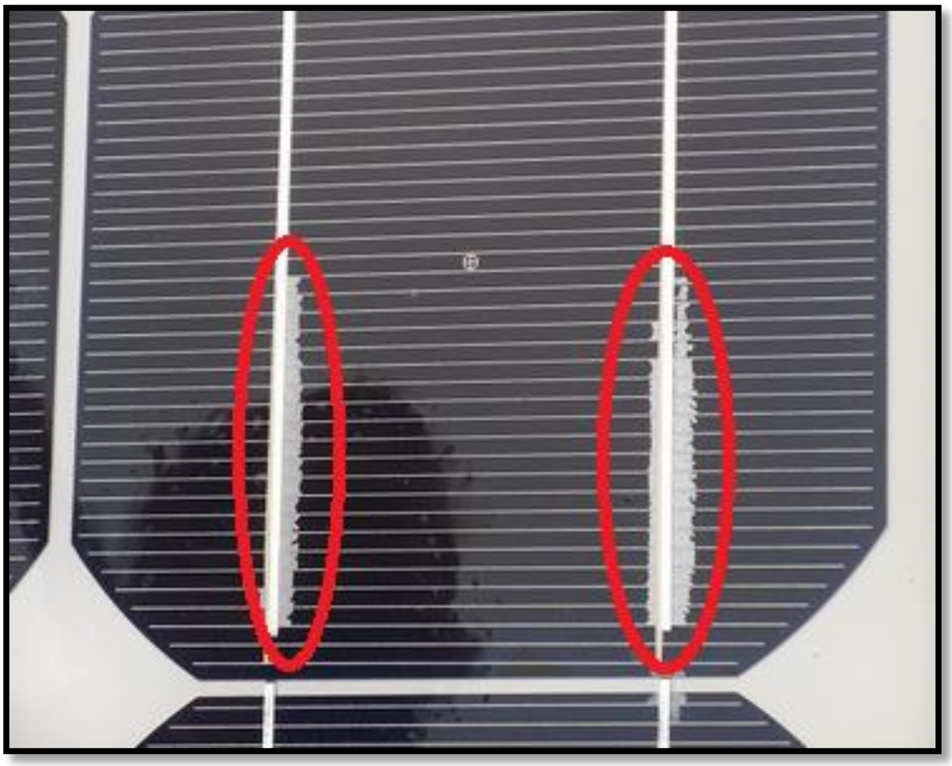

Figure 32- Delaminated PV module (Source: (Clean Energy Investment, 2014))

3.5. BACK SHEET FAULTS OF PHOTOVOLTAIC MODULE

The photovoltaic module back sheet is the layer on the back of the PV module as shown in Figure 33. This layer is designed to act as a protective layer to protect the module from the back of the PV module. It protects the components from external stress and act as the electric insulator. In order to achieve this, the back sheet layer of the PV module must be designed and constructed to withstand against harsh external conditions. Typically back sheet layer is three layer laminate and have high dielectric properties. (Labthink Tensil Tester, 2013)

Usually, the back-sheet materials are TPT (Tedlar-PET-Tedlar) foil, a polyamide (PA) sheet and a polyethylene terephthalate (PET) composite film. (Cornelia Peike, 2012)

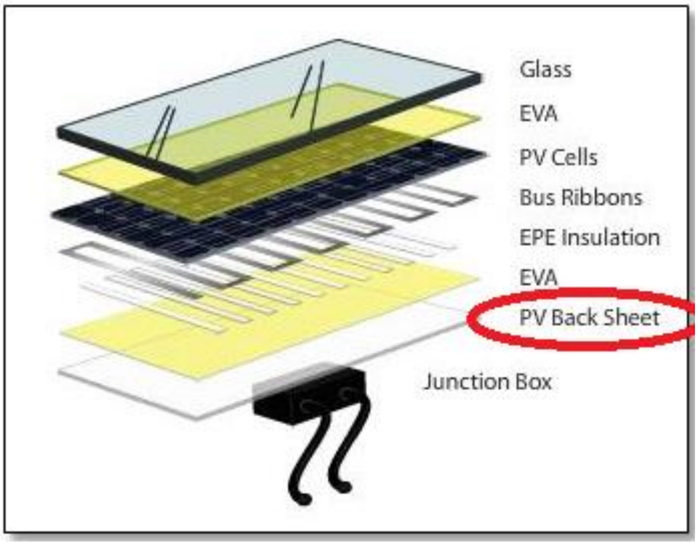

Figure 33: Structure of Photovoltaic module highlighting back sheet (Source: (Labthink Tensil Tester, 2013))

The back sheet of a PV module is usually UV resistant which protects the module from the thermal degradation. Construction of the Back sheet of the PV module must provide a moisture barrier to the PV module from the outer environment to prevent water ingression into the PV module. Back sheet of the PV module also must withstand against external stress to provide the safety to the module and to prevent the module from the harsh environment conditions. It must be able to provide tensile strength and high Durability to the PV module. The Backsheet of the PV module also provides an electrical insulation to prevent any short circuit issues and to prevent any potential damage due to unwanted electrical current. (Labthink Tensil Tester, 2013)

The faults in the back sheet are usually caused by hot cells which lead toburnt back sheets, delamination and sometimes cracked glass. (David DeGraaff, 2011).

Delamination and discoloration of the back-sheet impair the mechanical and aesthetic function and facilitate moisture ingress. (Cornelia Peike, 2012)The main reasons for discoloration and the primary form of visible degradation are de-acetylation, hydrolysis, photo-thermal decomposition, and degradation of additives such as UV light stabilizers, UV absorbers, and antioxidants. (Cornelia Peike, 2012)

Degradation of adhesion strength also leads to delamination of back sheet and encapsulant. Adhesion performance is directly dependent on the moisture and temperature of the site. Photo-thermal degradation of the back sheet polymer results in the chalking of the back sheet as shown in Figure 34. This is caused by the heat from the environment which causes the back sheet polymer to degrade. (Rajiv Dubey, 2014)

Figure 34: Chalking of the Back sheet of PV module (Source: (Rajiv Dubey, 2014))

3.6. GLASS BREAKAGE OF PHOTOVOLTAIC MODULE

3.6.1. PHYSICAL PROPERTIES OF THE GLASS USED FOR PV

Photovoltaic modules are manufactured with 3.2- 4 mm of the glass layer in the front and a polymer based insulator to be used on the back of the module. However, new technologies are working to reduce the thickness of the glass in order to increase the efficiency and reliability of the PV module. Glass is commonly used as the top cover of the PV module due to its normal physical properties such transmission, Hermetic, Durable, Strength and its low cost. (Dr. James E. Webb, eere.energy, 2011)

Glass corrosion affects the performance of the PV module and results in the lower efficiency of the system. In the events of harsh weather conditions and hail storm, glass cover on the PV module can be damaged easily. So it is important to increase the durability of glass on the PV module. One way to increase the durability is to eliminate the non- bridging oxygen atoms. This makes the structure of the glass to come close to each other and increase the strength of the glass. It also slows down the chemical reactions so increased the chemical durability of the glass. (Dr. James E. Webb, eere.energy, 2011)

Other way is to use specialty Glass. Specialty glass is highly resistive as compared to the normal soda lime silica glass. It is more resistive about 8th order of magnitude than soda lime silica glass.

3.6.2. COMPOSITION OF GLASS USED IN PV

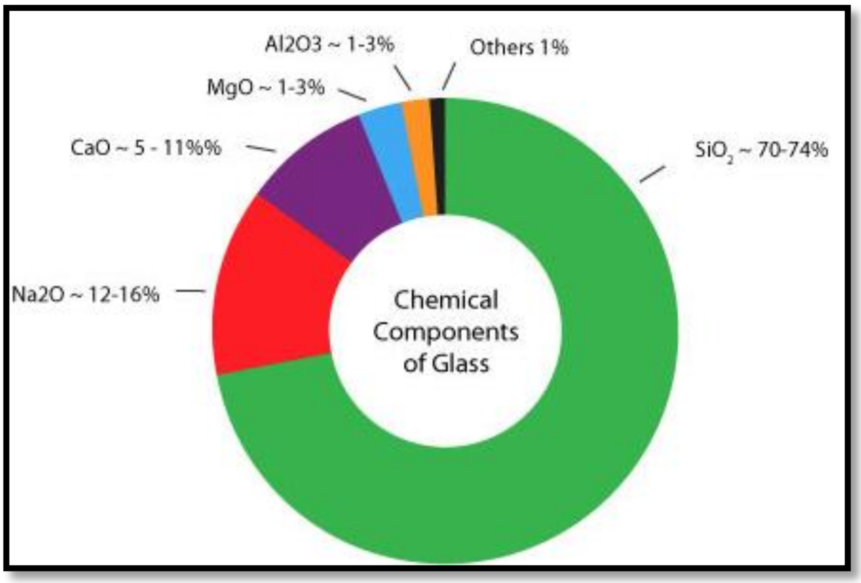

Figure 35: Chemical composition of Glass Cover of PV module (Source: (Green Rhino Energy, 2013))

The main composition of the PV module glass is Silicon Oxide (SiO_2). The components are heated above 1500° C in the furnace and then cool down slowly. Then glass is then heated again about 620° C and then rapidly cool down by the airflow. This results in increasing of the glass strength by around 4 times. Alkali is the second major component present in the PV module glass. (Green Rhino Energy, 2013)

3.6.3. GLASS FATIGUE

Breaking of the glass due to glass fatigue is an important factor causes power loss in PV systems. Moisture plays a significant role in causing the glass fatigue. Figure 36 shows the stages of the reaction of the breakage of the glass.

Moisture Effect on the Crack growth:

$$SiO_2 + H_2O + Stress = Si(OH)_4$$

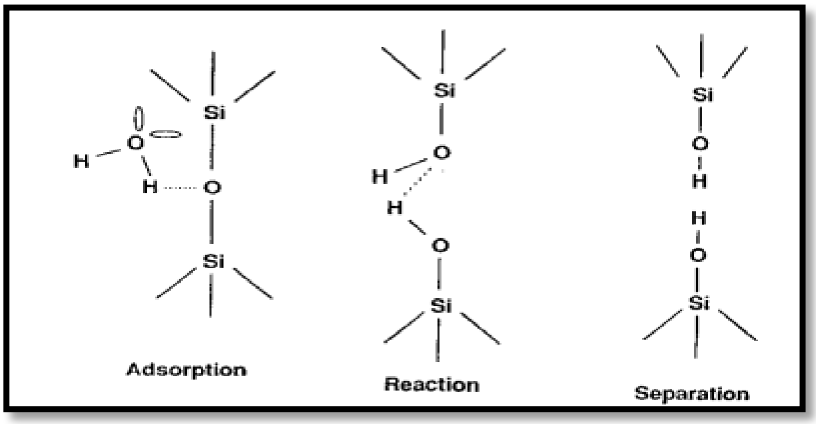

Figure 36: Stages of reaction of H2O with Silicon Dioxide (Source: (Dr. James E. Webb, eere.energy, 2011))

3.6.4. DEPENDENCY OF GLASS RESISTIVITY ON ALKALI CONTENT

Resistivity of glass is inversely proportional to the alkali content in the glass. Electrical isolation can be improved by increasing the resistivity of the glass. The graphs below represent the relationship between the resistivity of the glass and the alkali content. Resistivity of sodium and potassium- silicate glasses decrease with increase in the temperature of the glass and with the alkali content of the glass. (Dr. James E. Webb, eere.energy, 2011)

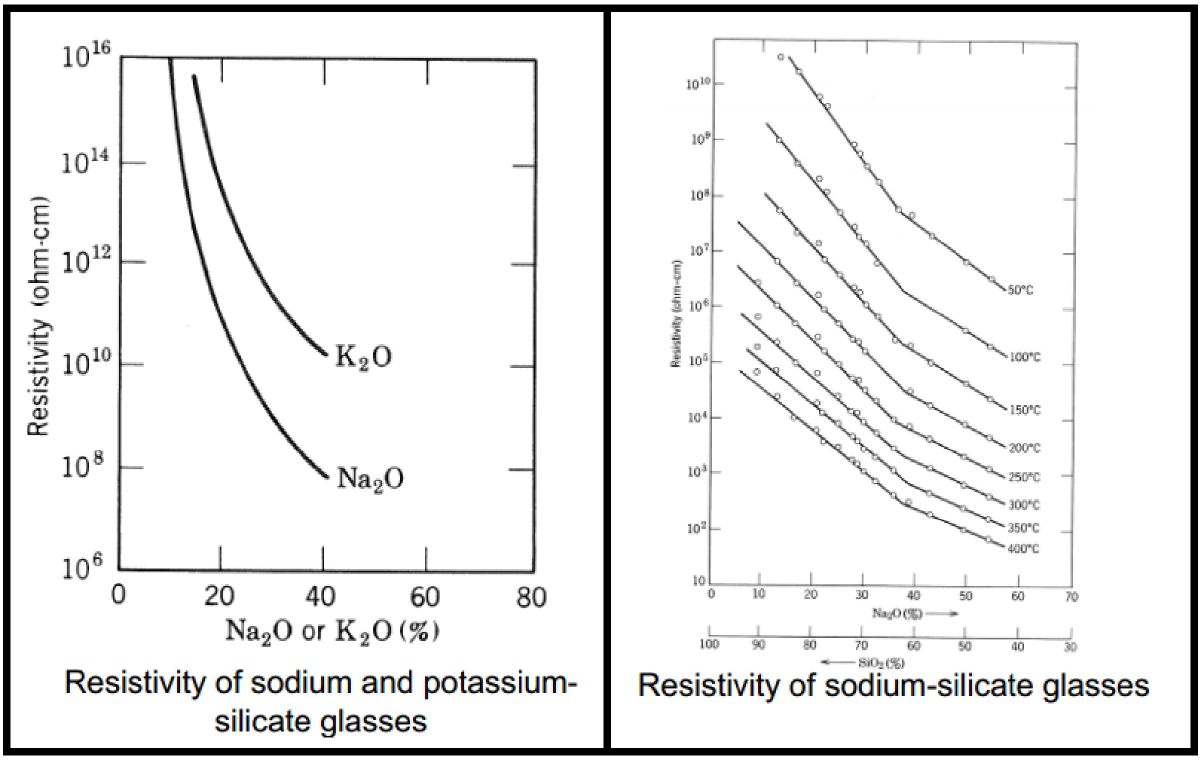

Figure 37: Glass resistivity on Alkali Content (Source: (Dr. James E. Webb, eere.energy, 2011))

3.6.5. MECHANISM OF GLASS CORROSION

The process of Glass corrosion is governed by two mechanisms.

1. Diffusion controlled leaching (ion exchange)

$$SiO^-R^+ + H_2O \longrightarrow SiOH + R^+OH^-$$

(Varshneya, 1994)

2. Hydrolytic dissolution of the glass (Varshneya, 1994)

$$\equiv M\text{-}O\text{-}M\equiv + H_2O \leftrightarrow \equiv M\text{-}OH + HO\text{-}M\equiv$$

(Dr. James E. Webb, eere.energy, 2011)

Glass Corrosion affects the performance of the PV module and results in the lower efficiency of the system.

In the events of harsh weather conditions and hail storm, glass cover on the PV module can be damaged easily. So it is important to increase the durability of glass on the PV module. One way to increase the durability is by eliminating the non- bridging oxygen atoms. This makes the structure of the glass to come close to each other and increase the strength of the glass. It also slows down the chemical reactions so increased the chemical durability of the glass.

Other way is to use specialty Glass. Specialty glass is highly resistive as compared to the normal soda lime silica glass. It is more resistive about 8^{th} order of magnitude than soda lime silica glass.

3.7. HOT SPOTS IN PHOTOVOLTAIC MODULE

Hot spot phenomena occur when 1 or more cells are shaded and producing much less voltage as compare to the other cells in the string. The shaded cell then become reverse biased having high resistance in the circuit hence producing high heat on itself. (Christiana Honsberg, 2014)

Hot spot heating occurs in a PV module when the operating current of the module exceeds the reduced short circuit current of the shaded cells within the module. (Daniel W. Cunningham, 2011). This may results in the glass breakage due to the extreme heat produced at a particular spot as shown in figure the below.

Most common cause of hot spot is the resistive heating of the shaded cells. This usually happens in the case of faulty bypass diode and defective soldier joints. (Daniel W. Cunningham, 2011)

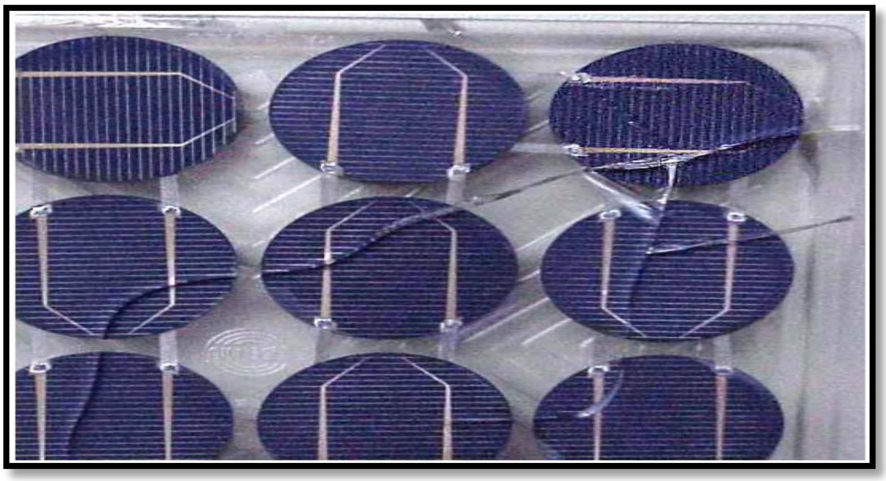

Figure 38- Cracked module due to the heat dissipated in the shaded module (Christiana Honsberg, 2014)

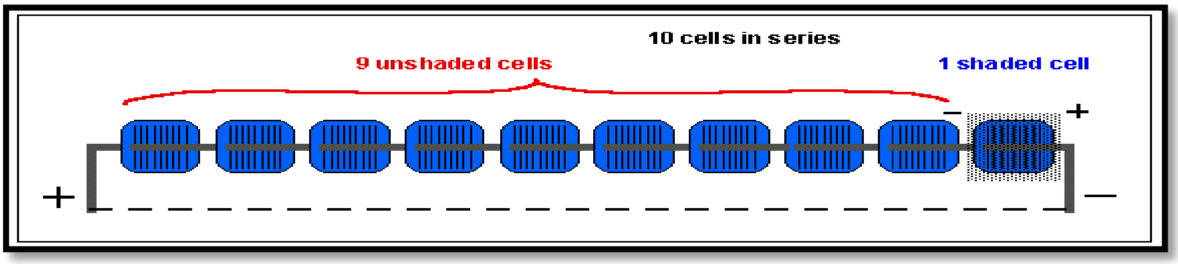

Figure 39- Hot Spot Phenomena Case (Source: (Christiana Honsberg, 2014))

3.8. MICRO CRACK, SNAIL TRAIL AND CELL DAMAGE

Often the solar panels are handled and installed by the installers without proper care. If the unwanted load is placed on the top of a solar panel, it may result in the hairline or micro crack on the panel. This will result in the damaged cells. The damaged cells will have more resistance and will heat up quickly and which may result into hot spot on the cell and the cell gets damaged and this leads minimising the efficiency of the system.

From manufacturing to installation, PV module needs proper care while it gets transported from the manufacturer to the end user. Micro cracks are often caused due to poor handling and improper care during installation as shown in Figure 40. (Roest, 3 quality issues in solar panels, 2013)

Figure 40: Installer leaning on PV module may cause module to crack (source: (Roest, 3 quality issues in solar panels, 2013))

Harsh environmental conditions like hail storms and cyclones may also result in small invisible cracks which may grow up later on to form snail trails, micro cracks, etc. as shown in Figure 41. Moisture, oxygen, CO_2 and other compounds pass through these micro cracks to the encapsulant, results in the other faults like corrosion, delamination, etc.

Snail trail are also originated due to the presence of Ag_2CO_3 nanoparticles. These particles absorb and scatter the light which results in the discoloration of the module which are visible on the surface. (Vashishtha, 2014)

Figure 41: Snail Trails on PV module (Source: (Vashishtha, 2014)

3.9. JUNCTION BOX RELATED FAULTS

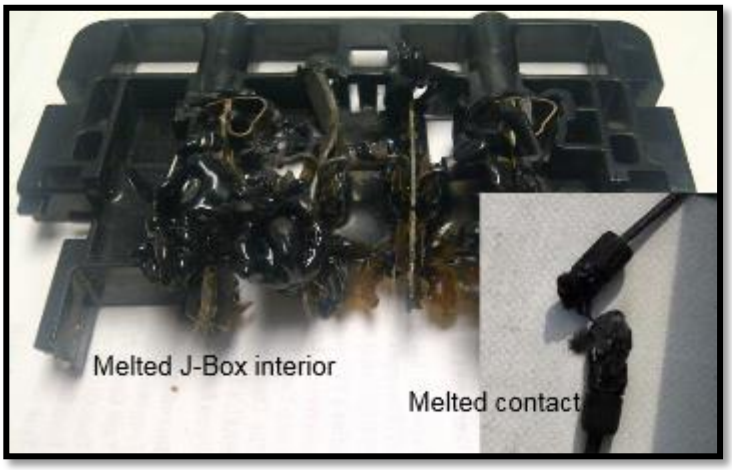

Figure 42: Damaged Junction Box (Source: (Kalejs, 2012))

In order to make a cost effective junction box, it is quite important to ensure that safety and quality should not be compromised. However this is not a case all the time. Figure 42 is an example of a junction box which is melted from inside due to the overheating effect within 2-3 years in the field. Melting of Junction boxes with non-soldering contacts is often experienced in 2-3 years of its operation in the field. There are other common faults which can be found in the junction box including plastic cracking of the connectors, cracking of the Junction box due to fatigue and melted connectors due to the poor installation. Corrosion is often experienced and lead to the damage to the junction box as shown in Figure 43in very humid areas. In very hot regions, high temperature may lead to the burning of the diode. (Kalejs, 2012)

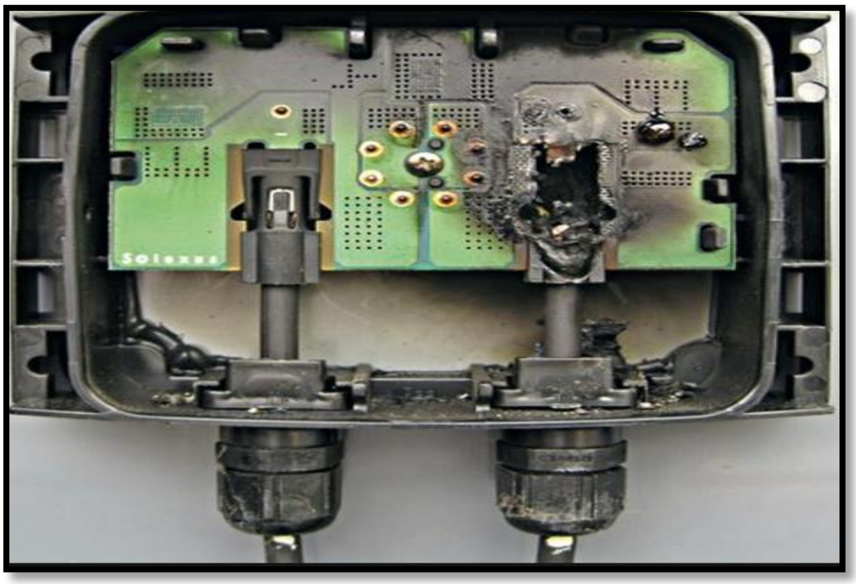

Figure 43: Corrosion in the Junction Box led to increase in contact resistance (source: (Ali-Oettinger, 2013))

Melting of the connectors and diode failure in junction box imposes a huge fire risk. If the connector gets disconnected it may produce an electric arc which may result into fire. (DeGeraff, 2011)

3.10. BYPASS DIODE FAILURE

Normally PV modules are equipped with bypass diode(s) to avoid the damaging effects of hot-spot heating caused by non-uniform irradiance or shading of the solar panel. In the situation of failure of Bypass Diode, other faults like hot spots usually occurs which further can led to the serious causes like short circuit or fire of the Photovoltaic module.

3.11. INVERTER FAULTS

If the inverter in PV module system is faulty, it may be due to the degradation of the inverter and its components. Faults in inverter leads to the partial or complete reduction in the system performance. Fault in the inverter is a very common cause of the PV module system failure. Usually the fault can be found in the following components of the inverter:

1) Battery voltage and connections
2) Fuse
3) Oscillator, Integrated circuit and associated components
4) Devices in Amplifier
5) Transformer malfunction

(Homemadecircuits and schematics, 2012)

4. CLIMATIC CONDITIONS IN AUSTRALIA

4.1. INTRODUCTION

Climate and environmental conditions of the site and the location of the Photovoltaic module affects directly on the performance and degradation of the PV module. Australia experiences a variety of climates e.g.; in the south part of Australia, temperature fall below zero. However the north-west region of Australia experiences extreme hot conditions.

As Australia is one of the biggest countries, it does not experience one particular type of weather or climate. Instead there are about six climate zones which describe the weather conditions of Australia.

4.2. CLIMATE ZONES IN AUSTRALIA REGION

There are six different climate zones in Australia. They are:

1) **Equatorial Climate:** is also known as tropical rainforest climate. Usually, this climate zone locates along the equator. Within this climate zone, the average monthly precipitation is at least 60mm. The total annual rainfall is generally more than 2000mm with relative humidity of around 80%. The temperature is usually constant along the year between 23^{o}C to 32^{o}C. (Sani, 2010)

2) **Tropical Climate:** Most of this climate belt is located along the equator. Within the tropical climate zone, there is abundant of rainfall. The temperature ranges between 22^{o}C to the maximum of 35^{o}C. (Tropical Climate, 2014)

3) **Sub- tropical:** are the regions with at least eight months in a year with the mean temperature of 10^{O}C.In this zone, cyclones brings abundant of rainfall during the wet season during the summer which contributes a significant percentage of annual rainfall.
4) **Desert:** Desert Climate is usually very dry region with very low rainfall. This climate zone may experience no rainfall at all some years. In Australia, most of the middle land comprises of hot desert land which experiences the extreme hot temperature over 45^{O}C.
5) **Grassland:** The Grassland Climate has hot summers and cold winters. The annual rainfall falls between 600mm to 1500mm. The temperature varies between -5^{O}C to 20^{O}C during winters and between 20-30^{O}C during summers.

6) **Temperate:** Most of the major developed cities of Australia are located in Temperate zone. This zone experiences four seasons including summers, winters, autumn and spring. The average annual Rainfall is 800mm. The maximum temperature is around $40^{O}C$, however annual average temperature in this region is between $0\text{-}20^{O}C$. (Meteoblue, 2014)

(Bureau of Metreology, 2014)

Figure 44, Map of Australia represents the physical location of the above climate zones in Australia.

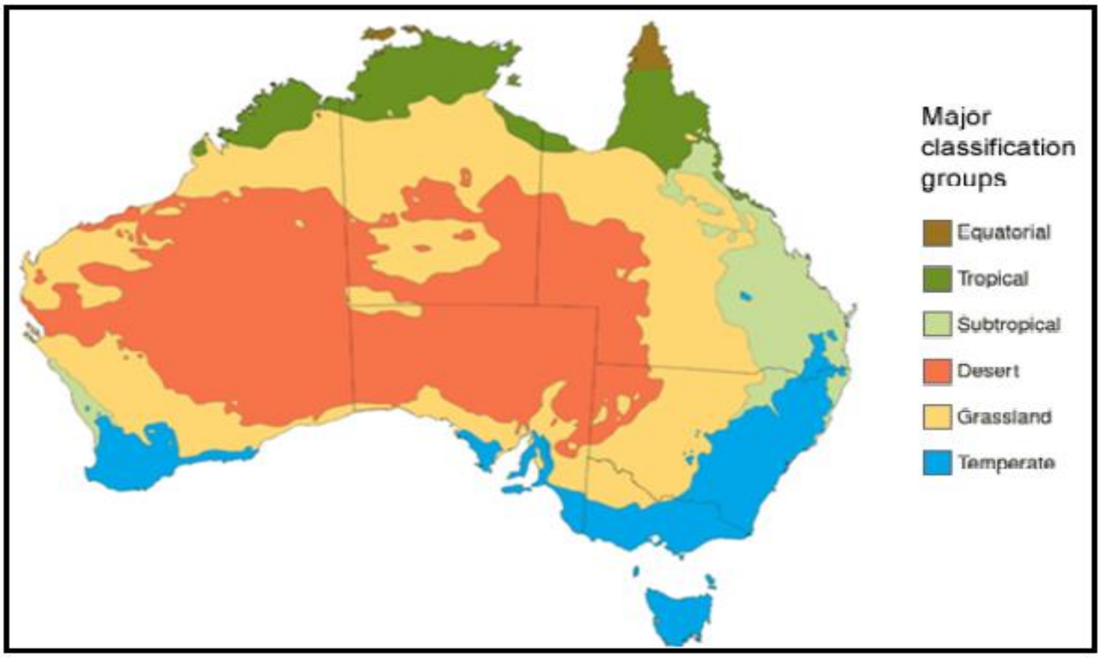

Figure 44: Climate Zones in Australia. (Source: (Bureau of Metreology , 2014))

The Equatorial zone in Australia is the area zone around the tip of Cape York and Bathurst and Melville Islands north of Darwin as shown in the Map above.

The Tropical zone is the area located across northern Australia including Cape York, the top end of northern territory, land south of Gulf of Carpentaria, and the Kimberley region.

The Sub- Tropical zone is located along the coast and island from Cairns along the Queensland coast and northern areas of NSW and coastal fringe North of Perth to Gerald ton in WA.

The Desert zone is located mainly across the centre of the mainland which includes a huge part of South Australia and Western Australia, South- Western part of Queensland and

North- Western part of NSW and about 50% of Northern Territory on its southern part. The major part of Australia is covered with desert region.

Grassland climate zone includes arid and semi- arid part of desert and located in the centre and north part of Alice spring in Northern Territory. It is essentially a belt surrounding the arid and semi-arid desert areas in the centre and seeping into the area north of Alice Springs in the NT.

Temperate zone is situated around the coastal hinterland of NSW, most of Victoria, Tasmania, south east corner of SA and south west of WA. The temperate zone consists of four seasons. Summer, autumn, winter and spring. Summer occurs during December till February, autumn takes place during March till May, winter happens during June to August and spring comes about during the months of September till November. (Wells, 2013)

4.3. IMPACT OF WEATHER CONDITIONS ON PHOTOVOLTAIC MODULES IN AUSTRALIA

4.3.1. CYCLONES

From October to May, northern part of Australia experiences its cyclone season. Every year, cyclones may enter into its category 3 to category 5 stage when it hits the land of Australia and then slowly settles down while moving towards inland. Category 5 cyclones bring the wind gust of up to 300 km/h with huge amount of rain. (Kemenev, 2012)

Strong winds generated by the cyclones do have potential to cause extensive damage to the PV modules and it turns the loose debris into missiles which can hit PV modules to cause damage like Glass breakage. (hpw.qld.gov, 2009)

Figure 45 shows the solar panel debris on the streets of Pilbara region after been hit by the cyclone Christine in December 2013. (Coasts Down Under, 2013)

Figure 45: Damaged Solar panel debris on the street after cyclone. (Source: (Coasts Down Under, 2013))

4.3.2. HAIL STORMS

Solar panels with clear silicon material are likely to get damaged by 1-inch diameter hailstones. However, the solar panels which are covered with acrylic can survive the hailstones of up to 2 inches diameter. Usually the PV module can survive the hailstone which hits the module with the velocity of 120 miles/hour. (LaMeaux, 2014)

In Australia, there is no particular time of the year and there is no particular location where hail storms are expected normally. But over the last few decades, there is a history of hailstorms which strike the cities, towns of Australia including Sydney, Canberra and Perth which caused significant amount of damage.

Sometimes, hail storms bring extremely large size hail stones which are large enough to produce the damage on PV modules as shown in the Figure 46.

Figure 46: Hail damaged PV module (Source: (Gold Coast Solar Power Solutions, 2014))

4.3.3. EXTREMELY HOT TEMPERATURE

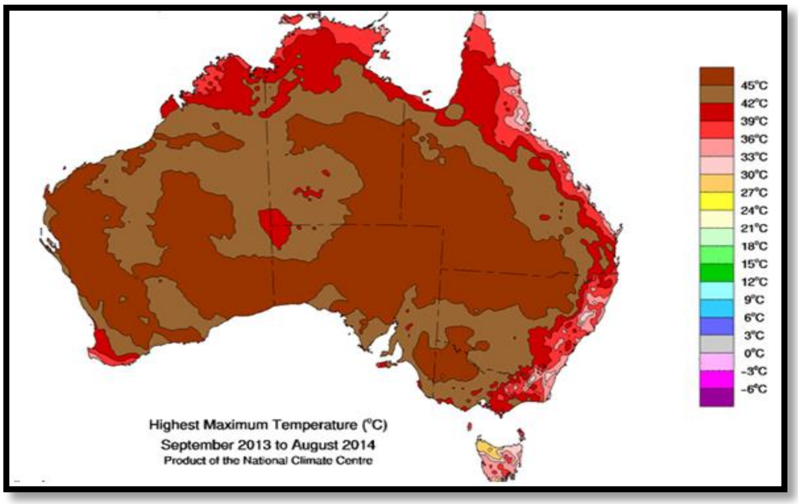

Figure 47: Maximum Temperature across Australia. (Source: (Australian Bureau of Meteorology , 2014))

A big part of Australia is covered with desert and experiences high temperature throughout the year. Major part of Australia experiences the maximum temperature ranges between 40- 45 degree Celsius. Figure 47 shows the maximum temperature across Australia.

4.3.4. RAINFALL

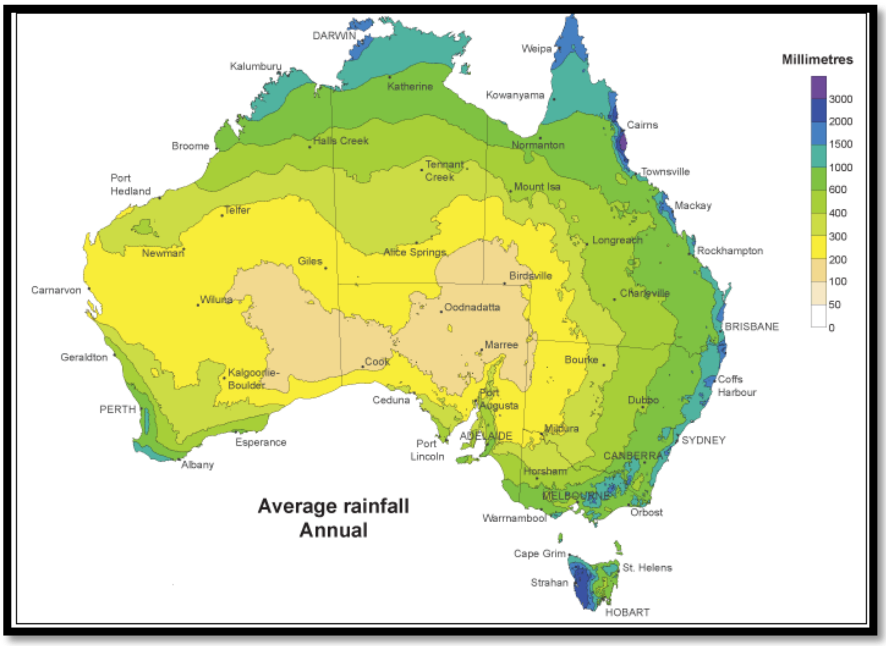

Figure 48: Average Annual Rainfall across Australia. (Source: (Australian Bureau of Meteorology, 2011))

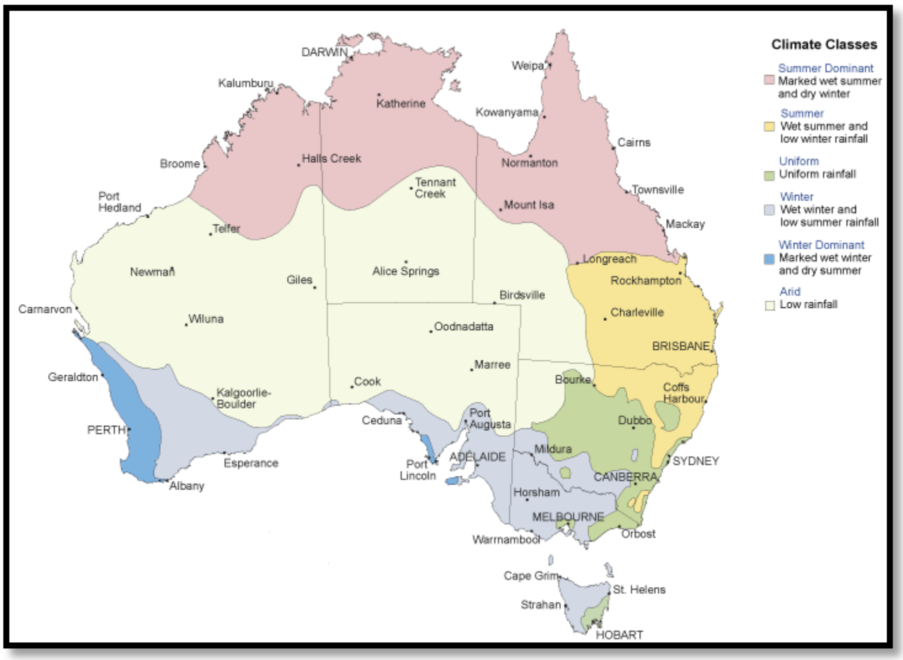

Figure 49: Major Seasonal rainfall zones of Australia. (Source: (Climate classification Maps, 2012))

The above maps shown in the Figure 48 and Figure 49 represent the average rainfall in Australia and the major seasonal rainfall zones of Australia. These maps show that most of the central Australia is extremely dry. These areas are located away from moist regions and the moisture level in those areas is very low. Average annual rainfall increases towards the coastal areas of Australia and coastal regions of the eastern side of Australia, North part of Australia and West Tasmania experiences a high level of rainfall around the year. Major cities of Australia including Melbourne, Sydney, Brisbane Cairns, Darwin, Adelaide and Perth all experiences a significant amount of rainfall as compare to the rest of Australia. (Australian Bureau of Meteorology, 2011)

Moisture levels in the climate plays a significant role in the Glass Fatigue resulting in cracking of the glass as discussed in the section 3.6.

5. LITERATURE REVIEW OF SIMILAR SURVEYS

5.1. INTRODUCTION

As a part of the thesis project, literature review contributes lot of the information in this report which has been published by other students and organizations as a part of other projects related to the Photovoltaic Industry. The other survey reports, journals and the project which are included in the literature review of this thesis provide readers the information about the background of the Photovoltaic Industry and the problems and issues faced by the users of the Photovoltaic Module systems.

Various relevant reports, journals, thesis reports and other articles have been used to establish the foundation of this report. To start with the background of the Photovoltaic Module System, it is interesting to know that the first Photovoltaic module was constructed by the Bell Laboratories in United States in the year 1955. The PV module constructed by The Bell laboratories used the solar cell with 3 cm of diameter and used silicon oil for the encapsulant within a plastic case. The efficiency of that module was up to 2%. (Rajiv Dubey, 2014). Later on, more development have been taken place and in the present day, EVA (Ethyl Vinyl Acetate) is used as the encapsulant layer of the Photovoltaic Module.

New technologies are still working very rapidly in order to increase the reliability, affordability and the efficiency of the Photovoltaic system. In order to achieve success in this purpose, it is important to analyze the performance of the Photovoltaic Module systems in the operation and it is very important to make sure that the new technology and research should eliminate the faults and the problems which occurs during the operation of the Photovoltaic Module systems. Various private and government supported organizations are actively conducting the campaigns and surveys to make people aware about the benefits of the renewable energy. They also work in order to collect the information about the issues and difficulties faced by users while using the PV module systems to understand the cause of the faults and issues in the PV module system.

In this report, some of the major projects and thesis reports will be discussed as a part of the Literature review which provide readers with the very useful information and the data which explain the faults and the causes of the faults according to the research and surveys conducted in those reports.

5.2. RESIDENTIAL PHOTOVOLTAIC INDUSTRY IN AUSTRALIA

5.2.1. INTRODUCTION

This section describes the trend of the Photovoltaic Industry in Australia over the last few years and the expectation of the growth of the industry in the coming years. Solar energy industry is growing very rapidly in Australia. Australia's Renewable Energy Target (RET) aims to source 20% of the electricity from renewable by the year 2020. State governments also encourage people to install the PV module systems on the roofs by providing them some grants and financial support. (Solar Energy, 2013)

5.2.2. SMALL SCALE/ RESIDENTIAL PV MODULE SYSTEM

A report noted that over 1 million homes in Australia have solar Photovoltaic module systems on their roofs. (Reneweconomy, 2014)

Figure 50 shows the growing number of small scale PV module systems in last 10 years. This shows a steep increase in the numbers from year 2009 to 2013. In 2014, the total number is expected to cross the 1000000 mark. (Solar Energy, 2013)

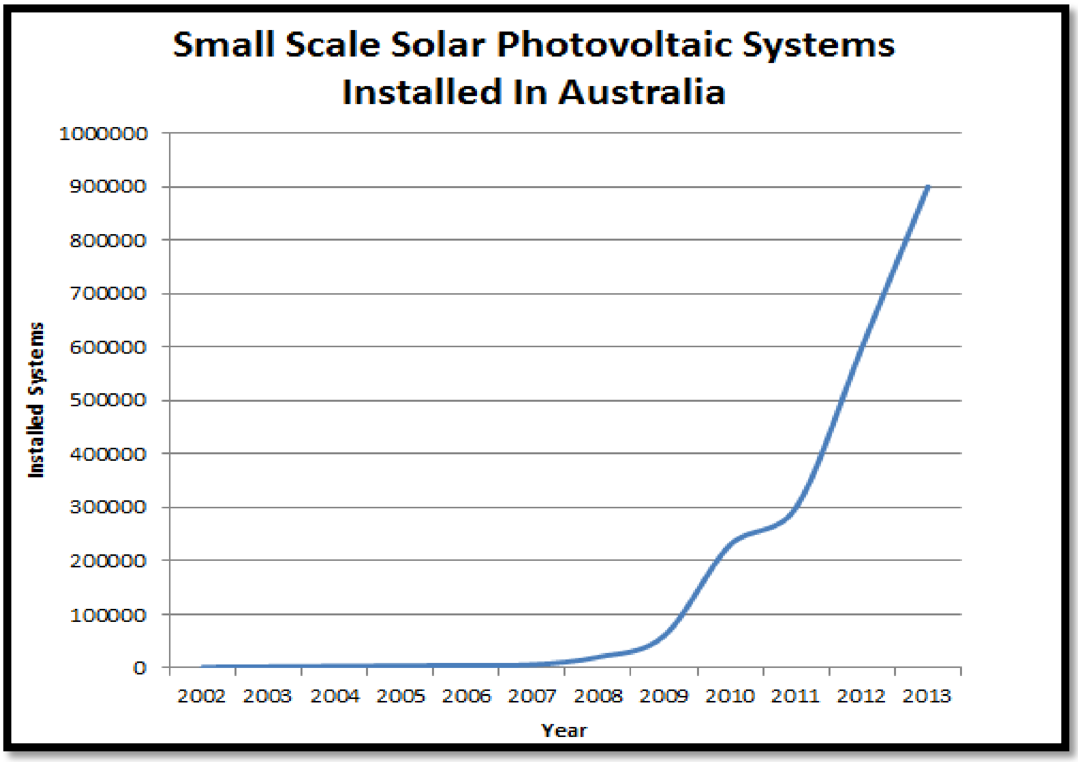

Figure 50- Number of the Installed PV module systems in Australia. (Illustration: (Solar Energy, 2013))

5.2.3. TOTAL PV MODULES INSTALLED CAPACITY

Figure 51 shows the total Installed PV modules capacity of Australia in last 10 years. A steep increase can be seen from 2009 onwards in the growth of PV modules installed capacity. It is expected to increase the renewable energy share to 20% by the year 2020. (Australian PV Institute, 2014)

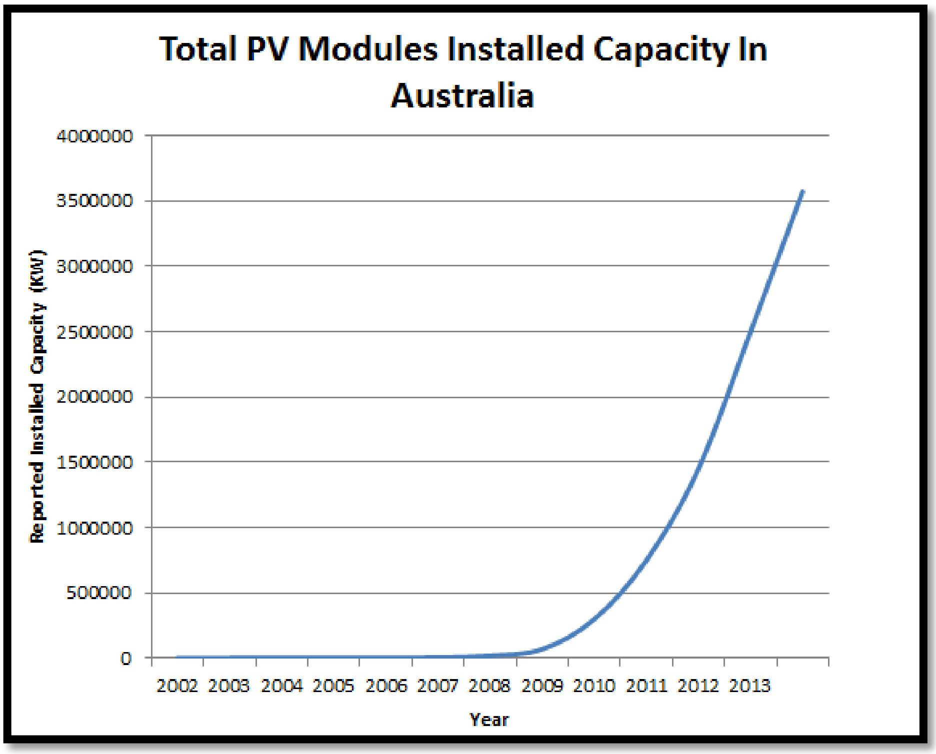

Figure 51- Photovoltaic Module System Installed Capacity in Australia. (Illustration: (Australian PV Institute, 2014)

5.2.4. PERCENTAGE OF HOUSES WITH PV INSTALLATION

Figure 52below shows the percentage of houses in each state of Australia with PV module systems installed. It is shown that about 25% of houses in SA and QLD use PV module system to produce electricity for the domestic use. 18.4% of the houses in Western Australia have PV module systems on the roofs and about 11% of the houses in NSW, Victoria and Tasmania use PV module system. Northern Territory only records 5.1% of the houses which are installed with PV module systems. (Australian PV Institute, 2014)

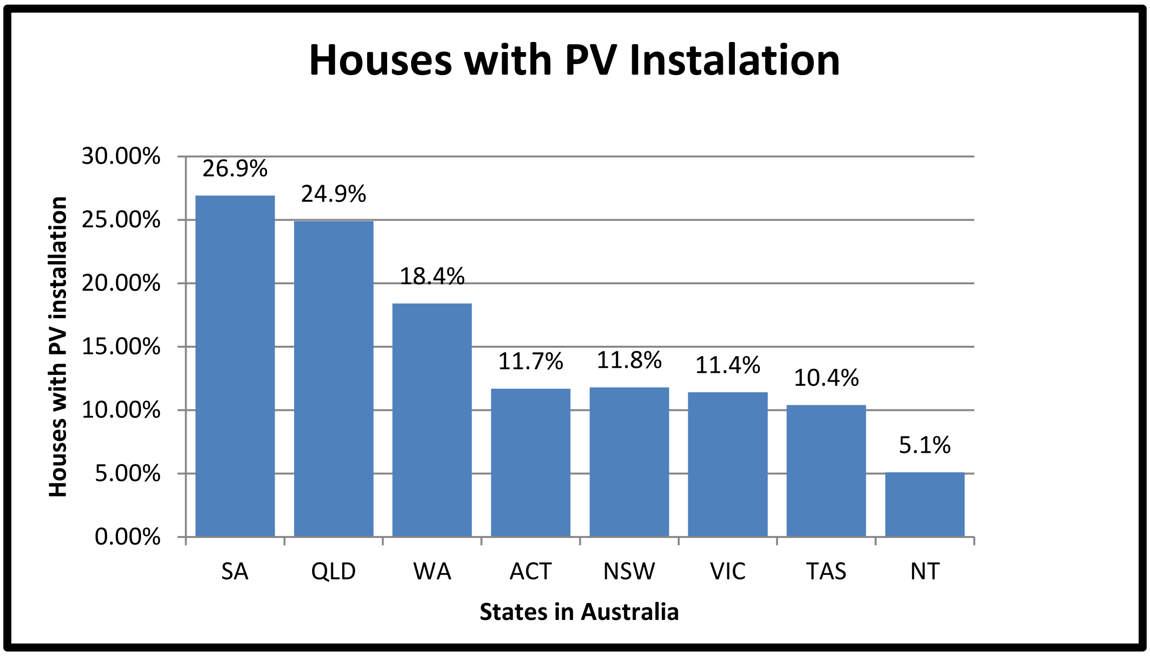

Figure 52- Percentage of Houses with PV module system in Australian States. (Illustration: (Mapping Australian PV installation, 2014))

5.2.5. TOTAL INSTALLED PV CAPACITY IN AUSTRALIAN STATES

Figure 53 below represents the total installed PV capacity in different states of Australia. This shows that Queensland have the highest amount of PV Generation capacity of 1152 MW followed by NSW with 713 MW and Victoria with 625 MW of PV generation capacity. South Australia is installed with 533 MW, Western Australia with 398 MW, Tasmania with 72 MW, ACT with 62 Mw and Northern Territory with 15 MW of installed PV generation capacity. (Mapping Australian PV installation, 2014)

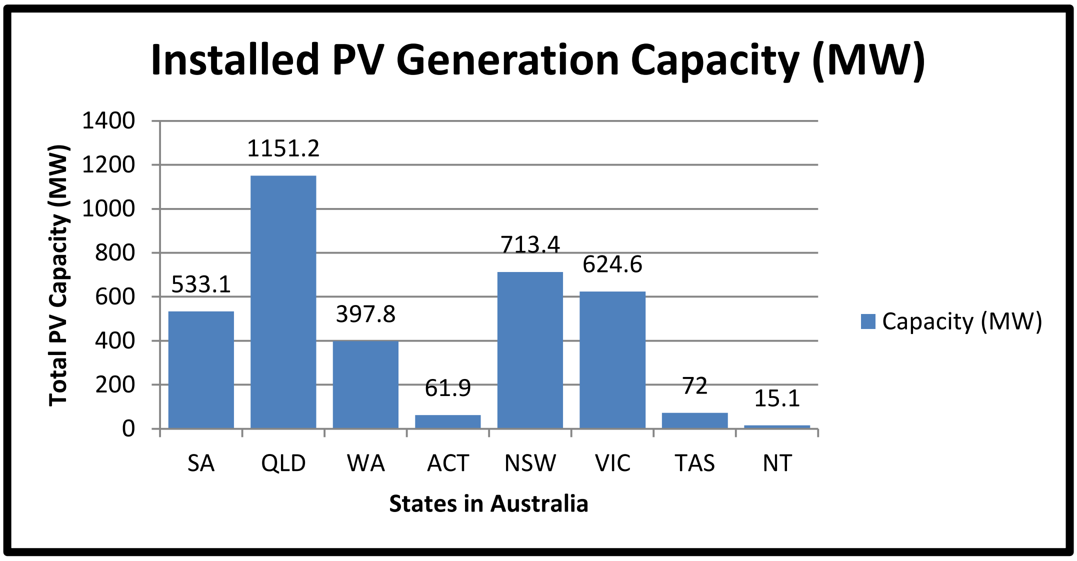

Figure 53- PV Generation Capacity of States of Australia. (Illustration: (Mapping Australian PV installation, 2014))

5.2.6. TOTAL ANNUAL SOLAR ENERGY GENERATED IN AUSTRALIA BY STATES

Figure 54represents the total amount of annual solar energy generated by PV module systems in each state of Australia. This shows that the Queensland is producing the highest amount of electricity (1592966 MWh) annually using PV module systems followed by NSW (989125 MWh annually) and Victoria (751430 MWh annually). Western Australia generated annual solar energy of 553899 MWh. (Mapping Australian PV installation, 2014)

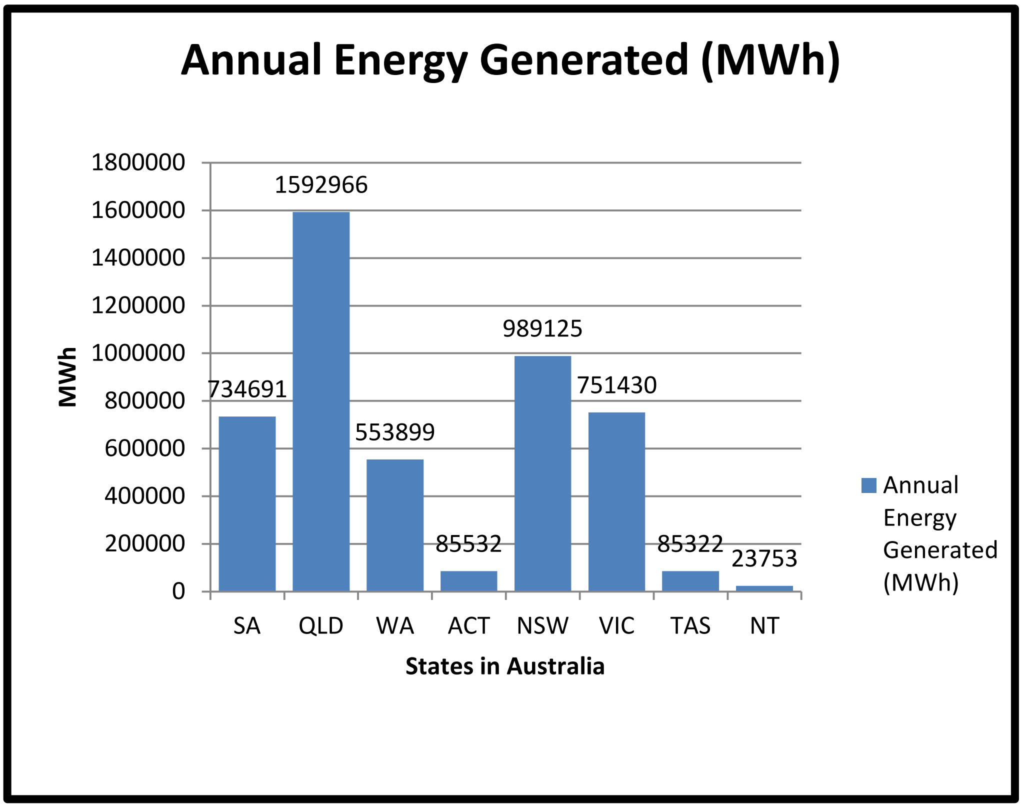

Figure 54- Solar Energy Generated Annually in the states of Australia. (Illustration: (Mapping Australian PV installation, 2014))

5.3. DATABASES

5.3.1. INTRODUCTION

In this section of the report, results and the findings of the other reports and the similar surveys are explained. These surveys and reports work towards finding the effects of the different factors which causes the faults and issues during the operation of the photovoltaic module system. A survey from the solar Business in Australia finds the trend and the consumers prospective to choose the Photovoltaic module system.

In this section of the report, a survey names as 'All India Survey of Photovoltaic Module Degradation' conducted by the National Center for Photovoltaic Research and Education, Indian Institute of Technology (IIT) has been section of the report. This survey report explains the degradation factors in different climate zones in India. Climate zones in India are very similar to the Climate zones in Australia. India experiences all seasons throughout the year and big part of India is covered in the Temperate zone region as well. Majority of the population in Australia also lives in the Temperate zone. So, this survey provides readers with some useful information and results which can be compared to the survey conducted by APVA and other organizations in Australia.

Another survey conducted by the APVA over the last 3 years has been discussed in this section of the report as well. Results from another survey Australian householder's interest in distributed Energy Market' has been discussed. Both surveys were conducted nationally on a high level and all the PV module system users and installers were encouraged to provide as much information as they can to improve the reliability of the PV module systems in the future.

More reports including fault analyses of Photovoltaic modules and its components and their experiments and results has been studied and another report from REN21 and International Energy Agency survey result has also been discussed in this section of the report.

5.3.2. SOLAR BUSINESS IN AUSTRALIA- SURVEY RESULTS

A survey has been conducted by Solar Business in Australia which aims to find out the factors which customers consider to make a choice of Photovoltaic module system they will install. The pie chart below in Figure 55shows that 34% of the respondents think that brand of the Photovoltaic system is not important and 78% respondents are Brand conscious. Another chart in Figure 56shows the consumers motivation which encourages them to get Photovoltaic module on their roofs of the houses. 78% of the consumers are financially encouraged to get PV module system installed while 22% of the consumers install PV module system in order to use the clean energy from environmental friendly source of energy production. (PV Industry Trends Survey, 2012)

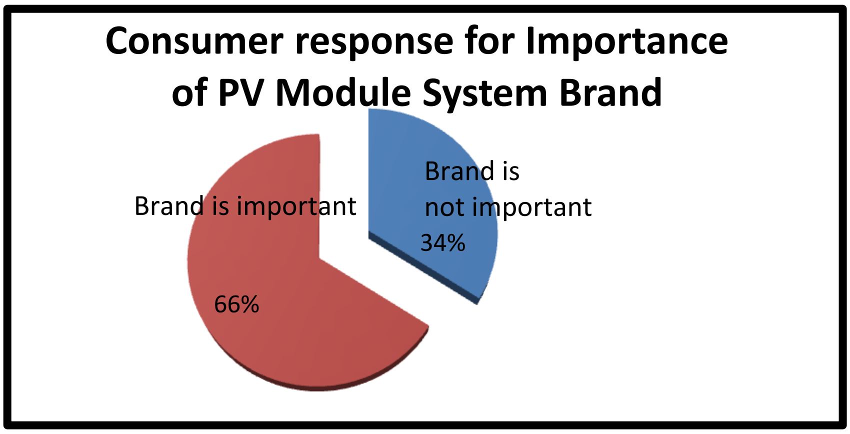

Figure 55- Consumers response for the Importance of the Brand of PV system. (Illustration: (PV Industry Trends Survey, 2012))

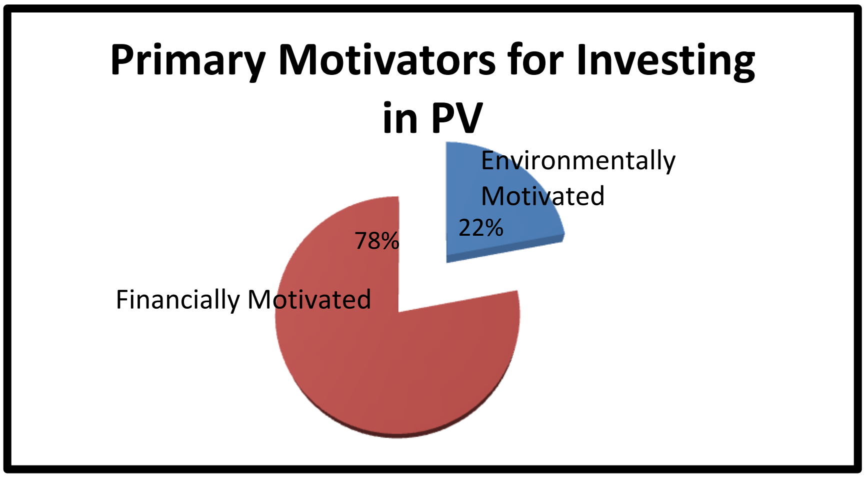

Figure 56- Factors which motivates consumers to Install PV module system. (Illustration: (PV Industry Trends Survey, 2012))

5.3.3. AUSTRALIAN HOUSEHOLDER'S INTEREST IN DISTRIBUTED ENERGY MARKET- NATIONAL SURVEY RESULT

This section of the report presents the results of a National survey which explains the motivation of the consumers to use the PV module systems. Figure 57 represents the percentage of households with the amount of their energy bills. It shows that 43% of the consumers pay the average energy bill. 27% of the population pays high energy bills and 9% pays very high bills for their energy consumption. Figure 58 shows the motivation of the consumers to use PV systems in their houses. It shows that 70% of the consumers are motivated to use PV systems to save their money on the power bills. (Romamach, 2013)

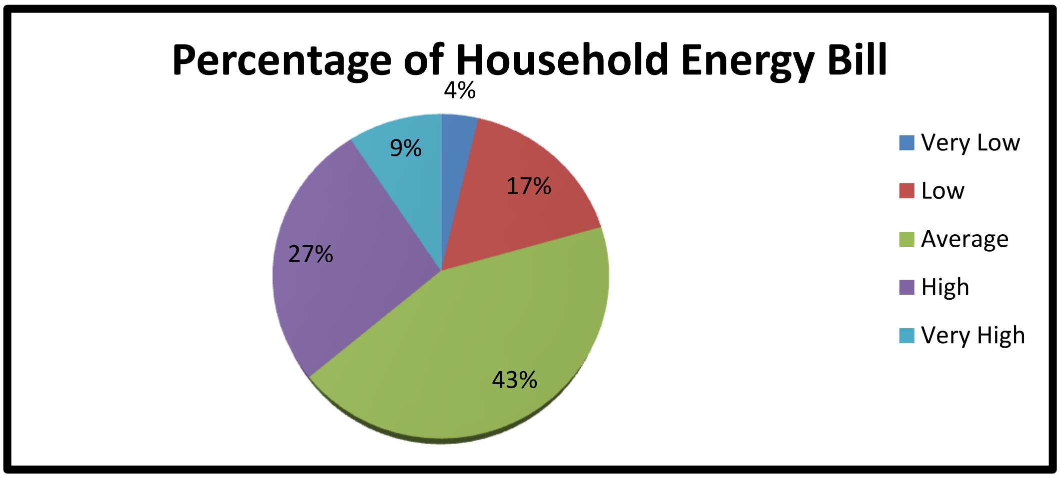

Figure 57- Percentage of Household Energy Bill. (Illustration: (Romamach, 2013))

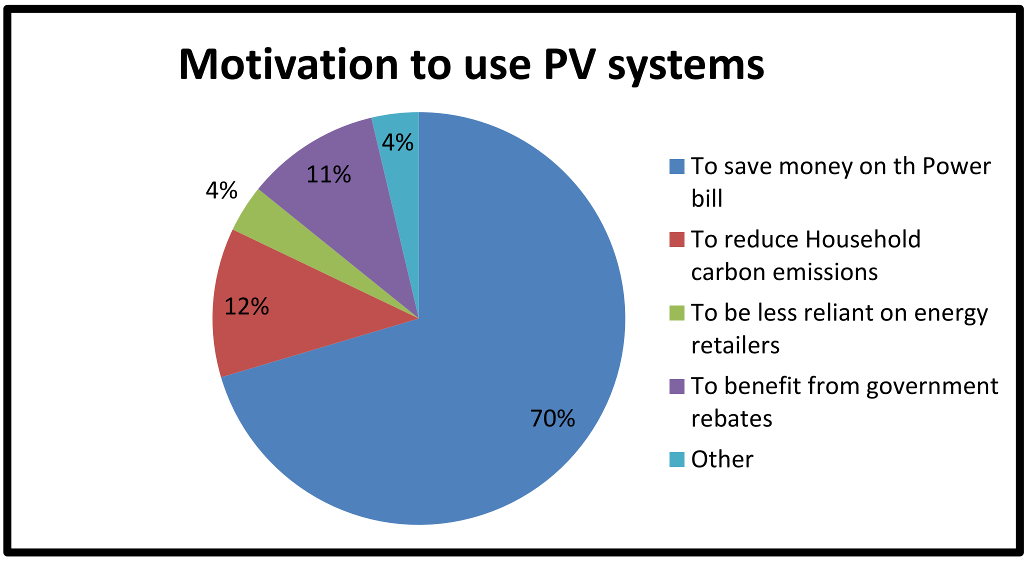

Figure 58- Motivation to use PV systems. (Illustration: (Romamach, 2013))

5.3.4. INTERNATIONAL ENERGY AGENCY- SURVEY RESULT

International Energy Agency published a report in which survey results provided the information about the typical failures which were observed during the operation of the PV modules in the field. Table 1 show that out of 32 reports, 28 reports are related to the faults with soldier bond failure. 3 faults has been reported related to the strings of the modules and 2 reports has been made regarding the breakage of the PV modules and 1 report suggest the failure of bypass diode. (Kato, 2012)

Table 1- Typical Failure Observed in Field Survey (Illustration: (Kato, 2012))

Typical Failure Observed in Field Survey	
Total PV Systems (Residential)	32
Solder Bond Failure	28
Module String Disconnection	3
Cover Glass Breakage	2
Bypass Diode Failure	1
Others	4

5.3.5. ALL INDIA SURVEY OF PHOTOVOLTAIC MODULES DEGRADATION

All India Survey of Photovoltaic Modules was conducted in 2013 to analyse the degradation of Photovoltaic Module systems in India from 3 to 30 years old. The main objective of this survey was to assess the effect of different climates on the PV modules with the age of the PV modules. The results of this survey which are related to the fault analyses of PV module systems are discussed below in this section of the report. (Rajiv Dubey, 2014)

5.3.5.1. DEGRADATION RATES OF IV PARAMETERS IN DIFFERENT CLIMATE ZONES IN INDIA

Table 2 represents the degradation rates of IV parameters of the PV module system. IV curve is used to graphically sketch the performance of the PV module systems. It also represents the maximum power point (MPPT method) to track the maximum power output of the system. The results show that the degradation rates of maximum power (P_{max}) per year is highest in Hot and Humid region of the climate zones with the value of 1.29% per year. (Rajiv Dubey, 2014)

Table 2- Degradation rates of IV parameters in different Climate zones in India. (Illustration: (Rajiv Dubey, 2014)

Climate Zone	P_{max} (%/ year)	I_{SC} (%/ year)	V_{OC} (%/ year)
Hot and Humid	1.29	0.98	-0.34
Temperate	0.24	-0.34	0.04
Composite	0.56	0.45	-0.17
Hot and Dry	1.55	0.78	0.20
Cold and Dry	0.19	0.72	-0.11

Table 3 represents the result of the research which is shown in the same survey. It shows the Degradation rates of maximum power output of PV module system in the different cities around the world. The result shows that degradation is highest in Perth, Australia with 2.7% per year with mono- crystalline PV modules and 5% per year in La Reunion Island (Indian Ocean) with poly- crystalline PV modules. (Rajiv Dubey, 2014)

Table 3- Degradation rates of maximum power output of two different types of PV modules in different climate zones and regions. (Illustration: (Rajiv Dubey, 2014)

Climate Regions of the test site	Location	Test Duration	Degradation rates of Maximum Power (% per year)	
			Mono crystalline	**Polycrystalline**
Temperate (Moderate)	Perth	1.5	2.7	2.9
	Hamamatsu	10	0.62	NA
	Ispra (Itly)	22	0.67	0.3
	Luguno (Switzerland)	20	0.53	NA
	Cologne (Germany)	3	0.5	NA
Hot and Dry	Mesa, Arizona (USA)	4	0.4	0.53
	Negev Desert (Israel)	3.4	NA	1.3
	Tuscon (Arizona, USA)	1	1	1.65
	SedeBoqer(Israel)	3	0.5	NA
Cold and Dry	Berlin	1	1.25	1.05
	Golden, Colorado (USA)	8	0.75	NA
	Zugspitze (Germany)	3	2	NA
	INES, Chambery (France)	2	NA	4
Hot and Humid	La Reunion Island (French Island in Indian Ocean)	2	NA	5
	Serpong (Indonesia)	3	1	NA

5.3.5.2. VISIBLE FAULTS IN PV MODULES

Table 4 represents the percentage of the modules affected by the visible faults. This shows that 79% of the modules are affected by the Discoloration of the encapsulant of the Photovoltaic module. 67% of the modules are affected by the corrosion of the metallization, interconnects and output terminals. 39% of the modules also show the corrosion on the front of the Photovoltaic modules. 26% of the modules are affected by the delamination on the front side of the module. 19% of the total modules have got chalking effect (white powder) on the back sheet. 22% of the modules got physical damage of the Junction box. (Rajiv Dubey, 2014)

Table 4- Percentage of Modules affected with visible faults. (Illustration: (Rajiv Dubey, 2014)

Visual Degradation Observed	%age of the modules affected (Total: 57)
Discoloration of encapsulant	79%
Corrosion of metallization, interconnects and output terminals	67%
Front side delamination	26%
Bubbles & Delamination in back sheet	12%
Chalking of back sheet	19%
Junction Box Breakage	22%
Frame damage/ corrosion	39%

5.3.5.2.1. EFFECT OF CLIMATE AND AGE CAUSING DISCOLOURATION OF ENCAPSULANT IN THE FIELD

Figure 59 demonstrates the percentage of the PV modules in different climate zones which shows the discoloration in the front of the module. It is shown that in hot and dry climate, every module shows discoloration of the front encapsulant after 5 years of operation in the field. In Hot and Humid Climate, 90% of the modules which shows the discoloration are 11-20 years old. 50% of the PV modules in hot and humid climate show discoloration in their first 5 years of operation in the field. In composite climate zone, 20% of the modules got front discoloration in their first 5 years; however 100% of the modules show discoloration after their 11 years of the operation in the field. In temperate climate zone, 100% of the modules got discoloration after 11 years and 65% of the modules in cold region show front discoloration after 11 years of the use in the field. (Rajiv Dubey, 2014)

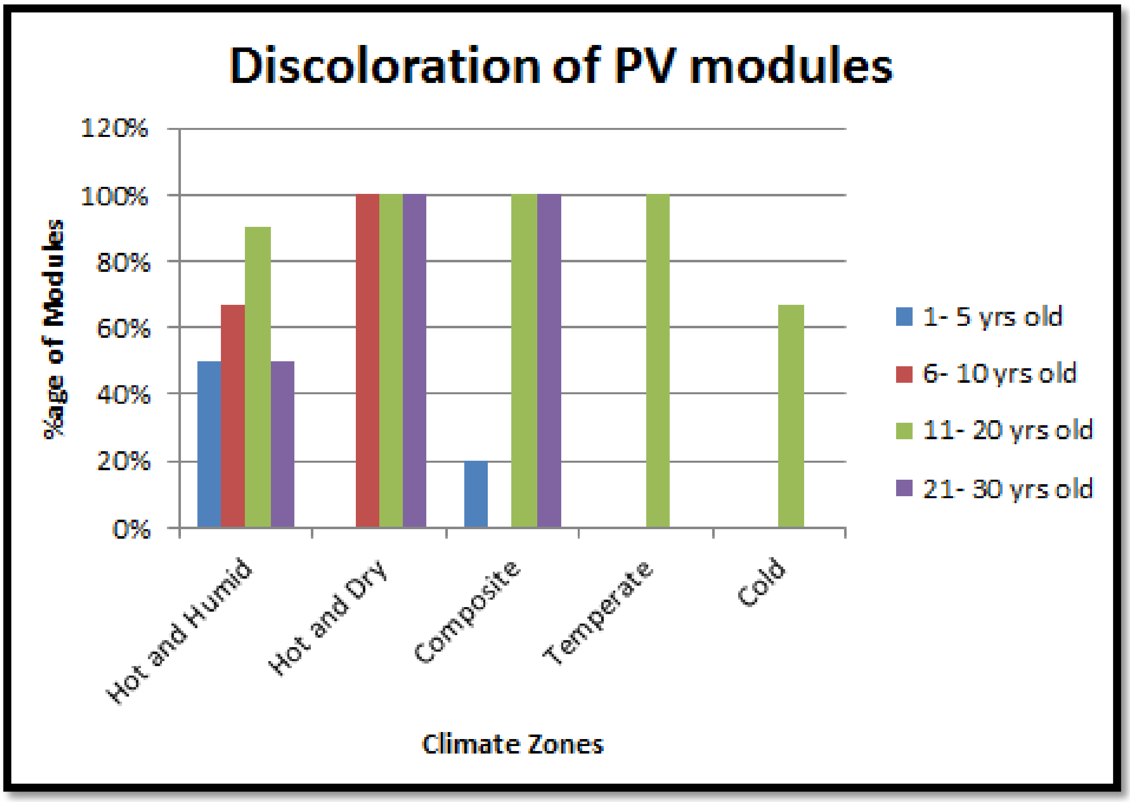

Figure 59- Discoloration of PV modules/ encapsulant with different climate zones. (Illustration: (Rajiv Dubey, 2014)

5.3.5.2.2. PERCENTAGE OF MODULES EFFECTED BY DELAMINATION IN DIFFERENT CLIMATE ZONES WITH THEIR AGE

Figure 60 shows the percentage of the PV modules in different climate zones that got the delamination of the modules. It is clearly shown that 100% of the modules which are more than 21 years old show the sign of delamination in Hot and Dry climate, and 50% of the modules which are 21 years old got delamination in Hot and Humid climate. About 30% of the 11-20 years old modules show delamination of PV modules in all the climate zones except temperate climate zone. No delamination of PV module is recorded in the temperate zone. (Rajiv Dubey, 2014)

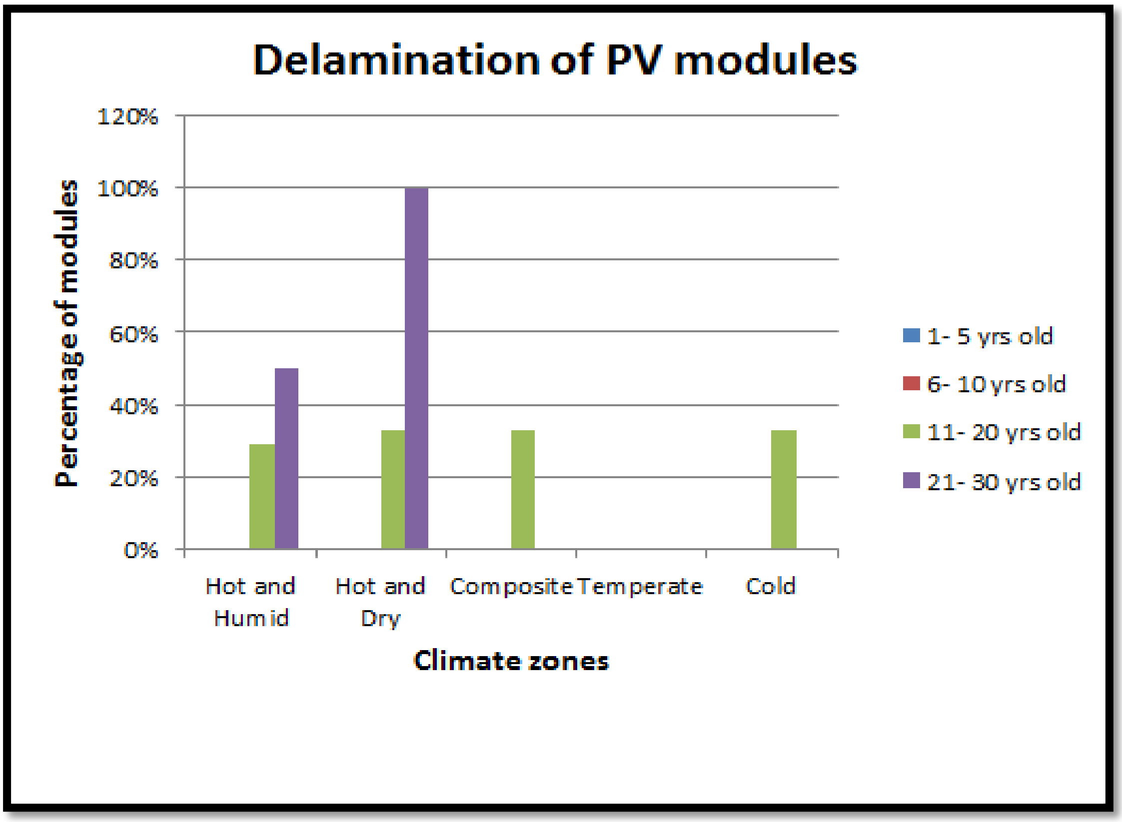

Figure 60- Delamination of PV modules with different Climate zones. (Illustration: (Rajiv Dubey, 2014)

5.3.5.2.3. PERCENTAGE OF MODULES EFFECTED BY CORROSION IN DIFFERENT CLIMATE ZONES WITH THEIR AGE IN THE FIELD

Figure 61 represents the percentage of the PV modules which are affected by the corrosion of the PV modules. It is shows that in hot and humid climate, 100% of the modules got corrosion which are 11-20 years old and 21-30 years old. 30% of the modules which are 6-10 years old show corrosion and 50% of the modules which are less than 5 years old shows corrosion. In hot and dry climate, 100% of the 21-30 years old modules are corroded, 35% of the 11-20 years old modules and none of the modules which are less than 10 years old shows the sign of corrosion. In composite climate, more than 80% of the 11-20 years old modules show corrosion and 100% of the 21- 30 years old modules shows corrosion. In temperate zone, 100% of the 11-20 years old modules are affected by the corrosion. No other data is recorded for the other modules in the field. In cold climate, 30% of the 11- 20 years old modules are affected by corrosion. No other data is recorded for the other modules in the field. (Rajiv Dubey, 2014)

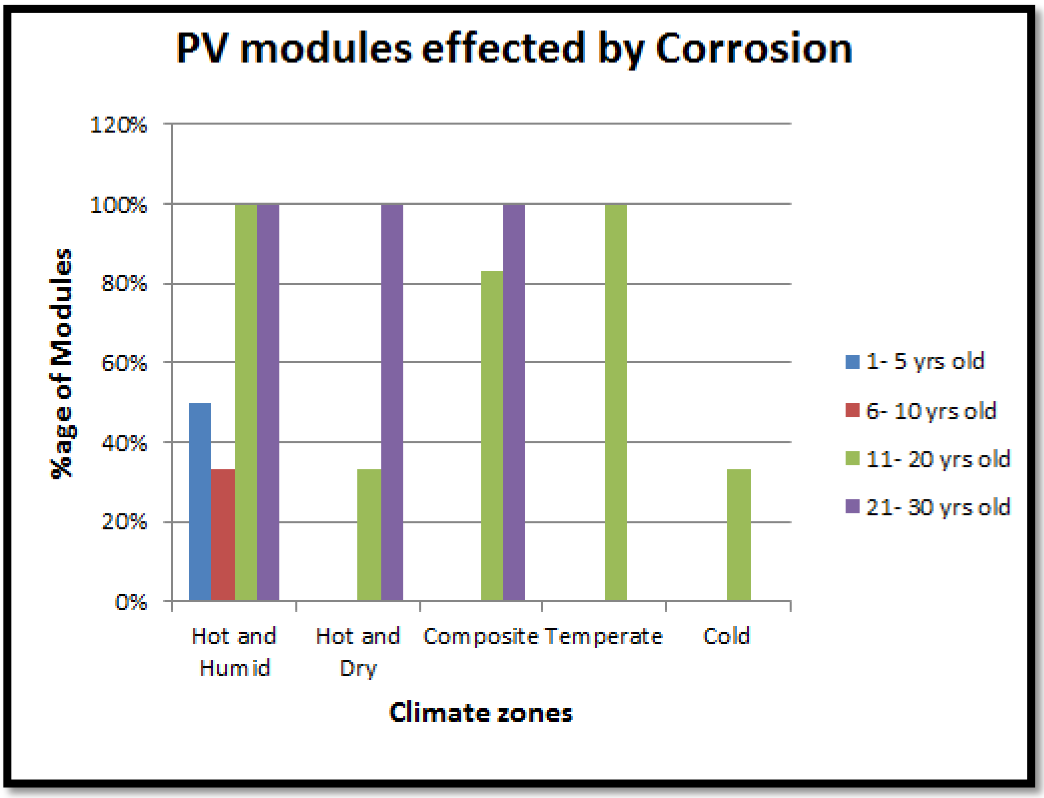

Figure 61- PV modules affected by Corrosion with different Climate zones. (Illustration: (Rajiv Dubey, 2014)

5.3.5.2.4. PERCENTAGE OF MODULES EFFECTED BY BUBBLES AND DELAMINATION IN THE BACK SHEET

Figure 62 shows the percentage of the PV modules which shows the visible signs of bubbles and delamination on the back sheet of the PV module. The graph shows that in hot and humid climate, 50% of the 21- 30 years old modules shows that bubbles and delamination of the back sheet and 24% of the 11- 20 years old PV modules shows the same signs. 18% of the 11-20 years of the PV modules in composite climate zone shows this issue in the PV modules. No other data is recorded for other climate regions regarding this fault in the modules. (Rajiv Dubey, 2014)

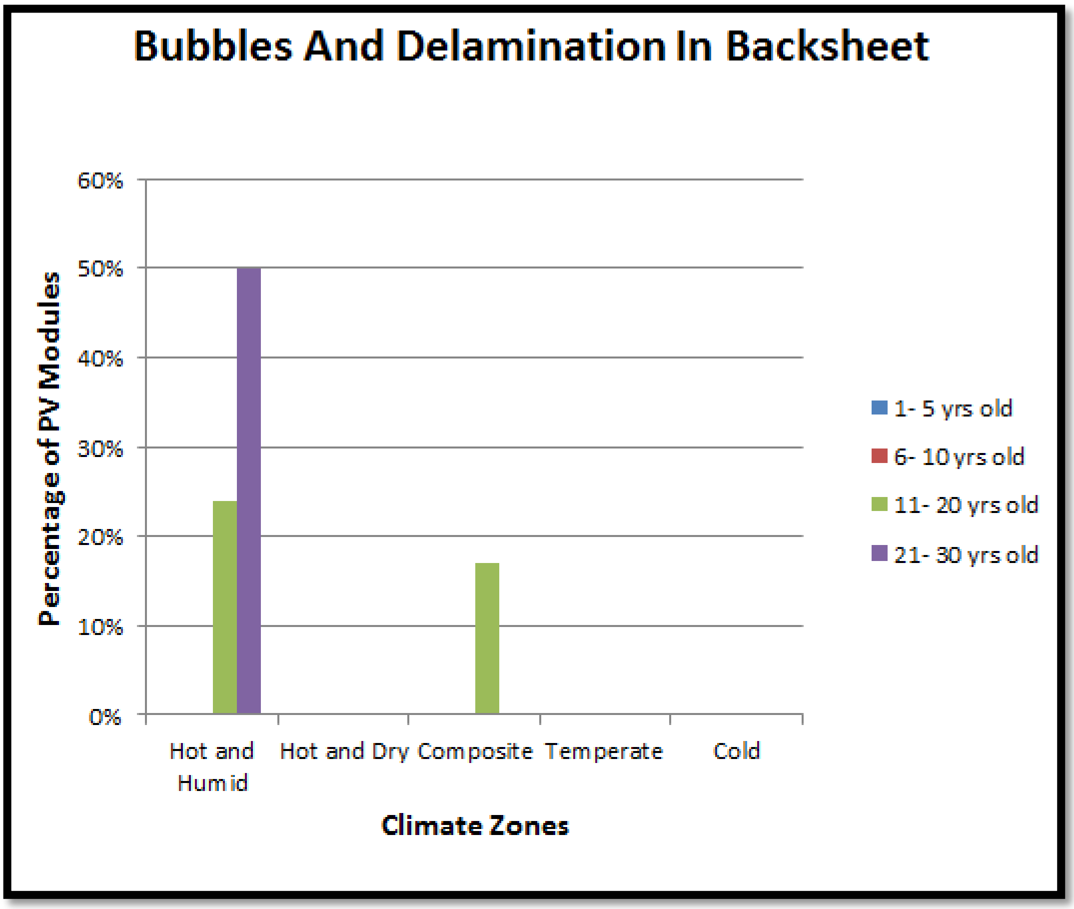

Figure 62- PV modules with bubbles and delamination in the back sheet. (Illustration: (Rajiv Dubey, 2014)

5.3.5.2.5. CONDITION OF JUNCTION BOX

The charts below shows the results of the survey regarding the conditions of the junction box of the PV modules. Junction Box is normally attached to the back sheet of the module.

Figure 63 represents the results from the survey which shows the structure of the junction box. It is shown that 78% of the junction boxes are undamaged. 12% of the junction boxes are undamaged but weathered due to the environmental conditions. 8% of the junction boxes got their back cover missing, and 2 % of the junction boxes got structural damage.

Figure 64 shows the condition of the attachment of the junction box on the back sheet of the module. The results show that 72% of the junction boxes are well attached and well-sealed to the back sheet of the module. 4 % of the junction boxes are loosely attached and 24% of them are sealed but the seal is leaking. (Rajiv Dubey, 2014)

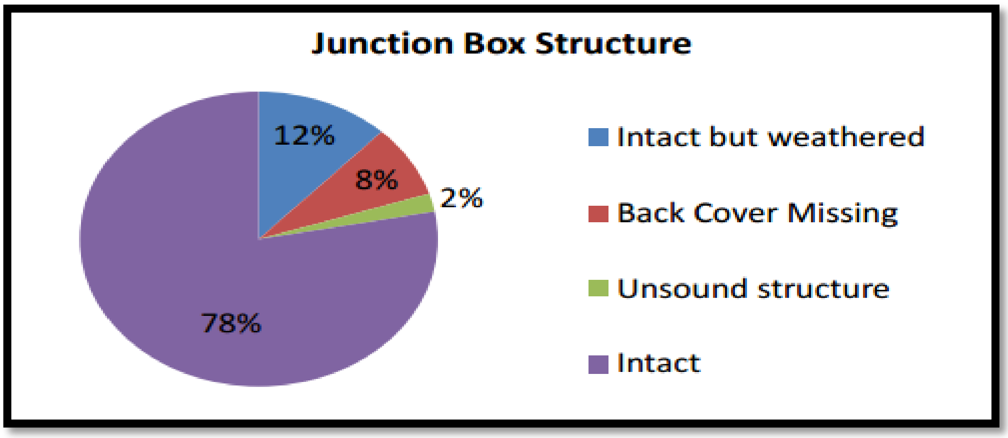

Figure 63- Condition of the Junction Box. (Illustration: (Rajiv Dubey, 2014)

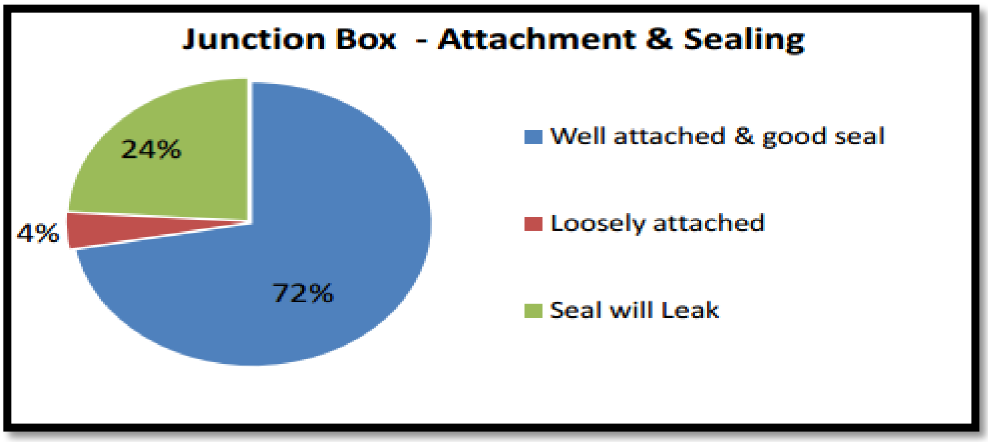

Figure 64- Condition of the attachment of the Junction Box. (Illustration: (Rajiv Dubey, 2014)

5.3.6. CLIMATE BASED PV SYSTEM PERFORMANCE AND RELIABILITY PROJECT-APVA

5.3.6.1. INTRODUCTION

This part of the report explains the results derived from the survey conducted by the APVA with its supporting partners over the 3 years of time. The aim of this project was to collect the on- going data on the performance on the PV module systems in the field, to analyze the reliability of the systems and to understand the effect of the climate on the degradation of the modules. This survey results provide the foundation to further studies in order to increase reliability of the PV module systems. The results of this report include the information regarding the failure modes of the PV module system and the components of the systems which cause the faults. This report uses the data and the information provided by the respondents who participated in the online survey conducted by APVA. (Sandy Pulsford, 2014)

5.3.6.2. FAILURE MODES OF THE PHOTOVOLTAIC MODULE SYSTEM

This section of the report explains the results of the report which are related to the components of the PV module systems. The graphs below, represents the number of the faults reported related to the components of the system.

Figure 65 illustrates the percentage of the faults reported which are related to the different components of the PV module system. It is clearly shown that 18% are reported for the degradation of the performance of the system. 15% of the systems are reported for the wet current leaking fault. 10% of the modules have reported to have bubbles in the back sheet and 9% of the modules have got bubble formation in the front side of the module. 7% of the total faults reported are concerned with the degradation of the cells in the modules, 6% of the faults are reported with the corrosion in the conducting paths and another 6% of the reported faults are the hole formation in the lamination of the module. 4% each has been reported with the faults related to the junction box and degradation of the coating of the module. 2% each has been reported for the faults including isolation test, discoloration of the lamination, glass breakage, defect in bypass diode, ripped back sheet and crack on the lamination. 1% each of the faults has been reported related to the damage of the frame and yellowing of the module. (Sandy Pulsford, 2014)

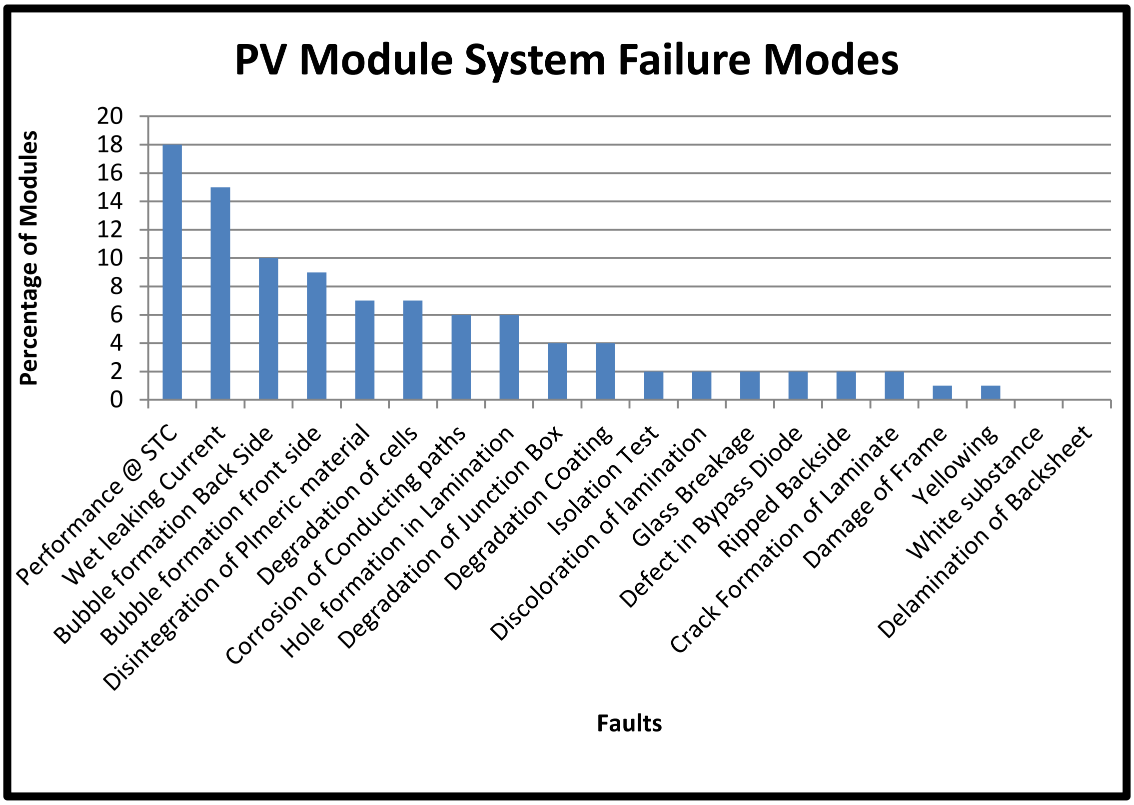

Figure 65- PV module system Failure modes (Illustration: (Sandy Pulsford, 2014))

Figure 66 shows the components of Photovoltaic module system where the faults have been reported. The most of the faults reported are related to the PV modules of the PV module system. Out of 17 respondents, 14 reported faults are related to the module of the PV module system. 2 reported faults are related to the inverter of the PV module system. 1 fault has been reported in relation to the installation fault. (Sandy Pulsford, 2014)

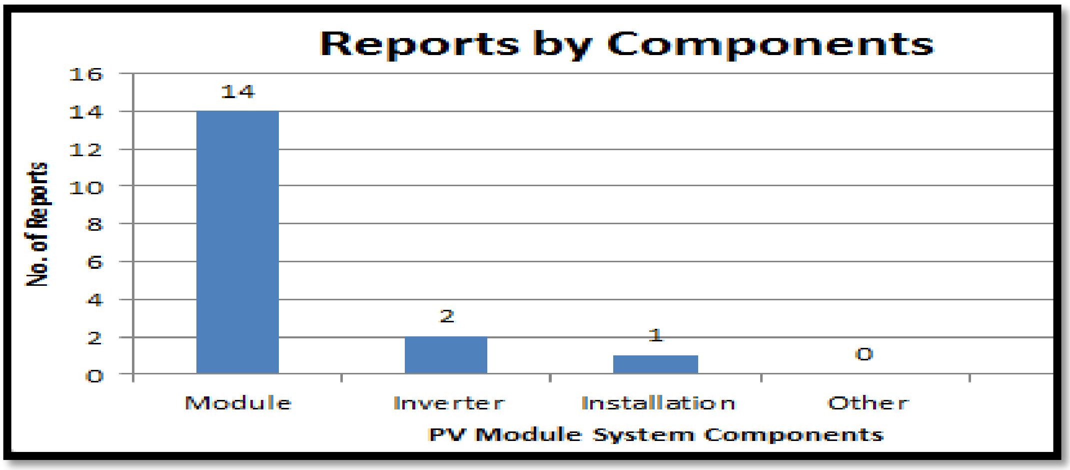

Figure 66- Faults reported by the components of the PV module system (Illustration: (Sandy Pulsford, 2014))

Figure 67shows the number of the faults reported related to the PV module. Most numbers of the faults are reported related to the issues of Back sheet deterioration and cell interconnect problem. 2 faults are reported in each of the areas including Frame Problem, water ingression, glass breakage and complete failure of the module. 1 fault was reported related to the front encapsulant of the module. (Sandy Pulsford, 2014)

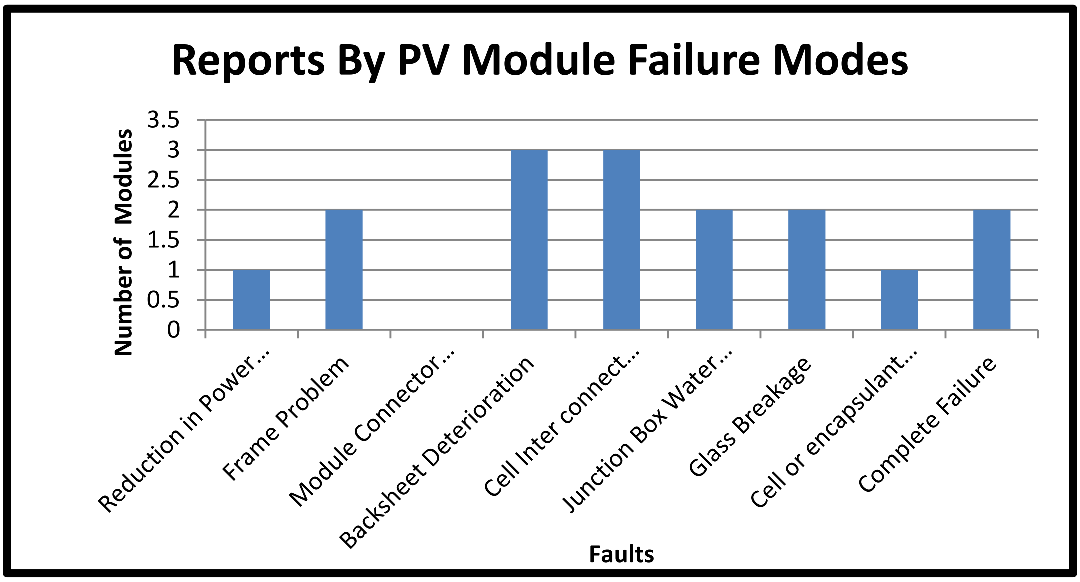

Figure 67- PV module failure modes (Illustration: (Sandy Pulsford, 2014))

5.3.6.3. INSTALLATION AND SYSTEM INFORMATION ABOUT THE REPORTED PV MODULE SYSTEMS

Figure 68 show the numbers of fault reports which are reported every year from 2009 to 2013. Figure 69 represents the number of faults reported by the size of the system. It shows that 7 faults were reported with the PV system of size 2.6- 5.0 KW and 5 faults were reported related to the system size of 0- 2.5 KW. (Sandy Pulsford, 2014)

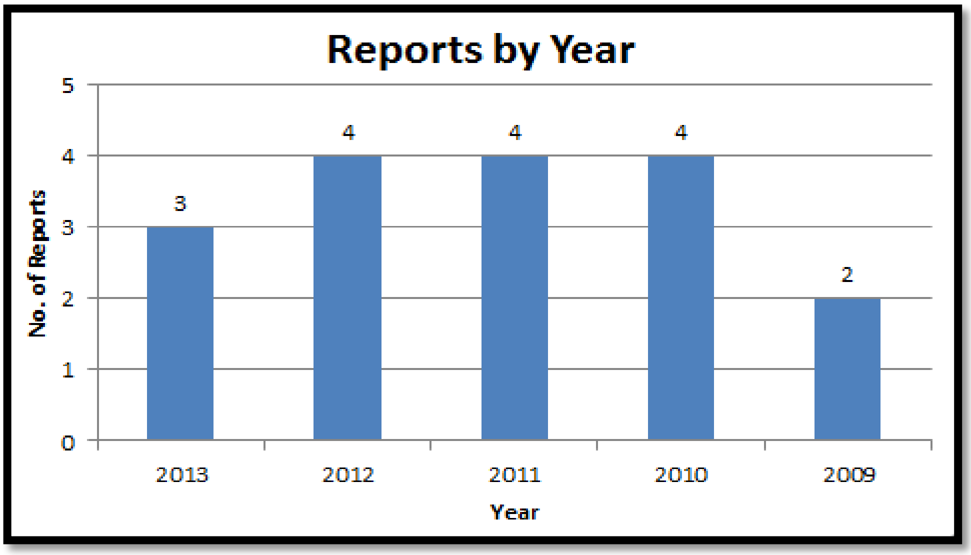

Figure 68- Fault reported by year of response (Illustration: (Sandy Pulsford, 2014))

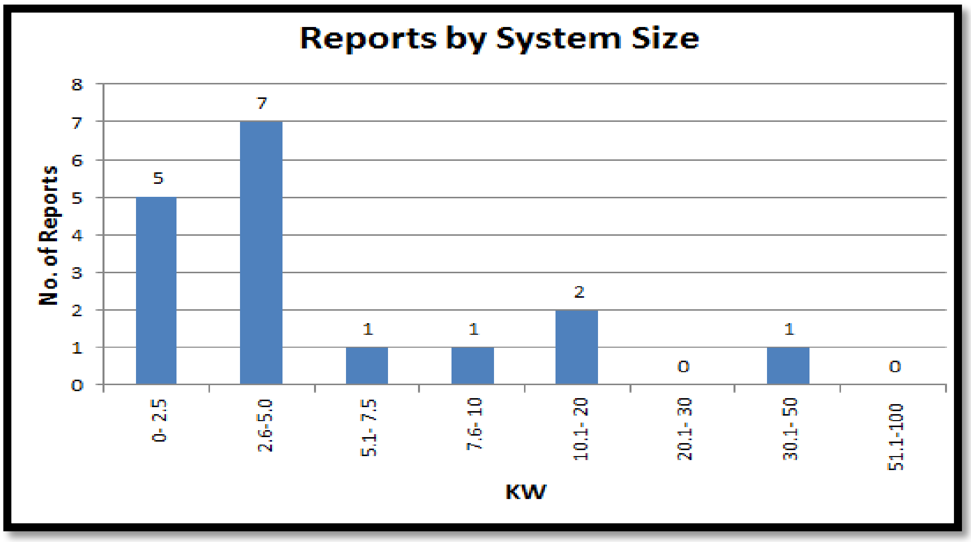

Figure 69- Faults reported by the system size (Illustration: (Sandy Pulsford, 2014))

Figure 70 represents the number of the fault reports with the information about the size of the PV modules of the system. Maximum number of the faults, 7 faults has been reported related to the system with the PV module size of 101- 150 Watts. 6 faults were reported with the system with the PV module size of 151- 200 Watts. (Sandy Pulsford, 2014)

Figure 71 shows that 41% of the faulty PV module systems are Stand- alone systems and 59% of the faulty systems reported are Grid- connected PV module systems. (Sandy Pulsford, 2014)

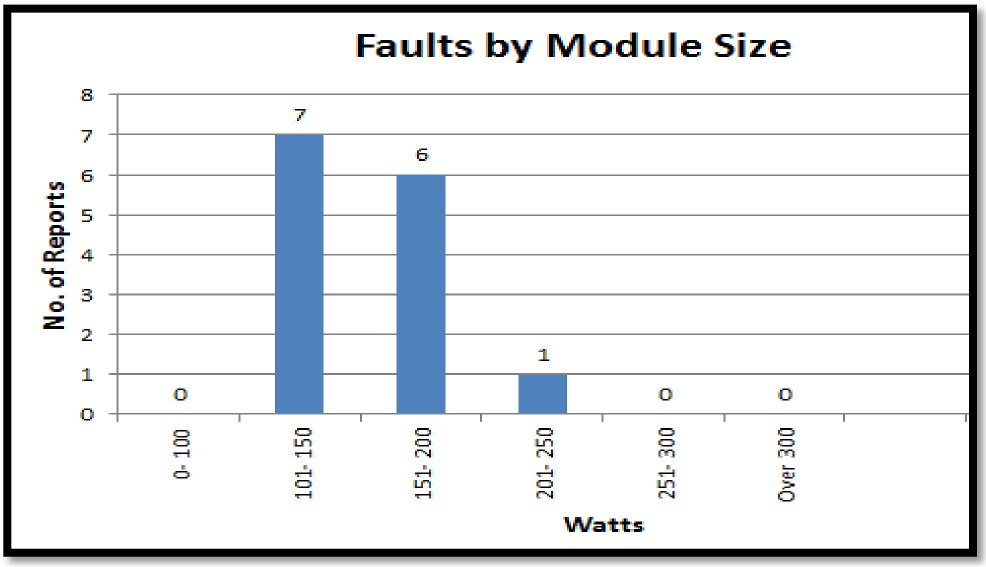

Figure 70- Faults reported by the Module Size (Illustration: (Sandy Pulsford, 2014))

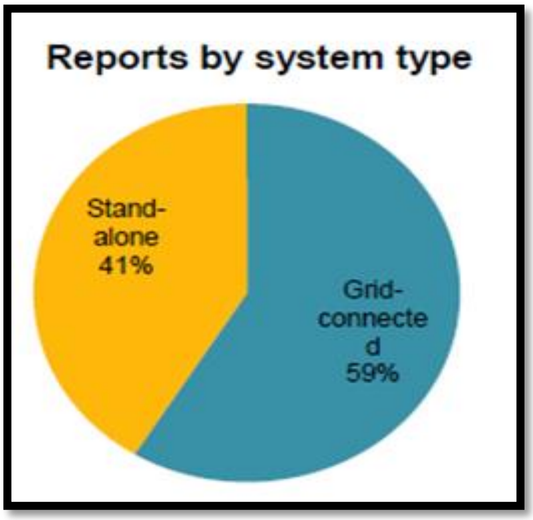

Figure 71- Faults reported by the system type (Illustration: (Sandy Pulsford, 2014))

5.3.7. CORROSION EFFECTS IN THIN- FILM PHOTOVOLTAIC MODULES- REPORT

5.3.7.1. INTRODUCTION

This report explains the experiment which has been conducted to test the effect of the corrosion in thin film PV module system. The experiment has been performed to conclude the causes of corrosion in thin film PV module with different types of transparent conductive oxides. Figure 72, graph shows the corroded area of coupons of tin- oxide coated glass as a function of time, which is biased at 100V in salt water. (D.E. Carlson, 2003)

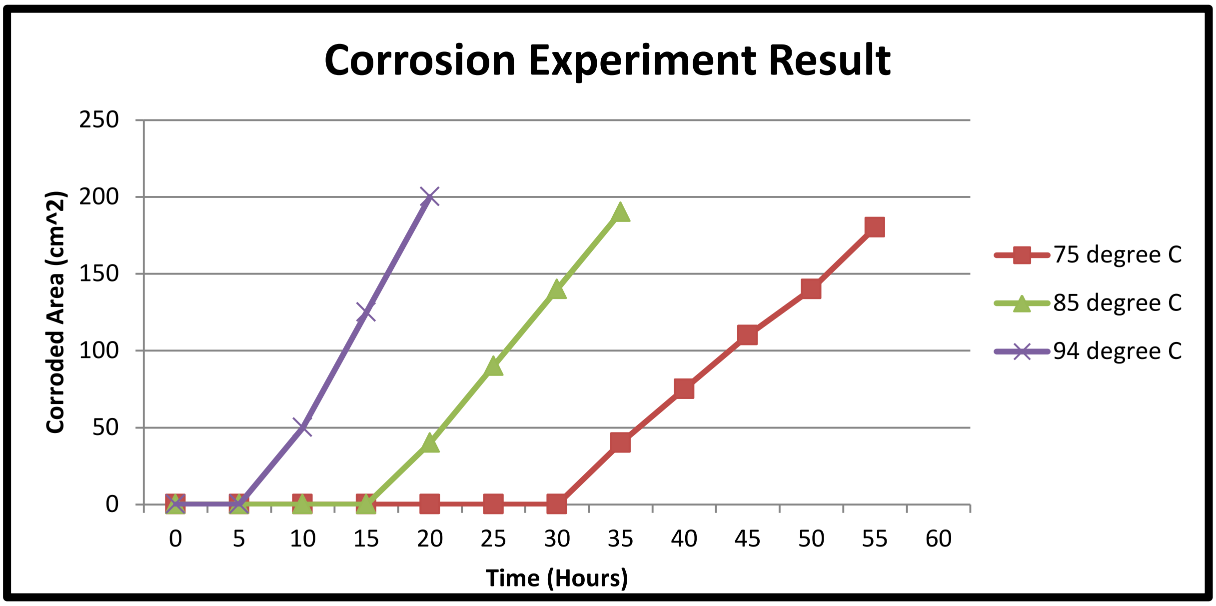

Figure 72- 3 Samples of Tin oxide fabricated glass coupons, biased at 100 V at different temperatures. (Illustration: (D.E. Carlson, 2003))

5.3.7.2. RESULTS

This report suggests us that the electrochemical corrosion occurs on tin oxide fabricated glass when it is operated on high voltages. So, corrosion is dependent on the voltages of the PV module of the system. Corrosion is also accelerated by the temperature of the module. Another factor which quickens the corrosion in PV modules is the water ingression in the module. Delamination is the major factor which causes water ingression. The process of corrosion can be slow down by using the plastic edges to avoid the delamination of the module. Corrosion can be reduced by providing the weep holes in the modules to avoid standing water. (D.E. Carlson, 2003)

5.3.8. FAULT ANALYSIS POSSIBILITIES FOR PV PANELS

5.3.8.1. INTRODUCTION

For lifetime efficiency in service of PV module, it is important to know the kinds of defects which occur, their location and the frequency of their occurrence. This report investigates a non- destructive method based on IR thermography which helps to measure the solar panels performance. Local dust particles are detected and analysed and hot spots which are invisible to the naked eye are analysed in this report. An experiment has been conducted in this project in which Infrared camera has been used to determine and analyse the faults on the PV module which are invisible to the naked eyes. (F. Ancuta, 2011)

5.3.8.2. REPORT RESULTS

5.3.8.2.1. COMMON PROBLEMS IN PV SYSTEMS

The common problems which have been found in the experiment and explained in this report are Power limitation by inverter to keep upper limit for line voltage, Partial shadings in PV modules, PV generator operating voltage below inverter input window, Power loss due to undersized inverter, Isolation faults, Bypass diode failure and the Faulty circuit breakers. (F. Ancuta, 2011)

5.3.8.2.2. EXPERIMENTAL RESULTS

During the experiment, defects which are invisible to the naked eye are determined and analysed using the temperature factor for PV modules under different environmental conditions. For this purpose, IR camera has been used. By using IR thermography, hot spots are detected in the PV modules as shown in Figure 73. Corrosion can be a factor of consideration which can cause the internal hot spot. It is also concluded that invisible hot spot occurs in the area where internal structure of PV module is beginning to decay which was visible from the IR camera. It is also assumed that Grown-in or structural defects in electronic material as well as electronic discharge or conducting particles are possible reasons of unwanted leakage in electronic devices lead to corrosion. (F. Ancuta, 2011)

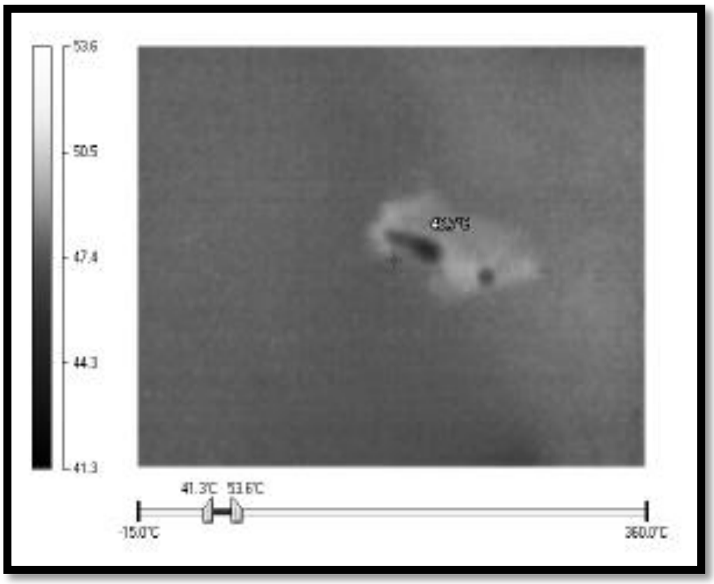

Figure 73- Hot spot resulted as dirt and impurities got stuck to the panel (Source: (F. Ancuta, 2011))

5.3.9. FAULTS DETECTION AND DIAGNOSTIC OF PV MODULE SYSTEM

5.3.9.1. INTRODUCTION

In this project, Matlab and Simulink simulation tools are used to observe the performance of PV module system using the statistic information. A model of PV system including its components have been constructed in Simulink and its operations have been observed and graphically represented using I-V curves under different environmental conditions such as shading under different conditions, string disconnection, degradation due to increase in resistance, soiling, grid outage and blackouts. (Wu, 2011)

5.3.9.2. RESULTS

This result of this report provides readers with the information about the usual faults and causes occur during the operation of the PV module system which causes the reduction in the performance of the system. These faults are disconnection or degradation of solar cells, soiling of panel, snow cover on the panel, tree leaves and bird droppings on the panel, grid outage and faults with total blackout. (Wu, 2011)

5.3.10. FIELD AGED CRYSTALLINE PV UNDER THE DESERT

5.3.10.1. INTRODUCTION

This report explains the reliability issues of crystalline silicon Photovoltaic modules under desert conditions. In this report, degradation rate and its frequency has been explained by using the data from 2074 reports about the faults of PV module systems. This report also shows the likelihood of the components of the PV module system to fail first. This is explained by the risk priority number, which is higher for the component which is more likely to fail before other components. (Joseph M.Kuitche, 2014)

5.3.10.2. RESULTS

The main reliability issues related to the crystalline silicon PV module are related to its Super state, encapsulant, cell and Interconnects and the back sheet of the module. The issues related to the super state are the UV stability and its ability to withstand in the harsh weather conditions like heavy rainfall or extremely hot temperatures. The back sheet encapsulant of the PV module also faces the reliability issues such as weather ability to survive in the harsh weather conditions and the environment conditions in long term. Encapsulant also faces the reliability issues like Dielectric Isolation, Thermal conduction and Light transmission. Cell and Interconnects are usually affected by the corrosion. Therefore, the quality of the PV module needs to be improved to prevent the water ingression.

This report also explains the risk priority of the different faults in PV modules. Figure 74 shows that the soldier failure faults are most likely to happen before any other faults in the PV modules followed by the discoloration of the encapsulant and back sheet detachment. (Joseph M.Kuitche, 2014)

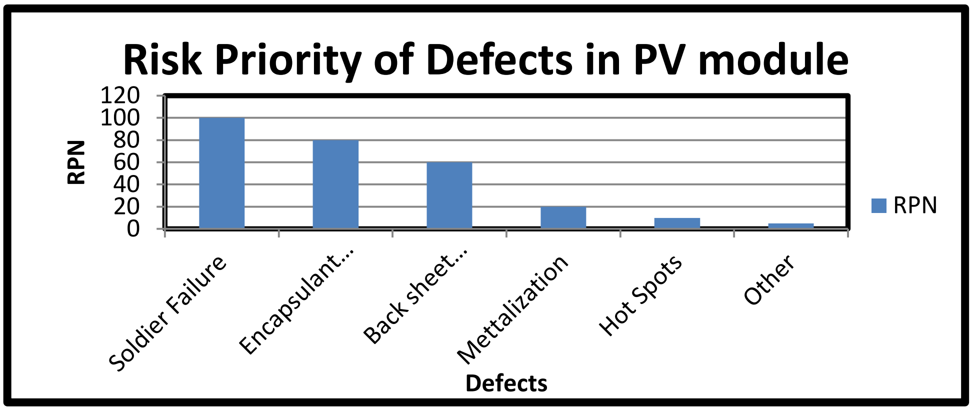

Figure 74- Risk Priority of the PV module defects. (Illustration: (Joseph M.Kuitche, 2014)

5.3.11. MOISTURE AS A STRESS FACTOR

5.3.11.1. INTRODUCTION

This report explains the Damp heat test which describes the effects of moisture with the time on normalised power of PV module system under two different temperature conditions. 7 different PV modules are tested under the two different temperatures conditions (85^{o}C and 90^{o}C). Humidity is considered as an important degradation factor of Photovoltaic modules. (Koehl, 2013)

5.3.11.2. RESULTS

Figure 75 and Figure 76 shows the graphical representation of the results of the damp heat test of 7 different Photovoltaic modules at 85^{O} C and 90^{O}C. Both graphs can be compared and they show that the temperature effects directly on the degradation of the normalised power output of the PV module system. It shows that normalised power of all of the PV modules at 90^{O}C reduces much earlier as compare to the PV modules tested at 85^{O}C. (Koehl, 2013)

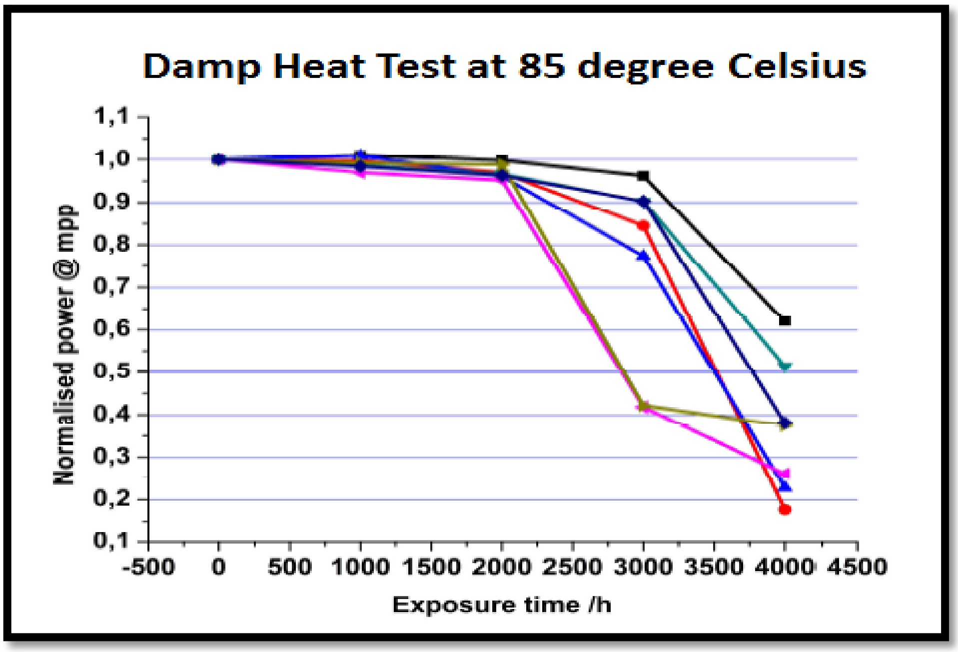

Figure 75- Damp Heat test of 7 PV modules at 85 degree Celsius. (Illustration: (Koehl, 2013))

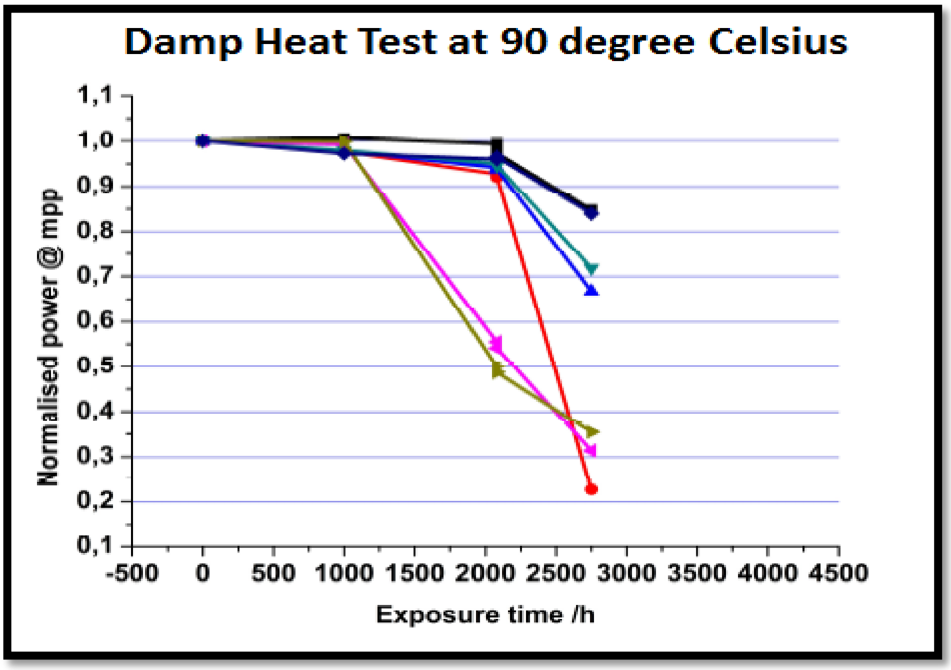

Figure 76- Damp Heat test of 7 PV modules at 90 degree Celsius. (Illustration: (Koehl, 2013))

5.3.12. RELIABILITY STUDY OF GRID CONNECTED PV SYSTEMS- 7 SURVEYS RESULTS

5.3.12.1. INTRODUCTION

This report represents the information about the surveys conducted by the several organizations in the frame of International Energy Agency (IEA), Photovoltaic Power system program. These organizations are from different part of the world including Germany, Japan, Austria, Switzerland, United Kingdom, etc. The report explains the information about the faults, their relative components in the PV module system and the location of the site. (Laukamp, 2002)

5.3.12.2. RESULTS

5.3.12.2.1. FAILURE OF PHOTOVOLTIC MODULE SYSTEM COMPONENTS

The graphs in Figure 77, Figure 78 and Figure 79 show the results of the 3 different surveys representing the components of PV module systems which are reported faulty from the information provided by the respondents. All of the given graphs suggest that most of the faults reported are related to the inverter of the PV module systems followed by the faults related to the PV module of the system. It also shows the numbers of the faults are continuously decreasing every year. It suggest that it could be a case of the continuous improvements has been made in the PV module designing and construction during those years. (Laukamp, 2002)

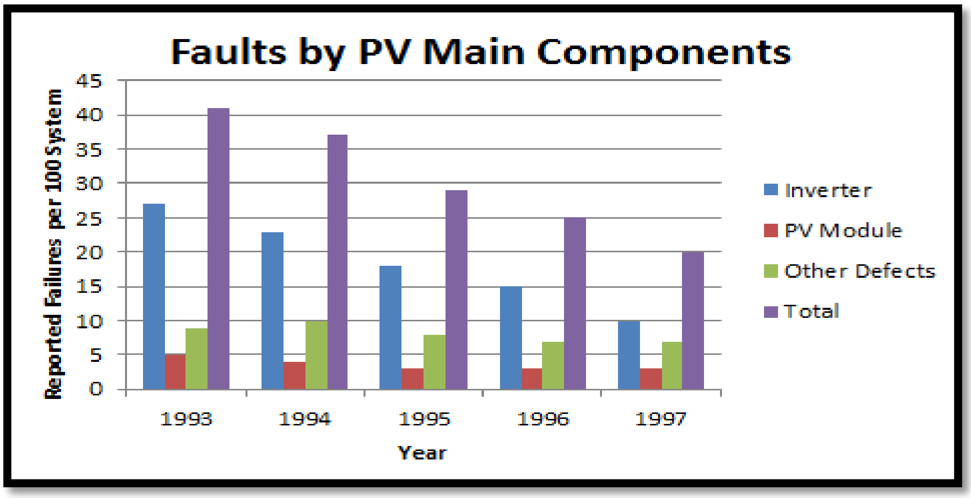

Figure 77- Faults by the components of PV module system- 1000 roofs Germany (Illustration: (Laukamp, 2002)

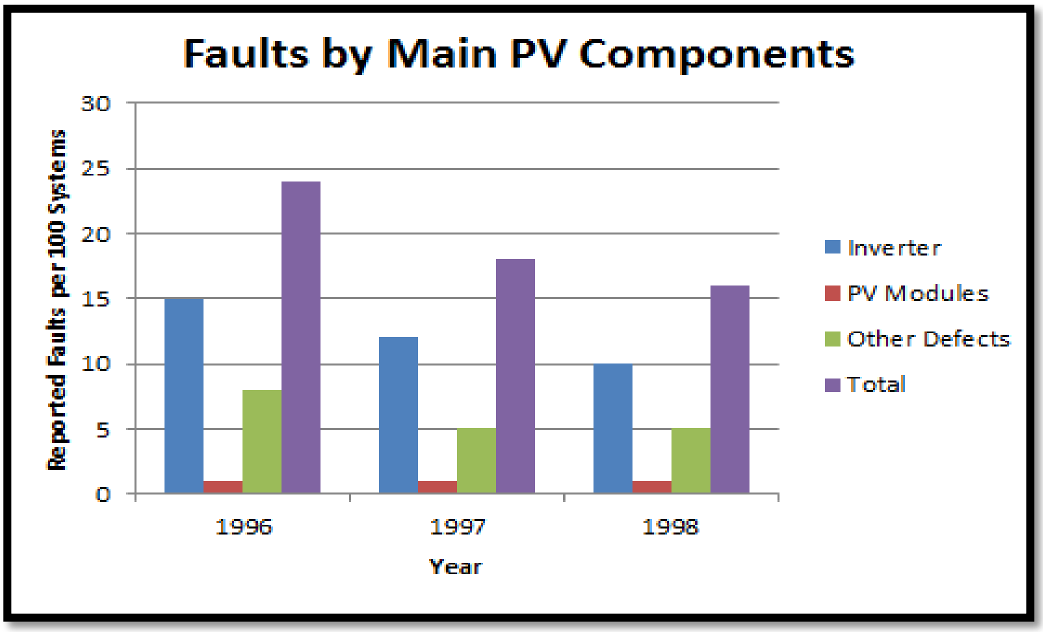

Figure 78- Faults by the components of PV module system- Residential Program Japan (Illustration: (Laukamp, 2002)

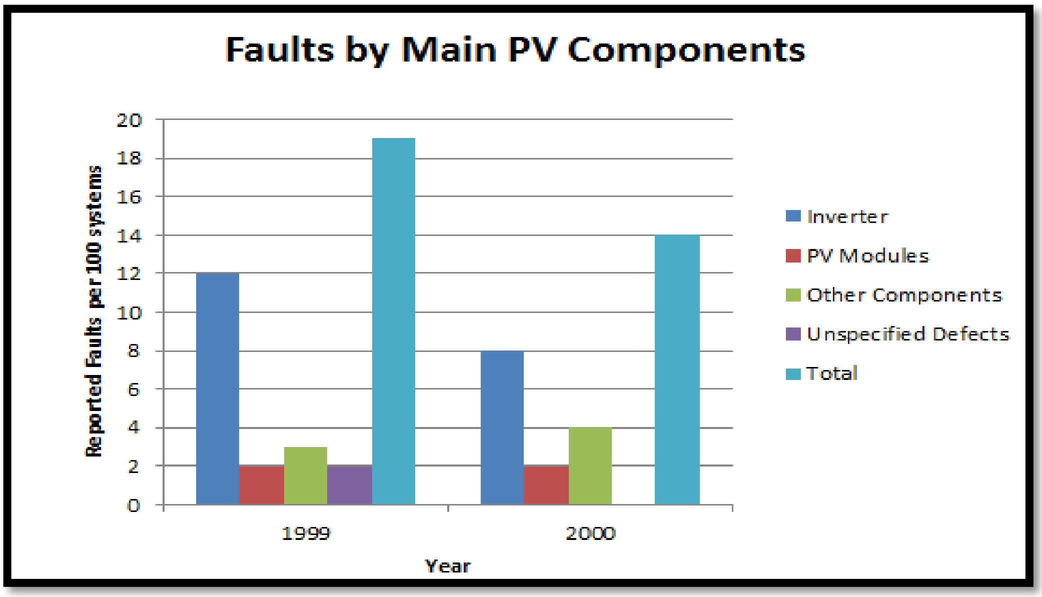

Figure 79- Faults by the components of PV module system- SonneIn Der Schule, Germany (Illustration: (Laukamp, 2002)

5.3.12.2.2. INSTALLATION FAULTS REPORTED IN 1000 ROOFS, GERMANY SURVEY

Table 5 shows the percentage of the systems affected by the different types of the installation faults. 60% of the reports related to the installation faults report lack of the heat dissipation of string diodes, 24% of the reports are related to the loosening of the cables and 5% report the poor installation of terminal connections being loosely connected. (Laukamp, 2002)

Table 5- Installation Faults- 1000 Roofs, Germany (Illustration (Laukamp, 2002))

Installation Faults	Fractions of System Affected
Solar Generator cabling not mechanically fastened	24%
Lack of Heat Dissipation of String Diodes	60%
Loose Terminal Connection	5%
Unsealed Cable Entry from Top of Junction	-
Broken Printed Circuit Boards in Junction Box	-
Others	11%

5.3.12.2.3. OPERATIONAL FAULTS REPORTED IN 1000 ROOFS, GERMANY SURVEY

Table 6 shows the percentage of the systems affected by the operational faults. 19% of the systems are affected by the corrosion, 12% are affected by the soiling and 4% of the PV systems are affected by the string fuses. Other types of faults are reported less than 2% each. (Laukamp, 2002)

Table 6- Operational faults- 1000 Roofs, Germany (Illustration: (Laukamp, 2002))

Problems During Operation	Fractions of System Affected
Corrosion and Defects in Mounting Structure	19%
Moderate to Strong soiling of Module	12%
Defective String Fuses	4%
Faulty Modules	< 2%
Defective String Diodes	< 2%
Corroded Plug/ Receptacle Connectors	1%
Defect Overvoltage protection Devices	< 1%

5.3.12.2.4. FAILURE RATES OF PV MODULES AND INVERTER FROM 7 DIFFERENT SURVEYS

This report also shows the failure rates of the PV modules and the inverter of the PV system. Figure 80 shows a very low rate of the PV module failures. Except EPFL 1996- 2001 survey, module failure rate per year is less than 0.3%. (Laukamp, 2002)

Figure 81 shows the failure rates of the Inverter of the PV module system. It shows the failure rate of 12% of three surveys. So, it can be concluded that the inverter failure is the major concern in the fault analyses of the PV module systems. (Laukamp, 2002)

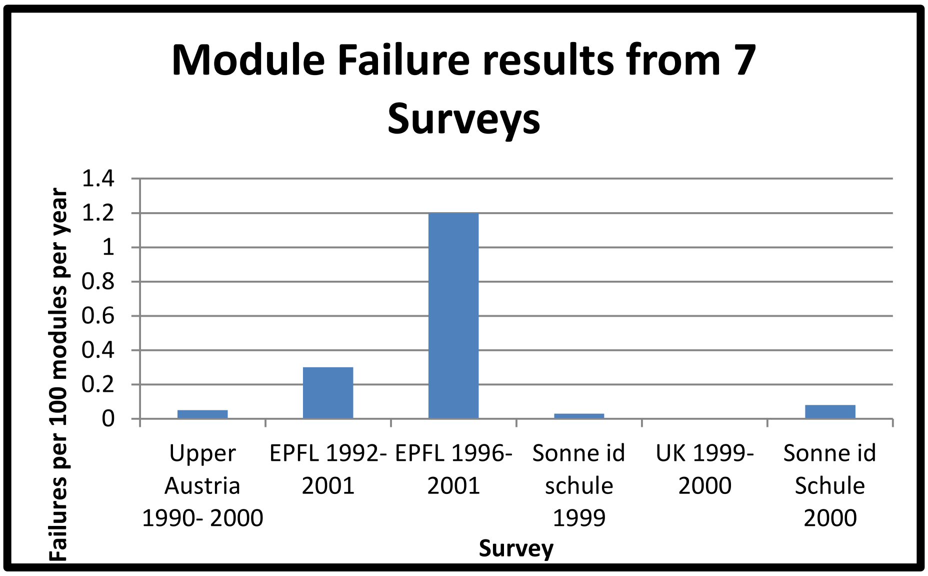

Figure 80- Module failure rates from 7 surveys (Illustration: (Laukamp, 2002))

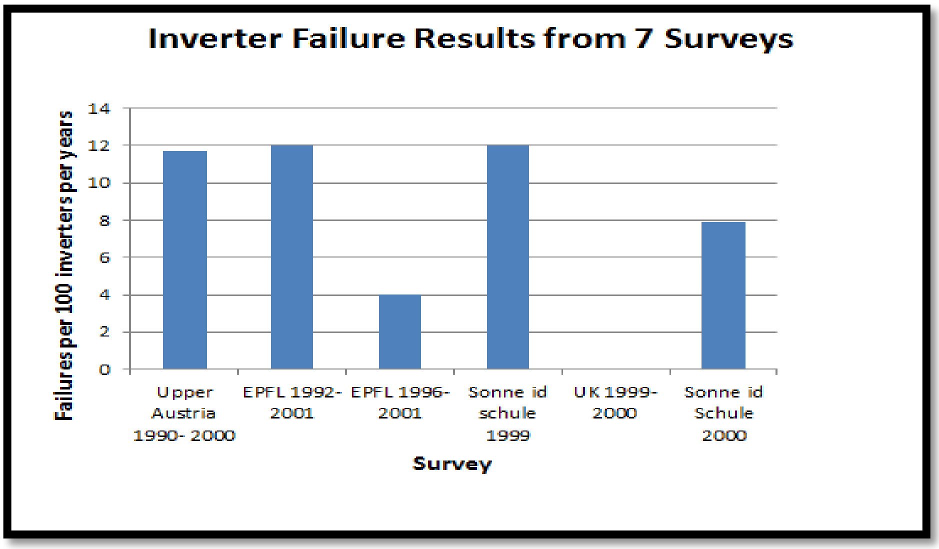

Figure 81- Inverter failure rates from 7 surveys (Illustration: (Laukamp, 2002))

6. SURVEY CONDUCTED BY APVI AND ARENA

6.1. INTRODUCTION

In order to increase the understanding and to collect the information regarding the ongoing faults, issues and problems and their frequency of occurrence, a web-based survey has been conducted. The survey is supported by Australian Renewable Energy Agency (ARENA) and coordinated by other renewable energy supportive organizations including Australian Photovoltaic Institute, the Clean Energy Council (CEC) and the partners, University of New South Wales (UNSW), Murdoch University and CAT Projects.

The survey invites the owner/ operators, installers and inspectors to complete the survey to provide the feedbacks and the information about their experience in relation to the performance and the faults and issues about the Photovoltaic module system they use or if they installed.

6.2. BACKGROUND INFORMATION OF SURVEY ORGANIZATIONS

6.2.1. AUSTRALIAN PHOTOVOLTAIC INSTITUTE (APVI)

APVI is the institute comprises companies, agencies, individuals and academics who actively participate in the solar energy research, advancement and related programs to support the increased development and use of the PV technology. (Australian PV Institute, 2013)

6.2.2. AUSTRALIAN RENEWABLE ENERGY AGENCY (ARENA)

ARENA is an independent agency established by Australian Government. This main objective of this organization is to increase the use of Photovoltaic technology and to reduce the cost associated with the use of PV technology. This organization is a supportive of all renewable energy technologies from small to large scale projects. (Australian Renewable Energy Agency, 2014)

6.2.3. THE CLEAN ENERGY COUNCIL (CEC)

CEC is an industry association made up of more than 550 member companies working in the sector of renewable energy. The members of this organization are involved in the development of the clean energy resources and related new technologies. (Clean Energy Council, 2014)

6.2.4. UNIVERSITY OF NEW SOUTH WALES (UNSW) AND MURDOCH UNIVERSITY

University of New South Wales and Murdoch University are the universities which are actively participating in the research projects related to the Renewable energy Technology. Both Universities encourages their students to study and work which is related to the field of Renewable energy by offering the relevant courses such as Bachelor in Renewable Energy Engineering and other research and Thesis Projects.

6.3. SURVEY METHODOLOGY

The survey organized by the APVI and other supportive organizations is a web-based survey. The information in the survey has been designed to provide information online by following and answering the survey questions. The primary aim of this survey is to collect and understand the information about the issues, faults and the problems encountered by the owners, operators, installers and inspectors during the operation, use or installation of the Photovoltaic module system. The survey questionnaires are designed to collect as much information about the user/ respondent, location of site, details of the installation of the PV module system, information about the performance and any faults related to the different modules of the PV module system and the reduction in the performance of the system due to the noticeable faults reported.

6.4. RESULTS

6.4.1. INFORMATION COLLECTED FROM THE SURVEY

This section of the report is derived from the information and the data provided by the respondents who participated in the survey and provide the information about the faults and the performance of their PV module system. The data is then analyzed in order to derive a clear picture of the information provided by the respondents.

It also includes the information about the types of the respondents, explaining if they are users or installers, location of the site where Photovoltaic module system is installed, type of the Photovoltaic module system, size of the Photovoltaic Module system, date of the installation and the types of the faults and the fault concerning components of the Photovoltaic module system. All of this information is provided by the participants of the survey organized by APVI with its partner organizations.

6.4.1.1. TYPE OF RESPONDENT

In the survey, different types of the respondents were invites to participate and they were encouraged to provide as much information as they can about their experiences regarding the Photovoltaic module they are using.

Figure 82 shows the information about the respondents who actually took part in the survey to provide the information about the faults they experienced while using the PV module system. This chart shows that the major part (88%) of respondents is owner/ operators of the Photovoltaic Module systems who actually use the system. However 6% of faults have been reported by the inspector and auditor. Other 6% of the total respondents were those who did not specify about their relation to the Photovoltaic Module system they were reporting about.

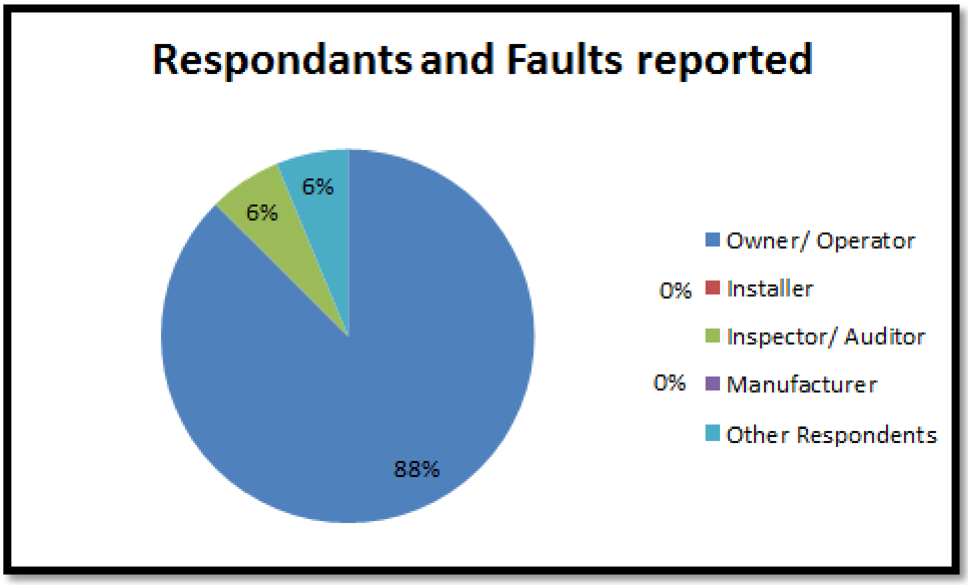

Figure 82- Type of Respondents who participated in the APVI Survey

6.4.1.2. LOCATION OF THE SITE

6.4.1.2.1. FAULTS REPORTED BY STATES

The survey invited everyone from every part of Australia to contribute their knowledge and experience about the faults and the issues they are fronting while using their Photovoltaic Module system and all of the participants were asked to provide the details of the site where Photovoltaic module system is located.

While comparing state wise from the charts below (Figure 83), it is shown that most of the faults are reported in State of Victoria (12%) followed by NSW (9%). 6% of the total faults are reported in WA and 3% are reported in QLD. No faults are reported from the SA, TAS and NT. 70% of the respondents have not mentioned their location.

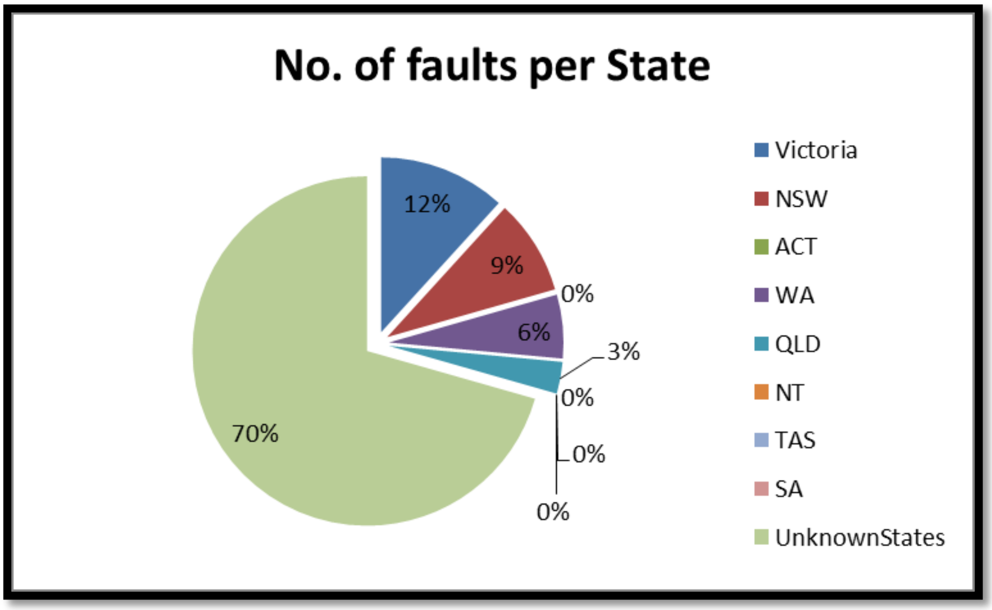

Figure 83- State Wise Location of the PV Module System Sites

6.4.1.2.2. FAULTS REPORTED BY CLIMATE ZONES

Looking at the climate zones of Australia, as shown in the chart below (Figure 84) , it is clearly shown that most of the faults (90%) reported in the survey occur in the temperate climate zone of Australia. Temperate zones are the zones where major cities including Perth, Melbourne and Sydney are located. And these cities are very densely populated. Due to the large population, number of installed PV module systems is expected to be much more as compare to the other climate zones of Australia.

Rest of the 10% faults are reported in the subtropical region of Australia. This region is located around the towns of Geraldton in WA and the popular towns of Queensland including Cairns, Cooktown, Townsville, Mackay and Rockhampton. These towns are highly populated as well.

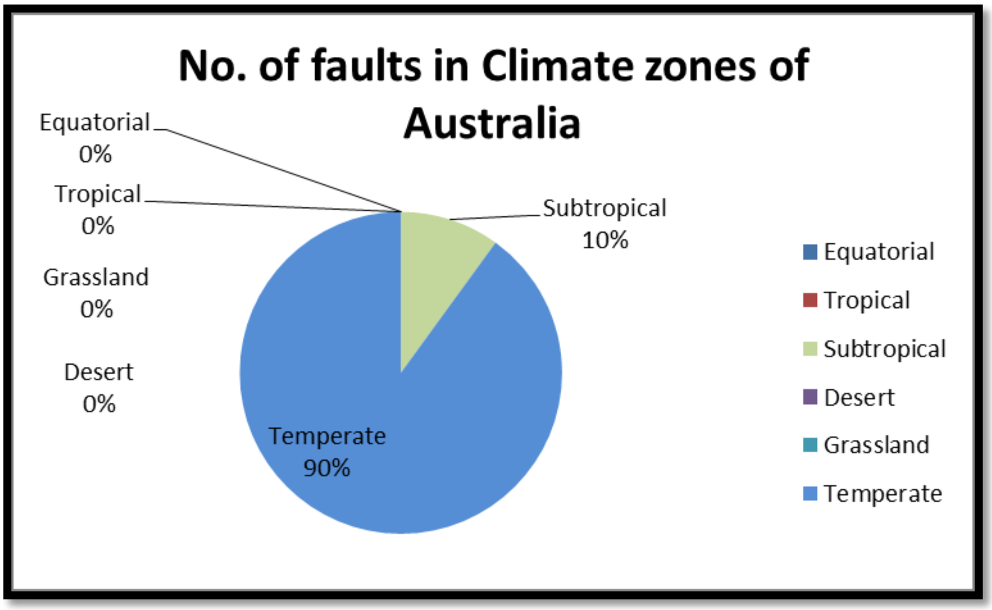

Figure 84- Climate Zone Wise Location of the PV Module System Sites

6.4.1.3. PV ARRAY SIZE

In the survey, participants were asked to provide the information about the size of the PV module system they are using. This will help to determine if there is any correlation can be seen related to the sizes of the PV array of the Photovoltaic Module system.

Figure 85 shows the results shows that the faults were reported in almost every size of the Photovoltaic module system. 3 faults have been reported related to the 4.1-5.0 KW system. 2 faults has been reported related to the system size of up to 1 KW and 1 fault from each system size of 1.1-2.0 KW, 2.1- 3.0 KW and 3.1-4.0 KW has been reported. However, no fault has been reported related to the system with the size of 5.1- 7.5 KW.

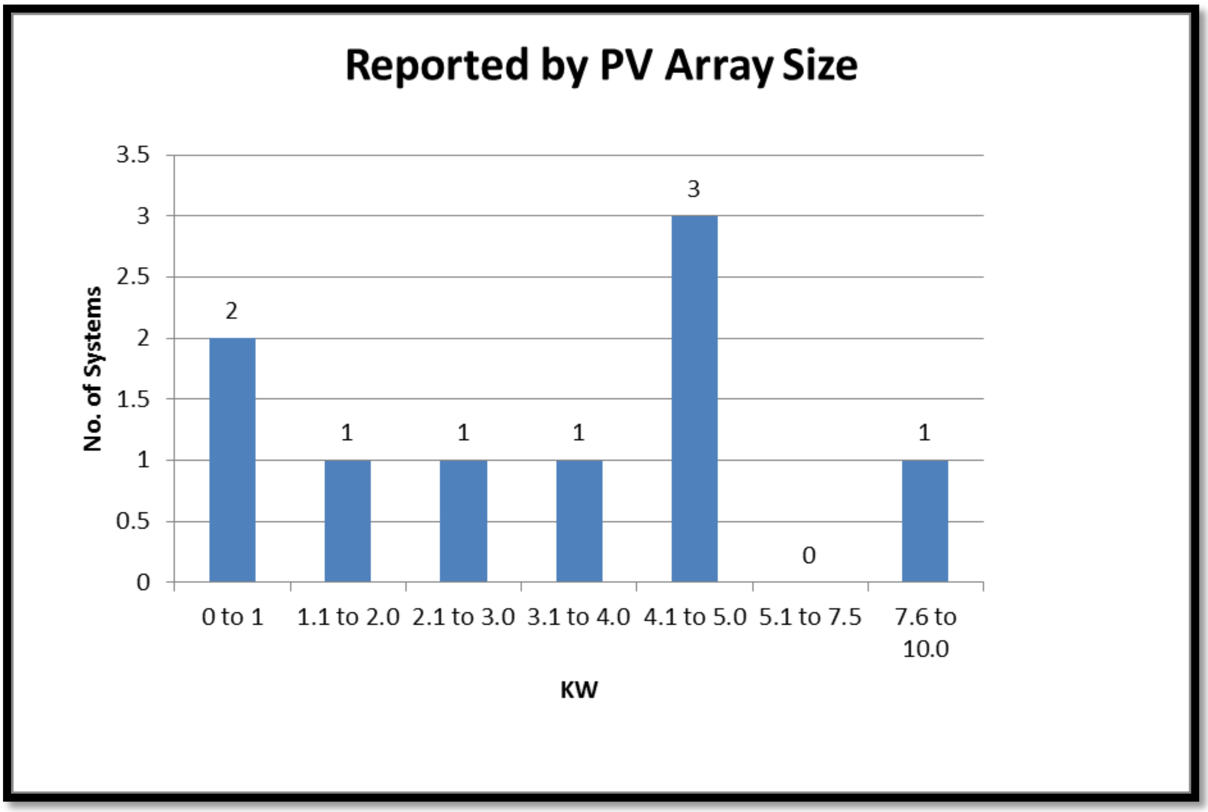

Figure 85- Faults reported by the Size of the System

6.4.1.4. PHOTOVOLTAIC MODULE SYSTEM TYPE

In the survey, participants were requested to deliver the information about the type of the PV module system they are using. This will help to determine if there is any connection can be seen connected to the types system with the reported faults of the Photovoltaic Module system.

Figure 86 shows that 91% of the faults have been reported related to the Grid connected without batteries. And only 9% of the faults have been reported related to the Stand alone system. No fault is reported related to the battery connected system. This will conclude that there is no battery related fault has been reported in the survey by any respondent.

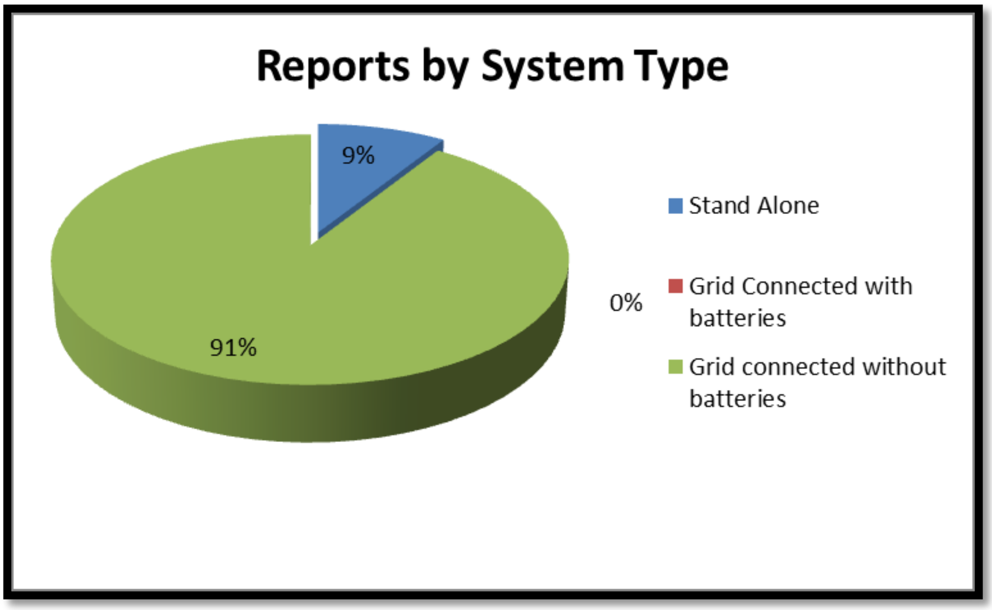

Figure 86- Faults reported by System Size

6.4.1.5. INSTALLATION DATE

In the survey, the respondents were requested to give the information about the installation date of the PV module system they are using. This will help to conclude if there is any correlation can be seen related to the time period of the operation of the Photovoltaic Module system. A PV module system normally degrades with the time. And the performance of the PV module system also reduces with the time.

Figure 87 shows that 7 respondents reported the date of the installation of their PV module system. 1 of the system was installed between (1995- 1999). 3 systems are reported which were installed during (2006-2010) and 3 systems are reported which were installed between 2010- 2014.

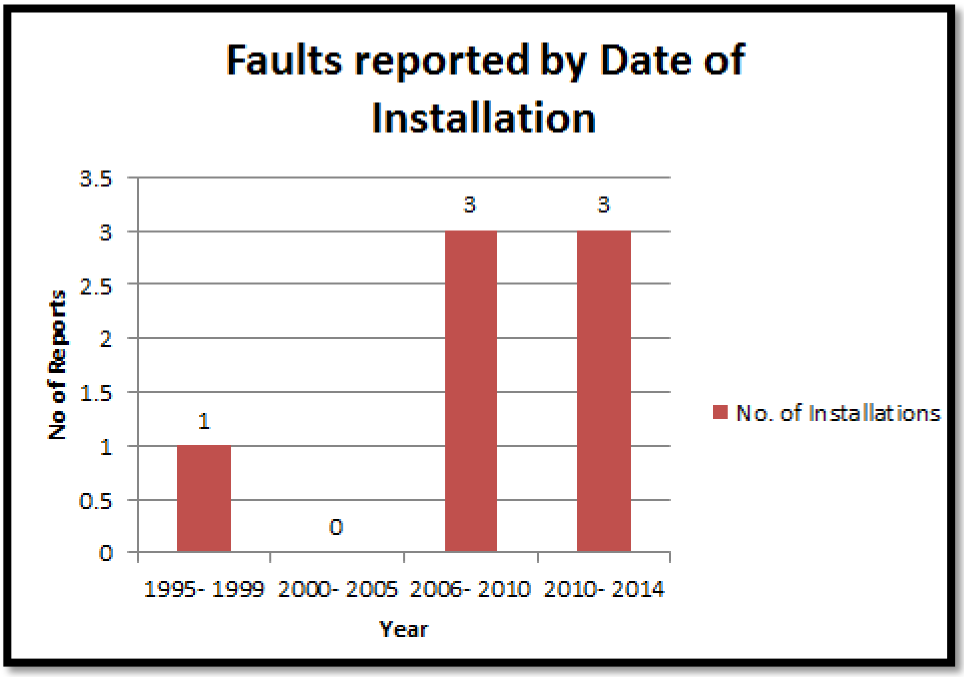

Figure 87- Number of faults reported by Date of Installation

6.4.1.6. COMPONENTS OF PV MODULE SYSTEM

Figure 88 represents the different major components of Photovoltaic module system where the faults have been reported. From the survey data, 21 respondents have reported the faults related to the specific component of PV module system. The most of the faults reported are related to the inverter of the PV module system. About 50% of the respondents reported the faults which are related to the inverter of the PV module system. 25% of the faults are related to the PV modules itself. There are other components including battery, cables and connections, installation, Junction box, etc. where faults have been reported. Failure in the inverters seems to be a major issue in the proper functioning of PV module system.

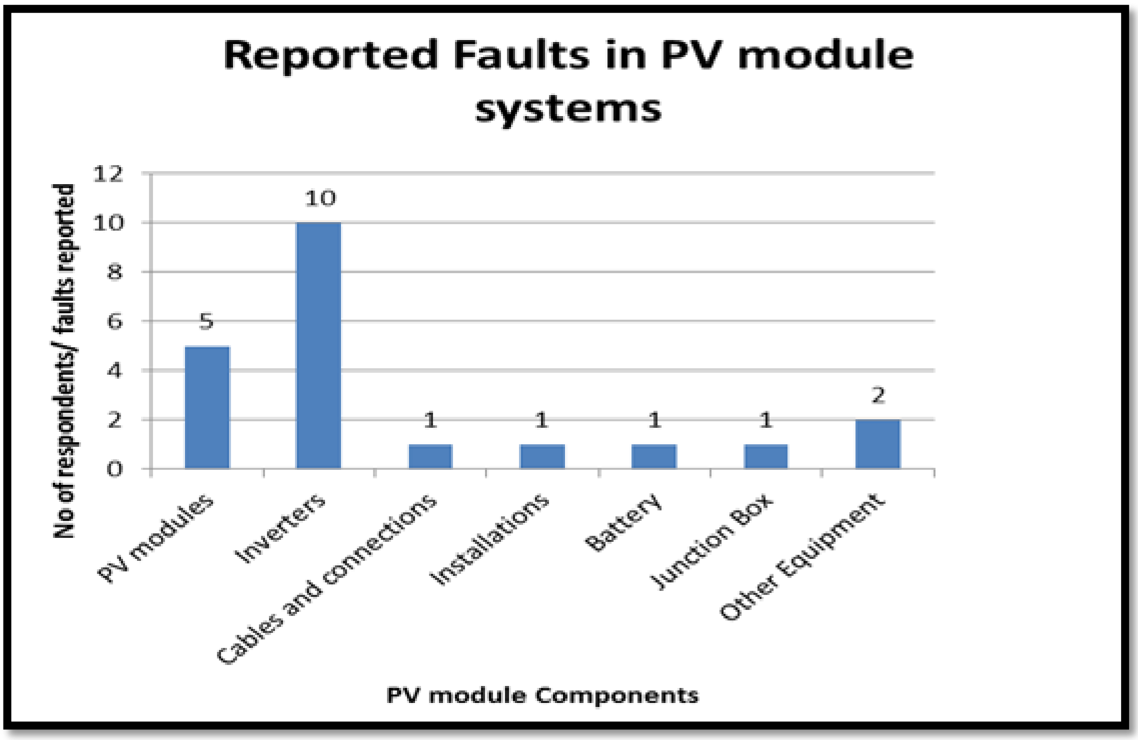

Figure 88- Number of faults reported in Different Components of PV Module System

6.4.1.7. REDUCTION IN OVERALL SYSTEM PERFORMANCE

The major aim of the survey is seeking the information to find out the performance of the Photovoltaic module systems in Australia. The survey questioners were designed to gather the information about the faults in the different component s of the system and to find out the overall level of the reduction in the performance of the system due to the faults reported by the respondents.

The graph below (Figure 89) shows the number of faults which lead to the reduction of the overall system performance. There are two cases where the PV module system performance reduced by 100%. 3 respondents reported 10 % reduction in the overall performance of the system. 2 respondents reported 21 to 30 per cent of reduction in overall system performance and there is 1 respondent in each case of the overall system performance reduced by (31-40) %, (42-50) % and (71- 80) %.

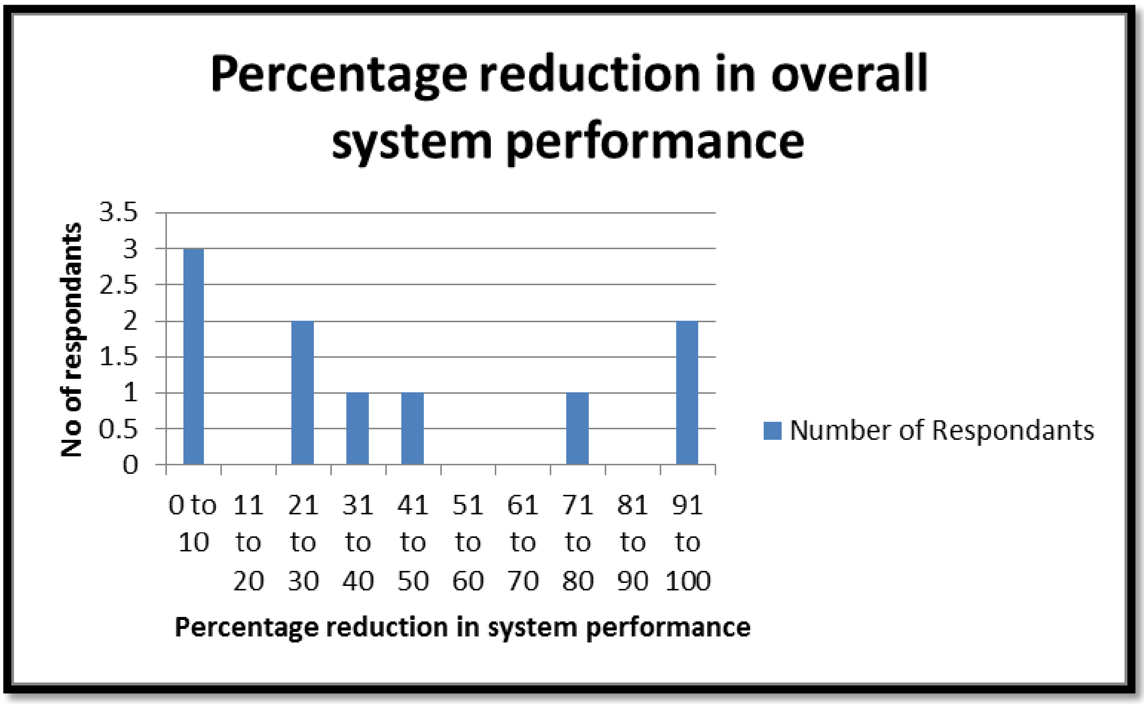

Figure 89- Faults reported with the reduction of system Performance

6.4.1.8. FAULTS REPORTED WITH PV MODULE

The chart below (Figure 90) shows the types of faults reported to the PV module panel in the Photovoltaic module system. 33% of the faults are related to the back sheet of the PV modules and 33% are the moisture related faults. These two areas are the areas of major concern. Water ingression normally happens in the regions of high rainfall. Majority of the Australian population lives in the Temperate zone where good amount of rainfall is received during the rainy season and throughout the year except summers.

17% of the faults are reported which are related to the Glass breakage of the panel and another 17% of the faults are related to the junction box which is located behind the panel on the back sheet of the PV module.

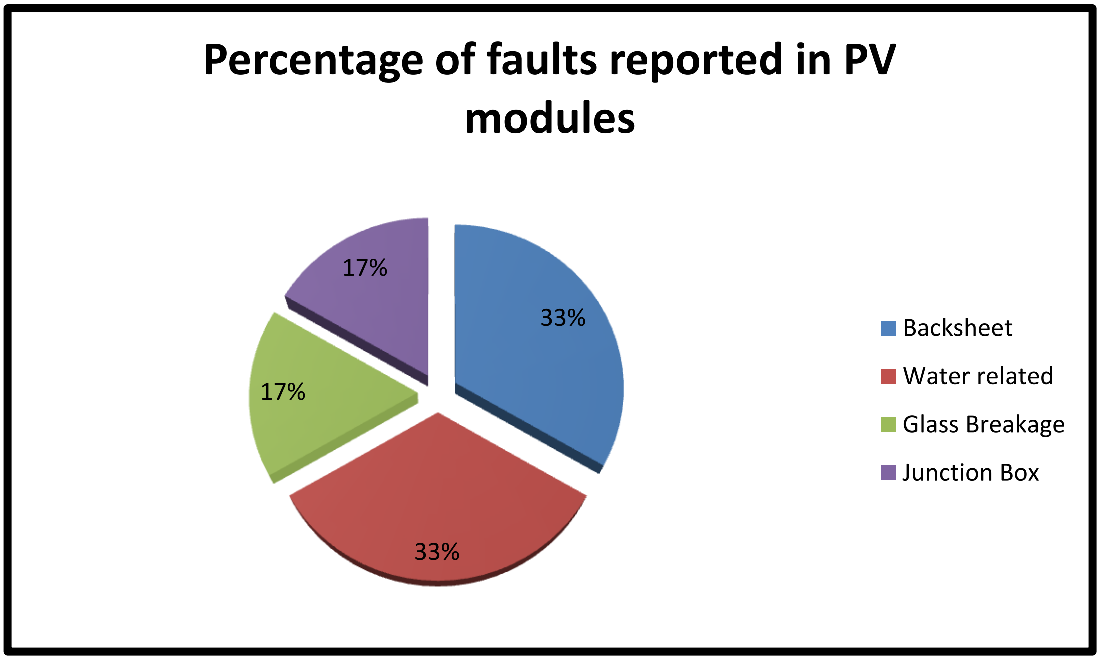

Figure 90- Faults reported with PV module Panels in the PV module system

6.4.1.9. TYPES OF INVERTER FAILURE

Inverter related faults are on the top of the list of the various components in the Photovoltaic module system where faults are reported. In this survey, 48% of the faults are reported which are related to the inverter of the Photovoltaic Module system. Faults in the inverter will produce a direct impact on the system performance. It often lead to the partial and complete failure of the system.

In this survey, as shown in Figure 91 respondents provide the information which represents that in 43% of the cases of the inverter problems, system fails completely. While in 57% of the cases, partial failure of the system is reported.

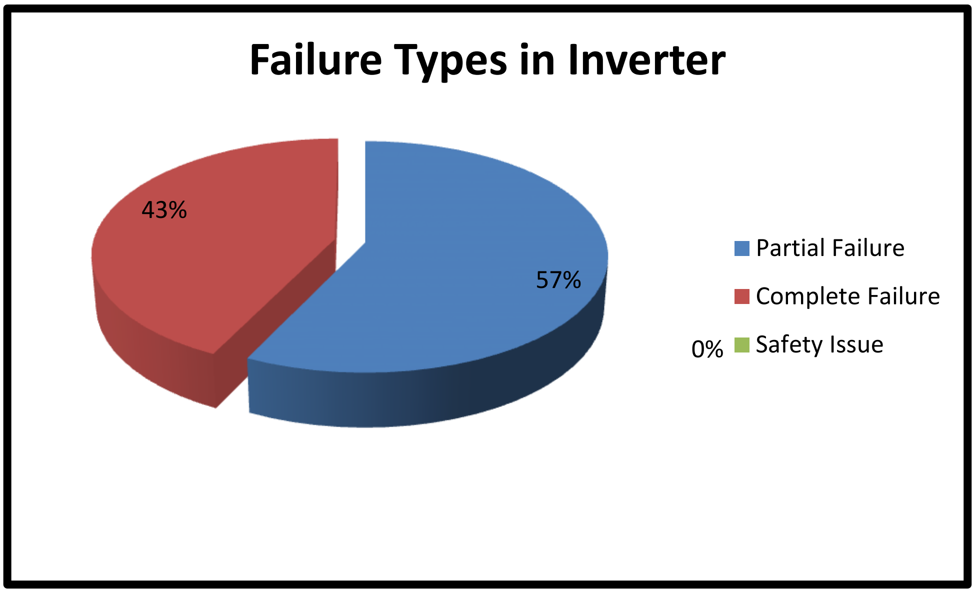

Figure 91- Types of Inverter faults reported

7. DISCUSSION

7.1. THESIS METHODOLOGY

This thesis targets to analyze the information about the faults and the issues related to the PV module systems, possible causes which accelerate those faults to occur. This has been conducted by Australian Photovoltaic Institute (APVI) to provide us with the data from last 3 months. The survey data provided the readers with the information about the type of respondents, date of installation, location of the site, faulty components and the information about the faults. The data has been analyzed and presented graphically in Section 6 of this report. Another major part of this thesis is the literature review. Literature review includes the research and derivation of the results concluded from the other surveys and other thesis reports in this field of study. These results are then presented in the similar pattern as of the results from the APVI survey. Both surveys are then compared and the information collected from the research has been used to find the relevance and the possible causes of the faults which occur in the different components of the PV module systems.

During the thesis, effect of the climate conditions on the degradation of the PV modules has been discussed. It has been found that hot temperatures and moist climate conditions accelerate the visible faults in the PV module systems. Some of the faults in PV module systems which are affected by the climate conditions are corrosion, delamination, discoloration, etc. Figure 84 shows that 90% of the faults reported in the APVI survey are in the temperate climate zone of Australia and rest of the 10% are reported from the subtropical regions of Australia. However, it should be noted that most of the population of Australia lives in the Temperate zone and then in subtropical zone. Figure 92 shows the comparison of the physical location of Australian population and the climate zones. In Australia, temperate zone with dense population is located on the coastal lines which results in the hot temperatures and moist conditions in the environment.

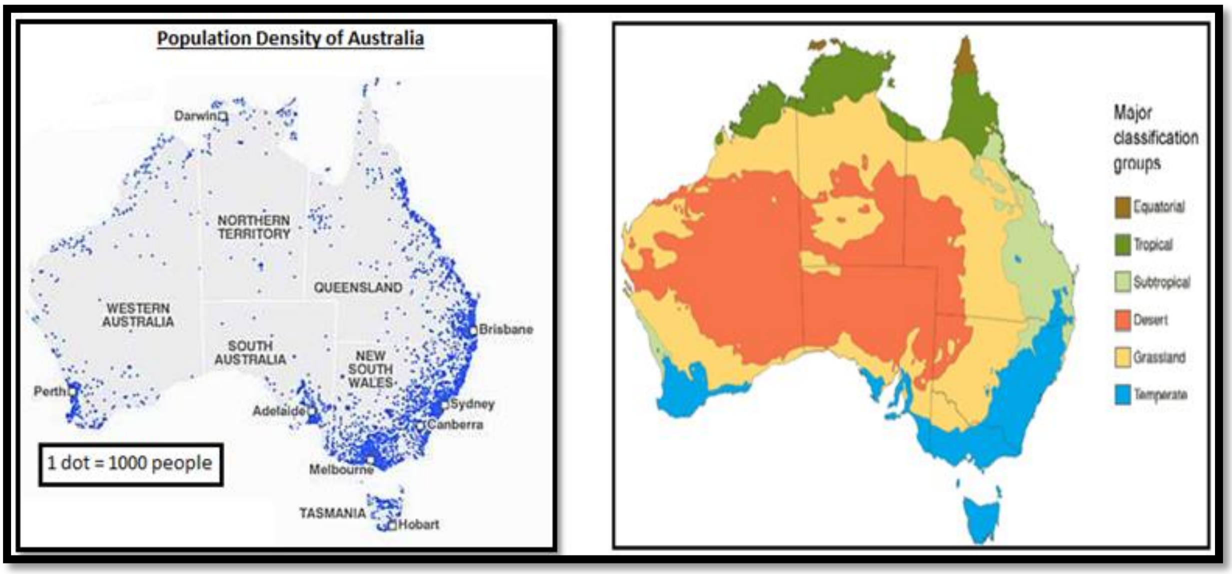

Figure 92- Comparison of Physical location of Australian Population and climate zones (Source: (Australian Bureau of Meteorology , 2014))

All India Survey of PV degradation (Refer section 5.3.5.2 for detail) also shows that these visible faults are more likely to appear quickly in hot and humid climate and then in hot and dry climate as compared to the cold climate, shown in Figure 93.

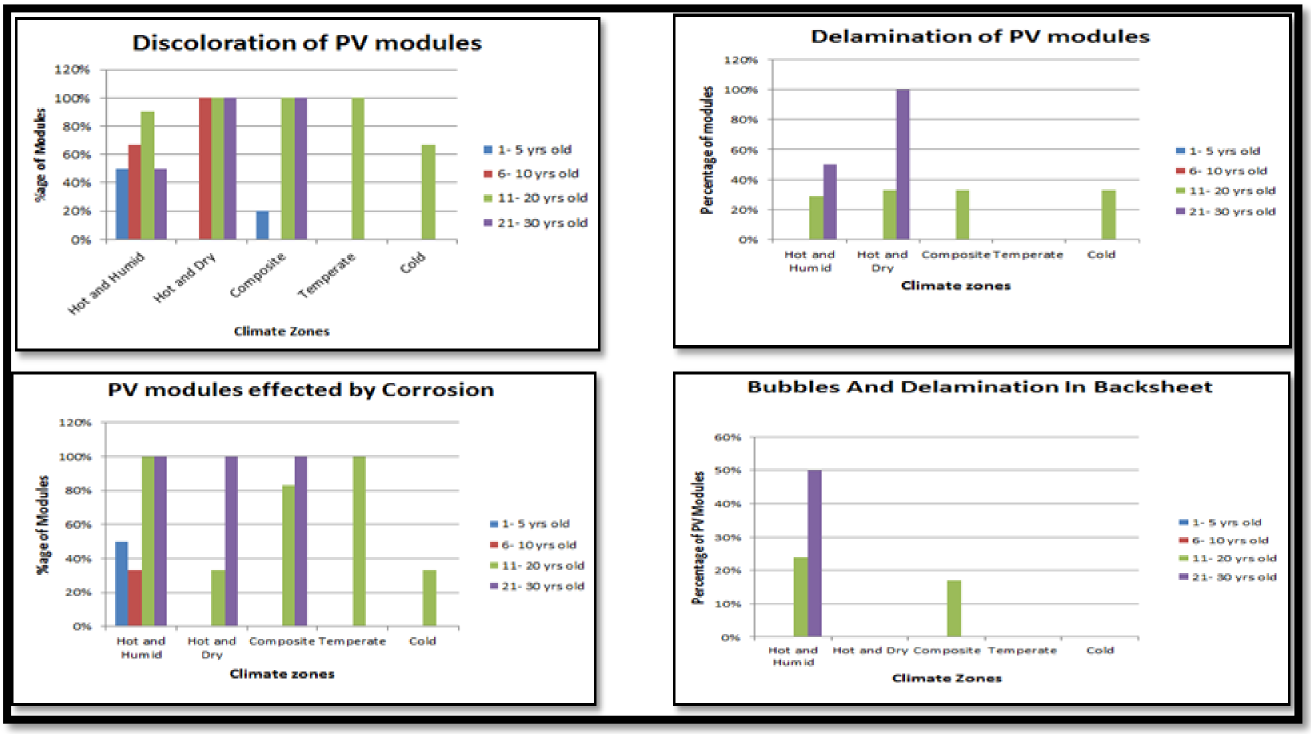

Figure 93- Visible faults in PV modules represented with their age and climate zone location (Source: (Rajiv Dubey, 2014))

Section 5.3.7, Corrosion Effects in Thin- Film Photovoltaic Modules- Report, explains that the corrosion is directly dependent on the voltages applied to the material and this test also explains that corrosion is clearly accelerated with the increase in the temperature at which material is kept.

Section 5.3.11, Moisture as a Stress Factor, shows the damp heat test performed on the 7 different PV modules with two different temperature conditions. This test explains the effect of the temperature on the degradation of the normalized output power which shows that the temperature accelerated the degradation of the normalized output power of the PV module systems.

APVI Survey results also provide us the information about the type of the system where faults were reported. Section 6.4.1.3 shows the size of the array of the system where fault has been reported in the APVI survey. It can be seen that most of the faults were reported in the system with array size of 4- 5 KW. Solar choice Australia, who are the national installers of PV systems in Australia suggest that about 70% of the installation they do are the systems with the array size of 3- 5 KW. On comparison of this information, the results obtained are highly good. Also, Section 6.4.1.4 explains that 91% of the reported faults are related to the grid connected systems and rest of the 9% of the faults are reported to the stand alone systems. This information is well matched to the information found during the research in which 794 grid connected systems were reported as compared to only 9 off grid systems, shown in Figure 94. Similar information is provided by solar choice Australia, as they mentioned that they install grid connected systems in metropolitan part of Australia.

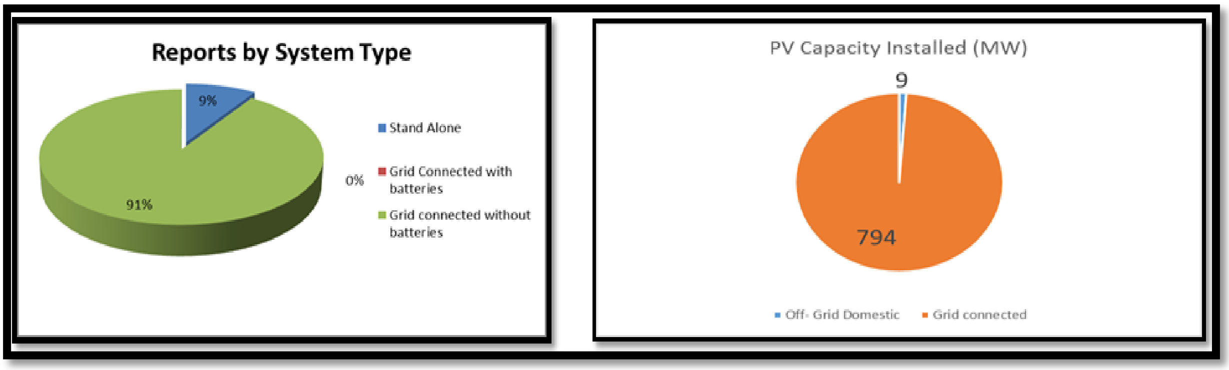

Figure 94- Comparison of APVI result and another survey for type of systems (Illustration: (Edis, 2014))

APVI survey results (section 6.4.1.6) also shows that the inverter is the most common component in the PV module system. About 50% of the total faults reported are related to the inverter of the PV module system. Other surveys including 1000 roofs Germany, Residential program Japan and Sonne der schule Germany as discussed in the section 5.3.12 shows the similar results where most of the faults are related to the inverter of the PV module system as shown in Figure 95. Graphs in Figure 95 also shows the information from the other 3 surveys which suggests that the total number of faults are decreasing with the time every year. So, it suggests that continuous improvements have been made in designing the PV modules during those years.

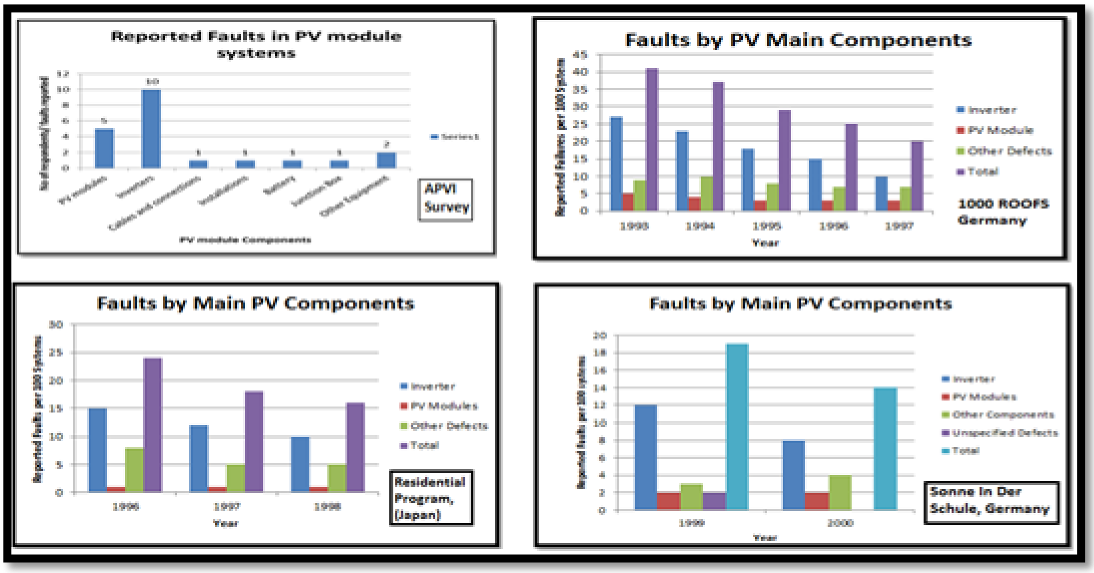

Figure 95- Some results which shows the faulty components in the PV module system (Illustration: (Laukamp, 2002))

8. CONCLUSION

This thesis report presents the results derived from the information provided by mainly users of PV module systems through a web based survey which was conducted by Australian Photovoltaic Institute. This presents the information and findings of the 3 months data. Although, there was not enough and detailed data available but the respondents who provided some information related to the problems and issues that they faced while using the PV module system assist this report to derive some really important results. These results are found to have a reasonable correlation with the information found from the similar surveys, reporting systems and other thesis reports as discussed in the literature review section of this report. It is worth noted that out of the 80 respondents, only 34 of them mentioned that they do have problems related to the PV module systems that they are using. Effect of the climate on the degradation of the PV module system has been seen. It is interested to know that most of the Australian population actually lives in the temperate zone and then in subtropical zone. That was the reason behind the result of the survey which shows that 90% of the faults were reported within the temperate zone and rest of the 10% were reported within the subtropical region of Australia. Effect of the temperature and the humidity on the degradation of the PV system has been discussed in the report. Moreover, it has been found that the PV systems are more likely to show the signs of faults in hot and humid climate as compare to the cold climate regions. Also, it has been found that houses in metropolitan part of Australia installs Grid connected PV systems which were the reason behind the survey result which shows that 91% of the reported faults were based on the Grid connected systems. It is also concluded that inverter is the most common faulty component in the PV module system reported in the APVI survey and in various other surveys. About 50% of the total fault reports are related to the inverter of the PV module system. In about 50% of the inverter related cases, fault in the inverter leads to the complete failure of the system. In the PV module (Panel) of the PV system, back sheet delamination, bubbles in the back sheet and water ingression are the most common and major problems which were reported in the APVI survey and found in this thesis. In about 50% of the cases where any fault has been reported to the any component of the system, reduction in the overall system performance has been reported. If there were more respondents, the clarity in the data could be improved. It also has been noted that lots of respondents did not mention their location and jumped to the next section of the survey. If there were more information about the location of the faults, more related results could be derived from that information.

9. FUTURE WORKS

This thesis mainly comprises a part of another project which is currently running at Murdoch University in the attempt to make the PV systems more reliable, durable and efficient. Climate based information which has been discussed in this thesis report can be used in that project. This report can be used to understand the designing and construction of the PV module system. The report can also be used to analyse the areas where most of the faults occur in PV module systems. The results of this thesis can be used in the various projects which involve the further development of the PV module systems in order to increase the reliability, durability, performance and the efficiency of PV module systems.

Also, survey questionnaires can be improved i.e. more detailed questions in order to provide much more information about the PV system. It will be beneficial if every respondent is more encouraged to provide more information about the location and the surrounding environment. More specified questions regarding the installation and the purpose/ motivation of the installation can be added.

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11. APPENDIX

This section shows the questionnaire of the survey which has been conducted by Australian Photovoltaic Institute (APVI). The survey data was used in this report to get the information about the faults reported by the respondents and the results have been derives and explained in this report.

1.0 Introduction

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. This independent research is supported by the Australian Renewable Energy Agency (ARENA) and coordinated by the Australian PV Institute (APVI), 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.

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 reports 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, however, your personal information will not be presented in any publications or disclosed to anyone outside the project team unless required to do so by law. The raw data will not be available for the public to view.

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

1

Figure 96- Screenshot of APVI Survey Questionnaires

Figure 96 shows the information which is provided to the respondent regarding the Project background, Survey Participants, Disclaimer, use of the information, rights of Participants, Privacy policy and the safety issues.

recommend that only competent people with appropriate 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.

Ethics Approval

This study has been approved by the Murdoch University Human Research Ethics Committee (Approval xxxx/xxx). If you have any reservation 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 6677 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.

Declaration

It is necessary that you fully understand and adhere to the safety instructions before you proceed with this survey. Please tick the box if you have understood the safety requirements, or send us an email if you have any questions.

- I have read and understood the project background and safety instructions.

[The questionnaire doesn't proceed to the next step unless the Declaration box is ticked]

2.0 Survey Overview

This survey has been structured into five different sections associated with Module, Inverter, Other Equipment, Installation and General Issues. Each section opens with a question asking if you have noticed a problem in relation to that part of the system. If you answer no, you will jump to the next section to avoid going through any unnecessary questions. However, you can always go back to previous questions by clicking the 'Prev' button if you wish to change your answers.

The 'General Issues' section is intended to collect information that does not fit elsewhere. For example, you should report here if you have noticed a reduction in system performance (kWh's of electricity produced) but do not know exactly why this is occurring. Also, you may have experienced documentation issues or customer service issues associated with your installation that you would like to report on.

It is not a requirement that you answer all questions. You may find some technical terms that have been used here are unknown to you, or not relevant to your system. In such cases, please feel free to skip those questions/sections.

Mandatory questions are marked with an Asterisk (*), you will need to answer these

2

Figure 97- Screenshot of APVI Survey Questionnaires

Figure 97 shows the information provided to the respondent regarding the ethics approval, disclaimer and survey overview.

questions in order to be able to move to the next question.

There is an "Exit this Survey" button at the top right corner of the screen. You can click this button if you, at any point, change your mind and choose to discontinue with your survey. Details you have provided this far will not be recorded.

At the end of the survey please click on the 'Done. Thank You' button to ensure that your survey has been completed and information you provided has been recorded.

3.0 Survey Questions

Have you experienced any problems with your PV system or would you like to provide information about a PV system that has experienced a problem?

- No. (You do not need to complete this survey questionnaire. Thank you.)

[Survey ends here and returns to APVI website]

- Yes. Please continue.

3.1 System description (this information is typically provided in your PV installation or user manual)

PV array capacity (kW)

Date of installation (if known)

Number of modules

Please note that Solar Module is also known as Solar Panel

Module manufacturer(s)

Module model(s)

Number of inverters

Inverter manufacturer(s)

Inverter model(s)

3.2 Type of system

- Grid connected without batteries
- Grid connected with batteries
- Standalone

Figure 98- Screenshot of APVI Survey Questionnaires

Figure 98shows the information provided to the respondent regarding the survey questions and asking the information from the respondents regarding the description of the system they are using.

5.3 Are you a PV system

- [ ] Installer
- [ ] Owner/Operator
- [ ] Inspector/Auditor
- [ ] Manufacturer/Distributor
- [ ] Other (please specify)

4.0 Issues and problems

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 e.g. charge controller (if any), batteries (if any), circuit breakers, data logger (if any), etc;
- System Installation i.e. any issue that may have arisen from an improper or non-standard installation
- Other Issues – this will help to provide information that does not fit elsewhere.

Figure 99-Screenshot of APVI Survey Questionnaires

Figure 99 shows the questions which have been asked the respondents to provide the information regarding the system and issues and problems they face while using the system.

Solar Photovoltaic System components

4.1 Have you noticed a problem with the modules?

- Yes
- No
- Not sure

["No"/ "Not sure" takes to question 4.2]

This section allows you to select problems that you have with modules. Please select one problem at a time and answer a number of further questions related to this problem only. You will be able to return to the list again if you have multiple problems.

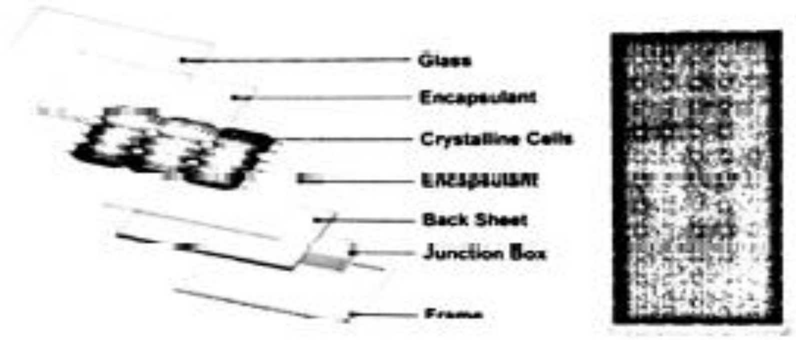
4.1.1 What module problems did you encounter? (Please refer to the explanatory diagram)

- Glass Breakage
- Framing
- Cell Discolouration (including cracks or snail trails)
- Encapsulant Discolouration
- Cell Interconnect (e.g. burn marks)
- Backsheet (e.g. bubbling, delamination, hole)
- Junction box (e.g. loose contact, burnt diode, etc)
- Module cable or connector (e.g. mechanical damage, overheating)
- Other (please specify) ____________

5

Figure 100-Screenshot of APVI Survey Questionnaires

Figure 100shows the questions which has been asked the respondents to provide the information regarding the problems related to the PV module.



4.1.2 How many modules had the [selection of 4.1.1] problem?

4.1.3 Have you noticed any reduction in system performance (kWh's of electricity produced) as a result of the [selection of 4.1.1] problem?

- No
- Yes

4.1.4 What would be a good estimate of the reduction of system performance (kWh's of electricity produced) compared to when it was first installed?

10% 20% 30% 40% 50% 60% 70% 80% 90% Not sure

4.1.5 Do you know how long had the system been operating at the time the [selection of 4.1.1] problem was discovered?

- No
- Yes (please enter duration in months)

4.1.6 Has the [selection of 4.1.1] problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)

4.1.7 What was the response to the [selection of 4.1.1] problem?

6

Figure 101-Screenshot of APVI Survey Questionnaires

Figure 101shows the questions which has been asked the respondents to provide the information regarding the problems related to the PV modules

- Fixed by installer
- Fixed by manufacturer
- Fixed by third party
- Not sure
- Other (please specify)

4.1.8 Do you wish to provide us with any further details on your experience in getting the problem fixed?

- Yes (please comment on your experience in getting the problem fixed)
- No

4.1.9 Do you have other problems associated with modules?

- Yes
- No

["No" takes to the next question and "Yes" takes back to section 4.1.1 to allow provide information about another type of module problem]

4.1.10. Are you aware of any issues related to module certification and labelling?

- No
- Yes.

4.1.11 What type of module certification and labelling issues did you have?

- Modules are not CEC approved
- Non-certified components used in modules
- Modules have lower power ratings than the nameplate ratings
- Poor quality modules are being sold as top quality products
- Modules do not have manufacturer's warranty
- Modules are not correctly labelled

7

Figure 102-Screenshot of APVI Survey Questionnaires

Figure 102shows the questions which has been asked the respondents to provide the information regarding the problems and other issues related to the PV module of the system.

4.2 Have you noticed a problem with an inverter?

- Yes
- No
- Not sure

["No"/ "Not sure" takes to question 4.3]

4.2.1 How would you best describe your inverter problem?

- Complete failure
- Partial failure
- Safety issue
- Unknown
- Other (please specify)

4.2.2 Have you noticed any reduction in system performance (kWh's of electricity produced) as a result of the [selection of 4.2.1] problem?

- No
- Yes

4.2.3 What would be a good estimate of the reduction of system performance (kWh's of electricity produced) compared to when it was first installed?

10% 20% 30% 40% 50% 60% 70% 80% 90% Not sure

4.2.4 Do you know how long had the system been operating at the time the [selection of 4.2.1] problem was discovered?

- No
- Yes (please enter duration in months)

4.2.5 Has the [selection of 4.2.1] problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)

8

Figure 103- Screenshot of APVI Survey Questionnaires

Figure 103shows the questions which has been asked the respondents to provide the information regarding the inverter of the PV system.

4.2.6 What was the response to the [selection of 4.2.1] problem?

- Fixed by installer
- Fixed by manufacturer
- Fixed by third party
- Not sure
- Other (please specify)

4.2.7 Do you wish to provide us with any further details on your experience in getting the problem fixed?

- Yes (please comment on your experience in getting the problem fixed)
- No

4.2.8 Do you have other problems associated with inverter?

- Yes
- No

["No" takes to the next question and "Yes" takes back to section 4.2.1 to allow provide information about another type of inverter problem]

9

Figure 104- Screenshot of APVI Survey Questionnaires

Figure 104shows the questions which has been asked the respondents to provide the information regarding inverter of the PV system.

Other equipment

4.3 Have you noticed a problem with other equipment?

- Yes
- No
- Not sure

["No"/ "Not sure" takes to question 4.4]

4.3.1 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)

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

- No
- Yes

4.3.3 What would be a good estimate of the reduction of system performance (kWh's of electricity produced) compared to when it was first installed?

10% 20% 30% 40% 50% 60% 70% 80% 90% Not sure

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

- No
- Yes (please enter duration in months)

10

Figure 105- Screenshot of APVI Survey Questionnaires

Figure 105shows the questions which has been asked the respondents to provide the information regarding the other components and system performance of their PV system.

4.3.5 Has the problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)

4.3.6 What was the response to the problem?

- Fixed by installer
- Fixed by manufacturer
- Fixed by third party
- Not sure
- Other (please specify)

4.3.7 Do you wish to provide us with any further details on your experience in getting the problem fixed?

- Yes (please comment on your experience in getting the problem fixed)
- No

11

Figure 106- Screenshot of APVI Survey Questionnaires

Figure 106shows the questions which has been asked the respondents to provide the information regarding the PV system they are reporting about.

System installation

4.4 Have you noticed a problem with the installation?

- Yes
- No
- Not sure

["No"/ "Not sure" takes to question 4.5]

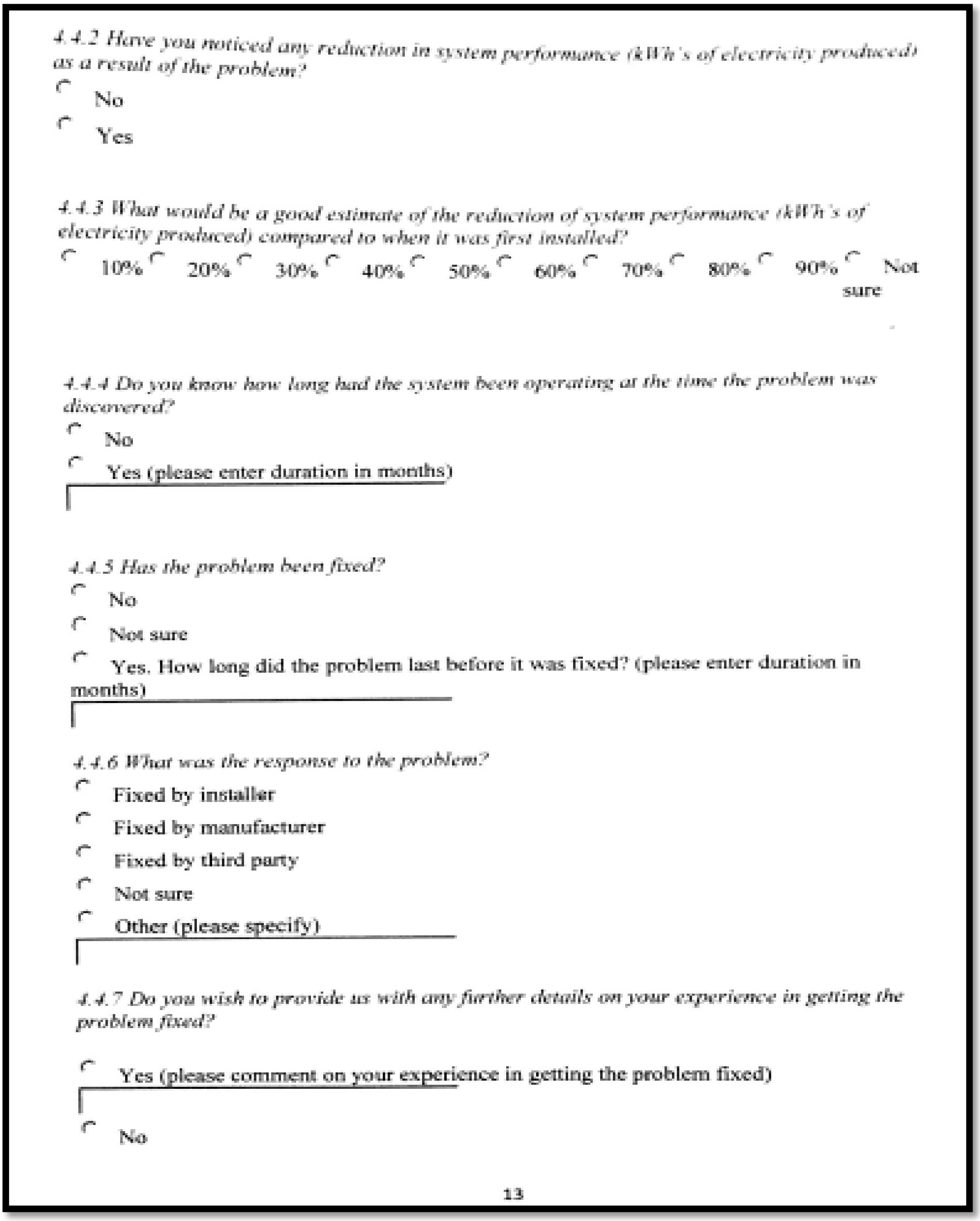
4.4.1 What type of installation issue have you noticed? Tick as many as applicable

- 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)

12

Figure 107- Screenshot of APVI Survey Questionnaires

Figure 107shows the questions which has been asked the respondents to provide the information regarding the installation of the PV system.



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

- No
- Yes

4.4.3 What would be a good estimate of the reduction of system performance (kWh's of electricity produced) compared to when it was first installed?

10% 20% 30% 40% 50% 60% 70% 80% 90% Not sure

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

- No
- Yes (please enter duration in months)

4.4.5 Has the problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)

4.4.6 What was the response to the problem?

- Fixed by installer
- Fixed by manufacturer
- Fixed by third party
- Not sure
- Other (please specify)

4.4.7 Do you wish to provide us with any further details on your experience in getting the problem fixed?

- Yes (please comment on your experience in getting the problem fixed)
- No

13

Figure 108- Screenshot of APVI Survey Questionnaires

Figure 108shows the questions which have been asked the respondents to provide the information regarding the problem and if the problem has been fixed yet and if there is any reduction in the performance of the system.

Other issues

4.5 Would you like to report any issues that have not been covered earlier?

- Yes
- No

["No" takes to question 5.0]

4.5.1 Please tell us the problems and/or issues that you are experiencing with your PV system.

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

- No
- Yes

4.5.3 What would be a good estimate of the reduction of system performance (kWh's of electricity produced) compared to when it was first installed?

- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- Not sure

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

- No
- Yes (please enter duration in months)

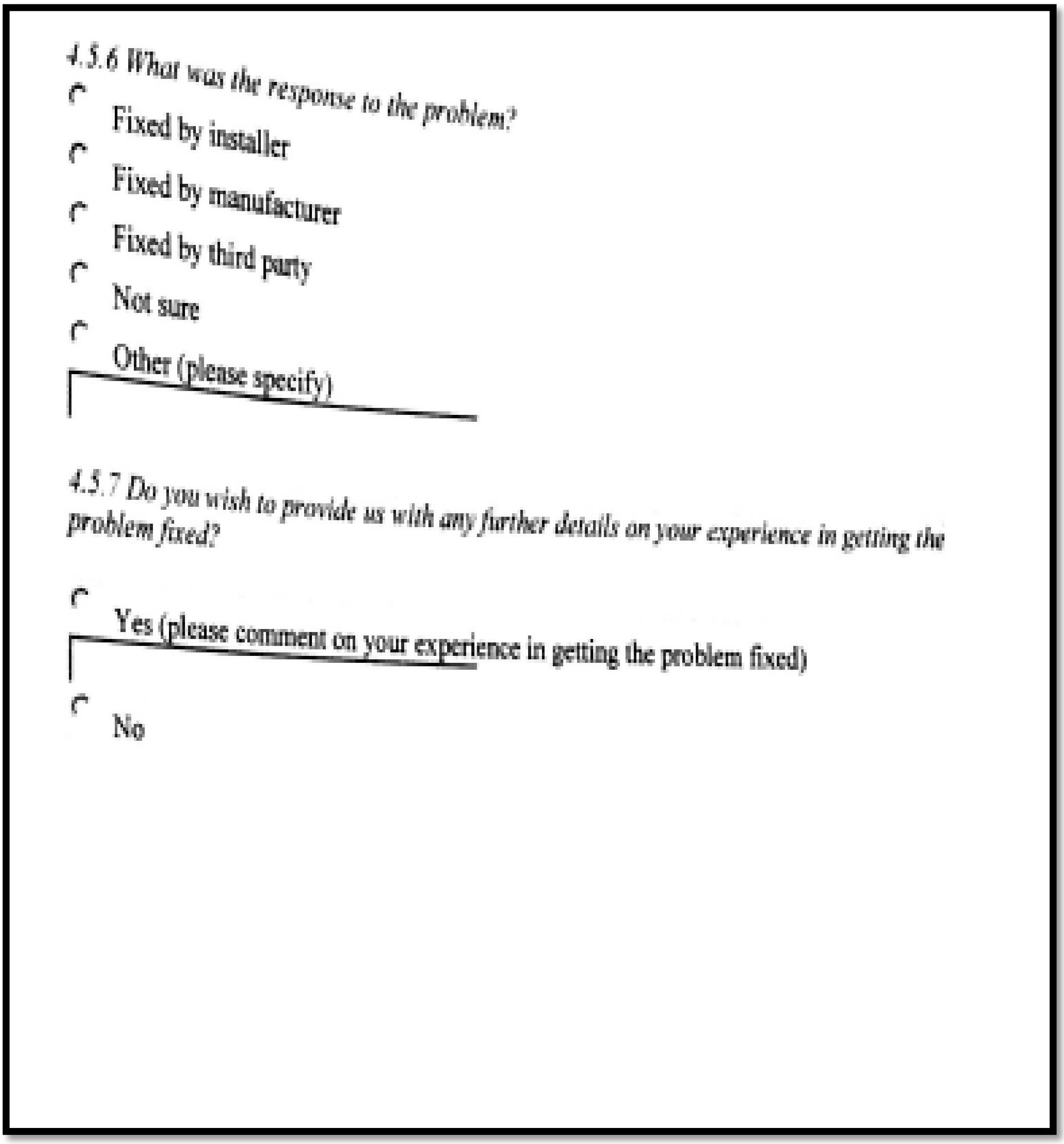
4.5.5 Has the problem been fixed?

- No
- Not sure
- Yes. How long did the problem last before it was fixed? (please enter duration in months)

14

Figure 109- Screenshot of APVI Survey Questionnaires

Figure 109shows the questions which have been asked the respondents to provide the information regarding the other issues which may not be mentioned earlier in the survey questions.



4.5.6 What was the response to the problem?

- Fixed by installer
- Fixed by manufacturer
- Fixed by third party
- Not sure
- Other (please specify)

4.5.7 Do you wish to provide us with any further details on your experience in getting the problem fixed?

- Yes (please comment on your experience in getting the problem fixed)
- No

Figure 110- Screenshot of APVI Survey Questionnaires

Figure 110shows the questions which have been asked the respondents to provide the information regarding the problem and if that problem has been fixed or not.