1. INTRODUCTION

1.1 RESEARCH MOTIVATION AND OVERVIEW

Solar Photo Voltaic (PV) modules based electric power supply systems are currently being designed for remote unmanned oil and gas facilities where grid utility power is not available within vicinity. PV modules are used in applications such as measurement of process data, telemetry, gas detection, cathodic protection and lighting with voltage levels of 12V, 24V and 48V.

A fire can occur in a hydrocarbon facility when there is an explosive mixture of fuel (gas / dust) and air and an ignition source, with sufficient energy to initiate it.

Hot spot heating is a phenomenon, occurring in PV modules, caused by faulty conditions such as partial shading / material imperfection / fabrication flaws / damages etc. The extent of hot-spot heating of solar cells is closely related to the properties of the semi-conductor materials.

1.2 OBJECTIVES

The main objective of this research is,

- To test, verify and evaluate hotspot phenomena of commercial Silicon PV Modules / Cells and its application into a hydrocarbon explosive atmosphere, with fire safety perspectives. Empirical research design is to be applied for conducting this study by releasing Carbon Di-Sulphide or similar hydrocarbon substances over partially shaded and hotspot prone PV modules. Also, the explosive dust deposition over PV modules creating a Hot-Spot is to be verified through sequence of test.

- For this test, Hydrocarbon fluids characteristics are obtained from the databases and records. Verification is based on Auto Ignition Temperature (AIT) of hydrocarbon vapour and Minimum Ignition Temperature (MIT) of hydrocarbon dust in atmospheric pressure, temperature and wind etc.
- To test PV cells made of different materials such as mono and poly crystalline Si with encapsulate and circuit design changes, such as by-pass diode combinations, so as to study the intensity of the heat rise.

The outcome of the above research objectives can lead to

- Creation of Application specific Solar PV modules for hydrocarbon industry to effectively minimize the effect of hotspots in an explosive atmosphere.
- Evolution of New application specific PV modules, with inherent safe properties, that shall not be capable to produce and/or minimizes open hot surfaces.
- Engineering design improvements such as location of bypass diodes (BPD) and number of by-pass diodes and bandgap engineered PV cells.

1.3 RESEARCH METHODOLOGY

Essentially the research methodology shall integrate the theory, data collection, sampling, procedures and methods into an outcome that meets the objective of (W.Creswell, 2003). This research study has adopted inductive mode of research methodology, wherein the hypothesis reasoning is (Buckley, 1976). Collected data of each empirical test are grouped together for data interpretation. Summary of data converged into a group gives overall pict
(CMES, 2011).

Research methodology for this work is depicted through following figures

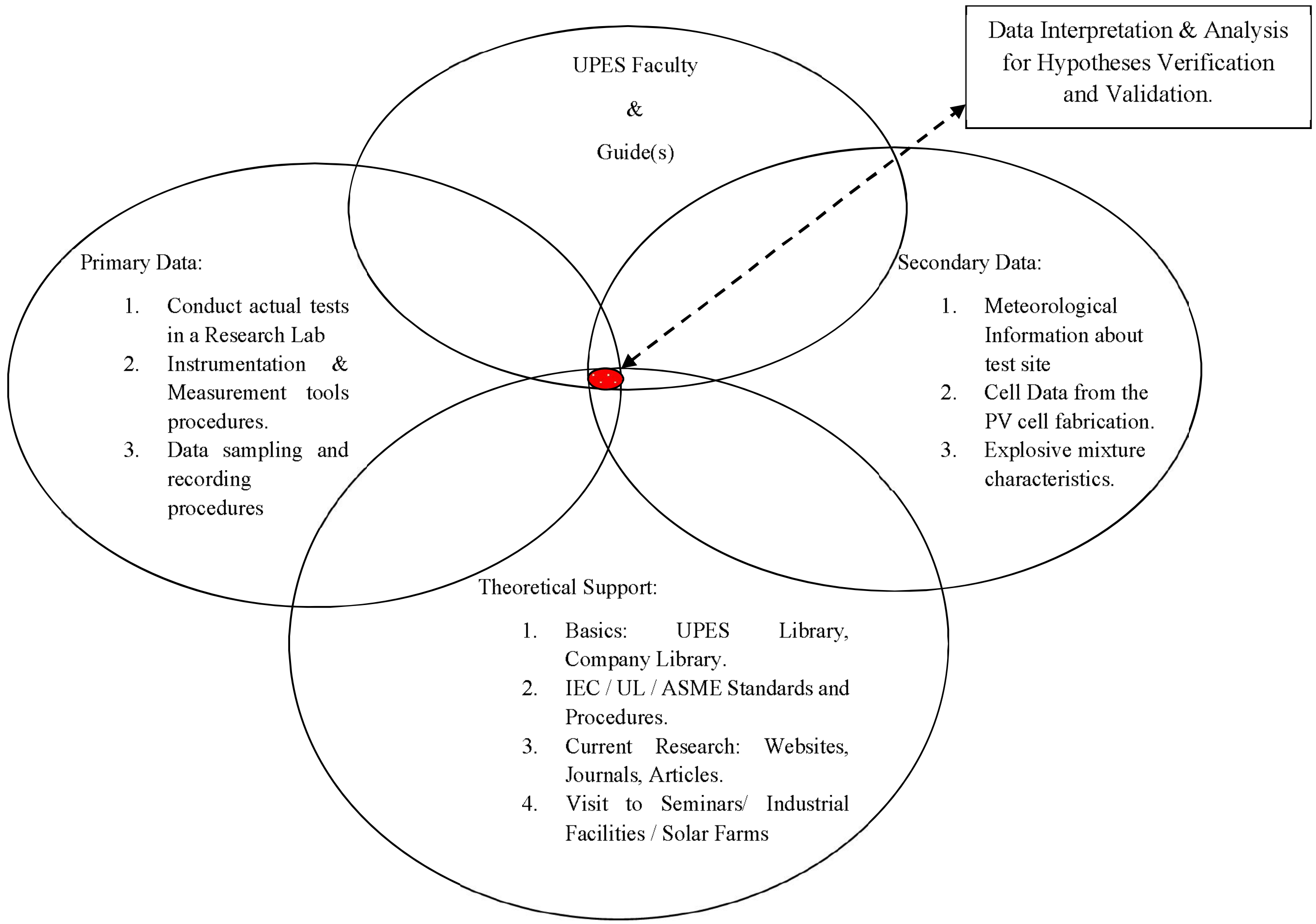

Figure 1.1 Research Methodology

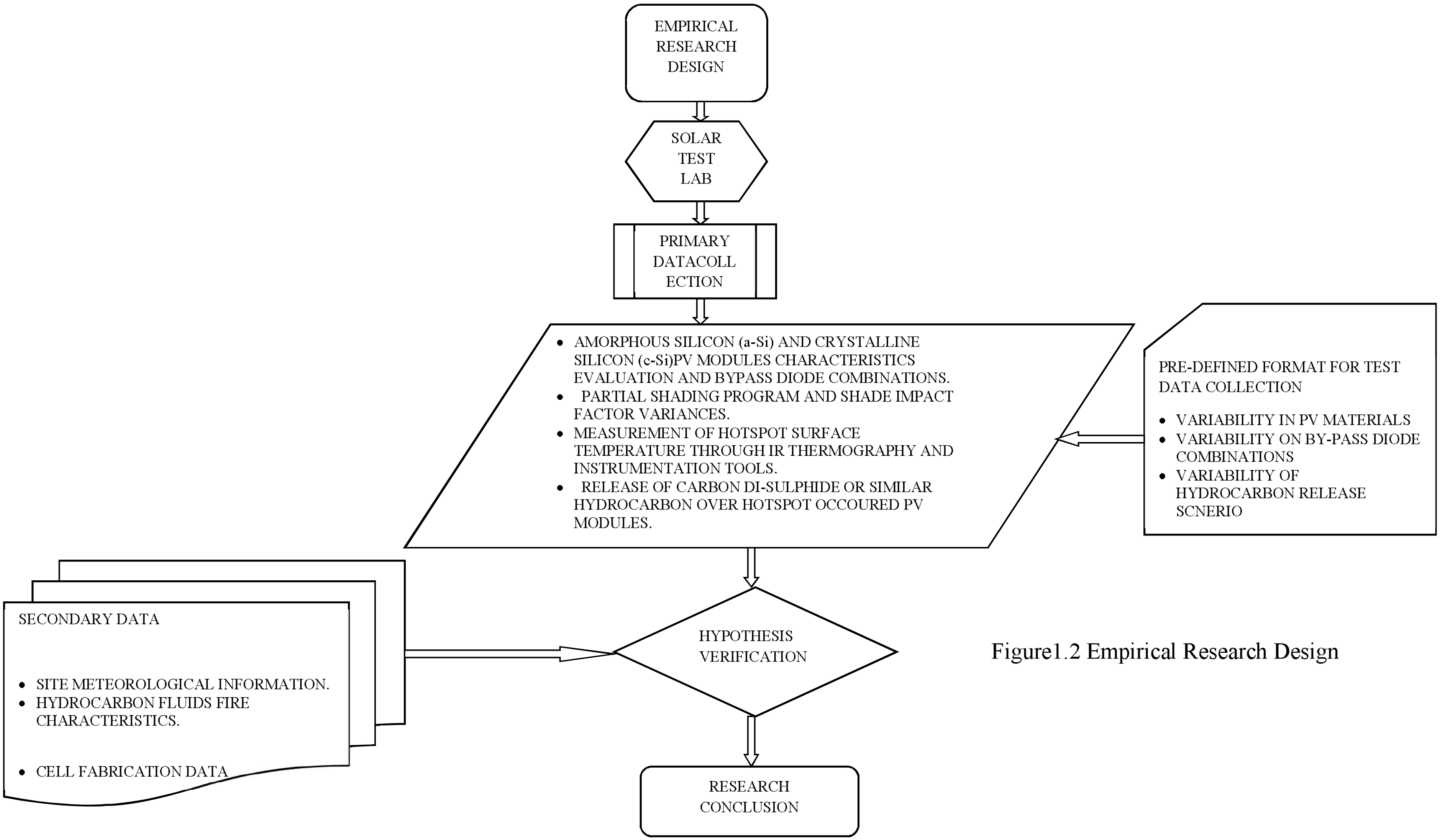

Figure1.2 Empirical Research Design

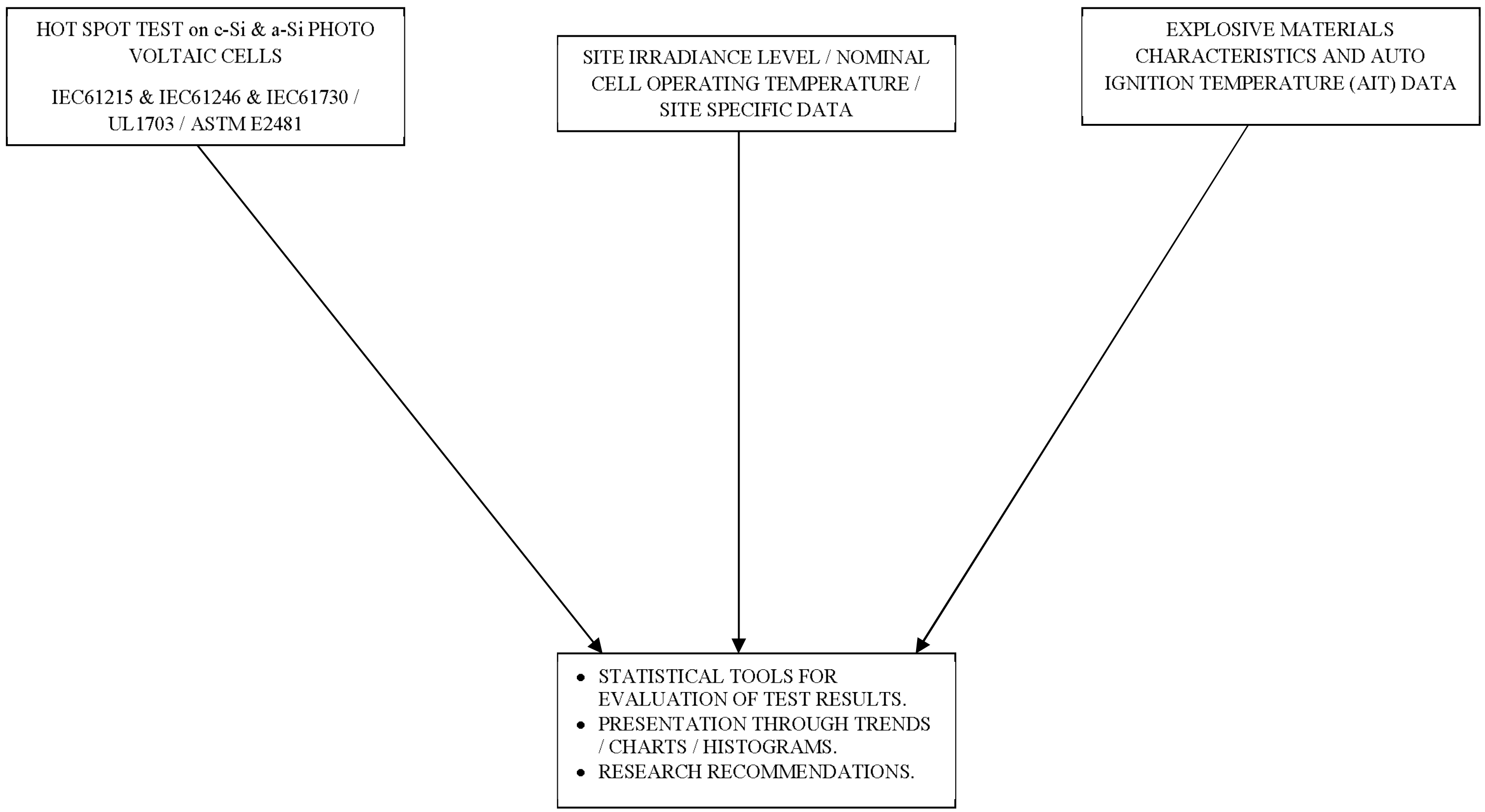

Figure 1.3 Data Collection and Analysis

- Figure 1.1 depicts the overall research methodology schematic.
- Figure 1.2 depicts the empirical research design process as a flow chart sequence.
- Data interpretation and analysis is in Figure 1.3.

1.4 REVIEW OF LITERATURE

Literature survey of solar PV cells indicates that hot spot phenomena of PV (BS 61215, 2005) known; however the study onto application (IEC 60079-14, 2007). Hence an application specific study and testing become necessary. Many researchers have studied the performance of PV modules through simulation (Fialho, 2014) (Ishaque, 2011) (Deline C. A., 2013). Researchers also studied the PV module performance degradations are well studied by (Osterwald, 2009).

Preliminary literature review reveals a number of independent and dependent variables (Buckley, 1976) for each test on the solar PV cells.

- **INDEPENDENT VARIABLES**

Generally the meteorological data, explosive materials characteristics and Auto (IEC 60079-14, 2007) (NFPA, 2012) Temperature (AIT), Minimum (ASTM-E1491-06, 2006) (K.Eckhoff R. , 1997) (Hadden, 2011) Temperature (MIT) are independent variables of the test. Data such as site (IBM, 2013), experimental setup environment, proportion of explosive mixture are independent variables.

- **DEPENDENT VARIABLES**

(ASTM-E-2481, 2008), voltage level of the module, shading level and fault location etc.

- **LITERATURE MAP & GAP IDENTIFICATION**

Application of solar PV modules introduces a fire hazard due to hot spot phenomena, in hydrocarbon field, where surface temperature above 85º (IEC 60079-14, 2007) is considered as source of ignition.

Auto Ignition Temperature (AIT) of various explosive mixture and dust are classified as T-Class in various standards such as IEC-60079/NEC70 (IEC 60079-14, 2007) (NFPA, 2012). It is inferred from the temperature classification, that surface temperature above + 85ºC (T6) shall become a source of ignition in an explosive atmosphere in the hydrocarbon industry.

When PV module is partially shaded with combustible dust or explosive particle (Achim Woytea, 2003), its short circuit current will be reduced compared to other cells in the series string (Alberto Dolara, 2013), leading to a hot spot. It is not practically possible to predict true faulty conditions and hence worst case possibilities shall be the testing criteria.

Reverse bias characteristics of a PV cell varies based on its shunt resistance. Cells can have either high shunt resistance where the reverse performance is voltage-limited or have low shunt resistance where the reverse performance is (ASTM-E-2481, 2008). Each of these types of cells can suffer hot spot problems, but in different ways.

The worst case shadowing conditions occur when, under illumination, the whole cell (or a large fraction) is shadowed leading to a localized hot spot due to large amount of current flowing through small area producing very high temperature (Chris Deline, May 2012) of +200ºC.

When a small fraction of the cell is shadowed, high shunt resistance cells limit the reverse current flow of the circuit and therefore heat up. Because the heating is uniform over the whole area of the cell, it can take a long time for the cell to get heated up.

At present, researches on hot spot behavior of PV modules are more focused towards needs of the power industry, such as cell degradation, longevity and (Deline C. , 2009).

The identified gap, the application of PV modules into an explosive atmosphere, shall be thoroughly studied and suitably designed to prevent a fire hazard.

1.5 CHAPTER SCHEME

This thesis is presented in a specific sequence, with following chapters. Chapter 1 describes the aim of the research, motivation of the research with review of literature and gap identification. Chapter 2 defines the Photo Voltaic theory, with its basic principles of operation, hot-spot phenomena and number of standards governing its test procedures. The explosive and fire hazardous atmosphere prevailing in a hydrocarbon industry is emphasized in Chapter 3. Prior to the empirical test, the PV system partial shade behavior and characteristics were analyzed through a simulation study, which is described in Chapter 4. Empirical research attributes are defined in Chapter 5 and the experimentation results are tabulated in the Chapter 6. Research discussions are elaborated in Chapter 7 and research outcome is concluded in Chapter 8. The references for the research, additional details of simulation studies and dissemination of research through publications are included in the end of the thesis.