5. EMPIRICAL RESEARCH ATTRIBUTES

5.1 OVERVIEW

Well-defined test configuration and rationale is necessary for performing a (Chris Deline, May 2012) and so a program is designed for the test sequences. This empirical research test is performed in SRM University, Chennai. The geographic location of SRM University campus is 12°49'25"N 80°2'39"E. Metrological data are obtained online from the web (IBM, 2013).

The experimental set-up is installed with poly crystalline PV module (100 Wp), poly crystalline PV module (230Wp) and mono crystalline PV module (250Wp).

5.2 RESEARCH DESIGN ATTRIBUTES

The units of measurement shall be generally System International (SI) units with other equivalent units which are defined in nomenclature. Topic research has to consider many attributes as the primary and secondary variables of the test.

A factor or phenomenon that causes or influences another associated factor or phenomenon is called a dependent variable. In a mathematical equation or model, the independent variable is the variable whose value is given. In an experiment, it is the controlled condition (that is allowed to change in a systematic manner) whose effect on the behavior of a dependent variable is studied, also called controlled variable, explanatory variable, or predictor variable.

The independent variables data such as Site Irradiation Data, Metrological Data, Ambient Temperature, and Solar Paths can be referred in Table 4.1 and Figure 4.1 from the previous chapter. Optimum Solar Angle for spring / autumn/winter in Chennai are 54^{o} ~ 77^{o} which is (Boxwell, 2012). Manual Sun Tracking is provided on the solar panel supports and it was set during the test period.

The schematic diagram of the experimental setup is given in Figure 5.1. The specifications of PV modules are given in Table-5.1.

5.3 TEST METHODOLOGY

This research study is to test the Group-IV Silicon PV materials in its crystalline forms such as Mono Crystalline (c-Si) and Polycrystalline PV modules for their partial shading temperature effects. All the tests are performed under direct sun radiation environment rather than closed lab environment with artificial sun. Four levels of variability are planned over the test as direct of partial shadowing, presence of bypass diode on the circuit, type of hydrocarbon substance for shadowing over the surface of PV modules and thickness / area of the partial shadow substances. Shading is done through a calculated Shade Impact Factor (Deline C. , 2009) by

$$SIF = \left(1 - \frac{P_{sys}}{P_{shade}}\right)\frac{A_{sys}}{A_{shade}} \text{---} \quad Eqn.5.1$$

Wherein P_{sys} & P_{shade} are the nominal and shade power produced by the PV module respectively, similarly A_{sys} & A_{shade} are the full and shaded area of the PV module respectively.

5.3.1 Characteristics Verification:

Initially, the PV module characteristic needs to be verified through preliminary tests to qualify the PV modules normal performance. This test ensures that there are no faults in the PV modules and further tests shall be performed to evaluate the partial shading phenomena.

PV modules are placed under the sun on the test site and Voltage, Current, Power, Site Metrological Data & Wind Flow Direction are measured and recorded.

5.3.2 Shading Techniques:

Partial shading can be created in two ways, one nearby shade obstruction such as a screen, pole in front of the module or to apply directly to parts of the array (Chris Deline, May 2012) a shading material such as opaque masking tape or a cardboard.

Direct shading method is followed with changes on number of cells shaded and initially the cell shading is done by opaque masking tape with 100% full opacity. In the cell shading program, the worst case shadowing of a selected cell is chosen by gradually increasing the shadowed area of the selected cell, until I_{sc} of the module coincides as closely as possible with I_{sc}. In this condition, the maximum power is dissipated within the selected cell and measured data are recorded in the defined formats.

5.3.3 Presence of By-Pass Diode

Second variability is to add or remove the diode(s) in the by-pass location and perform the test sequences. The direct shading is done as per the steps above and measured data are recorded in the defined format.

5.3.4 Hydrocarbon Dust / Layer Shading:

Carbon Disulphide is mixed with saw dust and coal seam powder is used for the dust layer. Each set of test is performed with coal seam and saw dust materials with same SIF, as planned for direct shading method.

5.3.5 Degree Of Partial Shading:

Degree of shading such as light shading, moderate shading and heavy shading varied through the thickness/area of dust layers is modified and two sequences charcoal dust and hydrocarbon dust is performed with same SIF, as planned for direct shading method.

5.3.6 Temperature Measurement

Temperature of PV cells is measured in two different methods

- Intrusive Method:

Skin K-Type Thermocouples (TC) is used to measure the point temperature. The location of temperature measurement is changed based on the Shade program.

- Non-Intrusive Method

Using Infra-Red (IR) thermometer and emissivity adjustment techniques, the maximum temperature of the PV cell shall be measured through non-intrusive hotspot test procedures for a specific duration of light exposure. Emissivity of the object is adjusted based on the shade material.

5.4 TEST SPECIMEN

The partial shade test is simulated on the PV cell by using three materials, first the high opaque masking tape, second the charcoal dust and the third, a mixture of charcoal dust, saw dust and Carbon Disulphide (CS2) as shading media.

For PV modules application in hydrocarbon vapour environment, a surface temperature rise above 85 ^{o}C is considered as fire hazard as this will then increase the likelihood of an explosion by igniting the hydrocarbon in the atmosphere. For PV modules application in ignitable dust environment, a surface temperature rise above 230 ^{o}C is considered as fire hazard for coal dust layer deposition.

5.4.1 Hydrocarbon Vapour

There were three scenario considered for hydrocarbon fire hazard and samples prepared for the partial shading of PV modules.

The hydrocarbon vapors prevailing in oil and gas fields application can come into accidental contact with the hotspot created PV modules, which is the worst case scenario. For simulating this fault condition, a high opaque masking tape was used as shade media. Ignitability of hydrocarbon vapour has many influencing factors and Table-3.1 gives AIT of few samples. The specimen was cut into the size of the single PV cell and shade test was carried out in different combination on the PV module matrix.

5.4.2 Charcoal Dust

Second, Charcoal dust which is prevalent in normal industrial atmosphere can deposit a layer on PV module leading to partial shade. Charcoal dust with particle size ranging from 10 ~ 500 µm was prepared, the laboratory test on ignitability of the dust layer is directly linked to the particle size distribution. Glow temperature for a 5 mm thick layer resting on a hot-plate is the best measure for the charcoal dust ignitability for our research test interest. Dust layer ignitability for charcoal layer is ranging from 320 ~ >450 ^{o}C.

5.4.3 Hydrocarbon Dust

Third, liquid hydrocarbon cannot have direct contact with hot surfaces created in open atmosphere and normally the vapor created can form an ignitable cloud. This research test requires a hydrocarbon dust to be deposited over PV module to develop a partial shade condition. Hence a "hydrocarbon dust" sample was prepared with the following materials

- Saw Dust
- Charcoal Dust
- Carbon Di Sulphide Liquid (CS2)

Equal volume of all the three materials were mixed and left in atmosphere for drying. Sawdust and Charcoal dust with particle size ranging from 10 ~ 500 µm was prepared, the laboratory test on ignitability of the dust layer is directly (Hadden, 2011) particle size. Carbon Di Sulphide is the lowest auto ignition temperature hydrocarbon liquid with 102^{o}C and its flashpoint as –43^{o}C. Glow temperature for a 5 mm thick layer resting on a hot-plate is the best measure for this dust ignitability for our research test which is assumed to be less than 300 ^{o}C.

5.5 TEST SEQUENCING

Sequencing of the test is essential for proper execution; following sequence is planned on one set each on Monocrystalline and Polycrystalline PV modules.

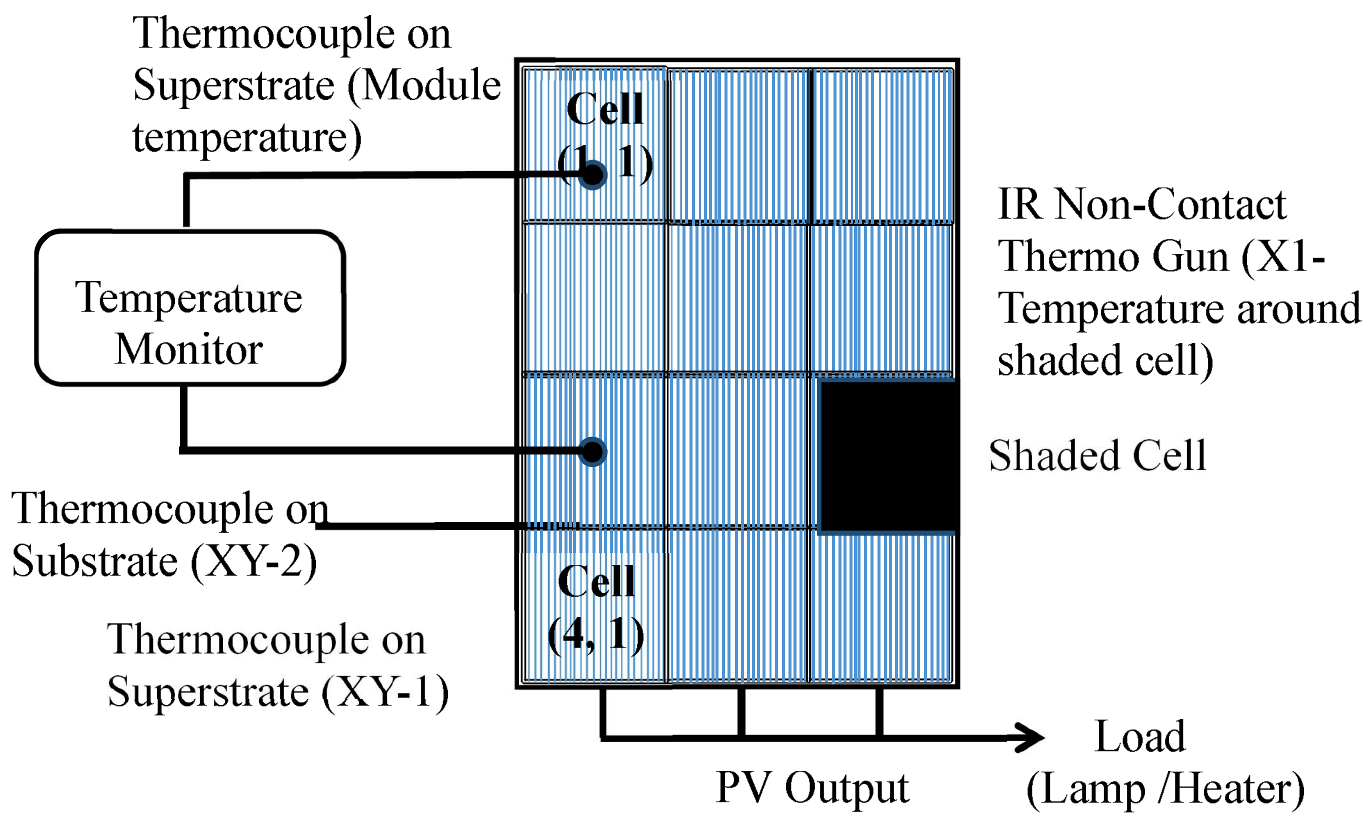

Figure 5.1 Schematic diagram of experimental set up

Table 5.1 Specifications of Poly Crystalline and Monocrystalline PV Modules

Specification	**PV Module (100W_p)-(poly)**	**PV Module (230W_p)-(poly)**	**PV Module (250W_p)-(mono)**
Voltage @ Max.Power (Vmp)	17.5 V	35.4 V	30.06 V
Current @ Max.Power (Imp):	5.71A	6.49 A	8.32 A
Open Circuit Voltage (Voc):	21.5V	43.97 V	36.78 V
Short Circuit Current (Isc):	6.28A	7.14 A	8.75A
Tolerance:	+/- 3 %,	+/- 3	+/- 3 %
Number of PV Cells:	36	72	60
Number of Bypass Diodes:	2 (removable) wired with 50Watts (12V) load lamp.	3 (Soldered) wired with 150Watts (12V) load lamp	3 (removable) wired with 150 ~ 200 Watts lamps (12V) load lamp

1. Test of characteristics verification of PV Modules through module tilt angle $54^o \sim 77^o$
2. Test of Partial Shading through high opacity masking sheet through module tilt angle $54^o \sim 77^o$.
3. Test of partial shading through hydrocarbon deposit over the surface of PV module through module tilt angle $54^o \sim 77^o$.
4. Sequence 3 is to test in varying thickness / area of hydrocarbon partial shade to verify the temperature rise.

5.6 HEALTH, SAFETY, ENVIRONMENT

During the research test, manual work related to setting up the materials and circuit wiring were involved. The related health risks such as falling of objects and damage to materials were identified and adequate precautions were taken on the job.

Research Test was performed under direct sun exposure. Body dehydration problems were faced and balanced through more water intake. Hydrocarbon substances were handled and hence fire hazards were present during the research test.

5.7 SUMMARY

This chapter has described the essence of the empirical research and its attributes. The test methodology is closely following the test procedure defined in Chapter-3. The specimen preparation methods for testing the hydrocarbon vapour and dust deposition are well defined. The test sequencing defined that is the key element in carrying out the hot-spot test. Envisaged health, safety environmental impact due to PV partial shade test is also defined within this chapter.