

**DEVELOPMENT OF MICROCONTROLLER-BASED PHOTOVOLTAIC (PV)
MONITORING SYSTEM**

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Dr. S. B. Ibrahim and has not been presented anywhere for the award of a degree, certificate or examination in any University. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and subsequent write-up by Yunusa Yusuf Agawa SPS/12/MEE/00044 were carried out under my supervision for the partial fulfillment of the requirements for the award of Masters Degree in Electrical Engineering (Power and Machine) 2012-2016 at Bayero University Kano.

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APPROVAL

This dissertation has been examined and approved for the award of Masters in Electrical Engineering (Power and Machine).

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ABSTRACT

Photovoltaic (PV) system performance highly depends on meteorological parameters and, to reduce frequent maintenance and avoid PV system failure, the meteorological and electrical parameters of the system need to be monitored. Also for unusual PV system it may be worthwhile to measure the details operation of the systems in order to understand the functions of its components in details, so PV system and its performance monitoring become an important factor. This research work developed a simple, reliable and high precision photovoltaic monitoring, which would obtain PV system parameters (i.e. PV panel temperature, irradiance, PV battery voltage, temperature, humidity and load current) in real time operation, display and store it in personal computer. The developed system adopt the use of Atmega328 microcontroller with Arduino board, electronic sensors obtain the PV system parameters, which are processed by a microcontroller and display in personal computer. The developed architecture permits the use of C language and LabView program, for real time display of the PV system parameters. From the experimental results conducted in this work, its shows that this developed system data obtained have good correlations with the standard commercial instruments used in meteorological stations and laboratory with 0.043% mean bias error for solar radiation intensity channel, 0.0412% of temperature channel, -0.297% for humidity measurement channel and for PV battery voltage is 0.024%, this shows good performance of the developed system. The knowledge and experience gained from this research would provide the development communities, PV manufacturers and academic researchers with important information that will be useful in improving PV system performance, reducing maintenance and avoid system failure. In general all the necessary meteorological and electrical parameters associated with PV system are important to be monitored, because in one way or the other can vary the output performance of the PV system.

CHAPTER ONE

INTRODUCTION

1.1 Background

The photovoltaic solar energy (PV) is the most direct way to convert solar radiation into electricity and is based on the photovoltaic effect. The photovoltaic effect is a physical phenomenon of converting the energy carried by optical electromagnetic radiation into electrical energy. Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material move free and create hole-electron pairs. These electrons, however, will fall back into holes causing charge carriers to disappear. If nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact whereby they will emerge as an electric current [1].

It was discovered by E. Becquerel in 1839, when he found that certain materials produce an electric current when exposed to light. The photovoltaic effect remained a laboratory curiosity from 1839 until 1959, when the first silicon solar cell was developed at Bell Laboratories in 1954. It already had an efficiency of 6%, which was rapidly increased to 10% [2]. Practically all photovoltaic devices are made with solar cells of semiconductor material which has to be able to absorb a large part of the solar spectrum. The main application also has been in space vehicles for many years, however terrestrial application of photovoltaic (PV) developed very slowly; nevertheless PV fascinated not only the researchers but also the general public [3].

Monitoring of photovoltaic systems is required for the detection of operational issues, and to compare the performance of different systems across a range of technologies and climates, this becomes essential to ensure high performance, low downtime and fault detection in a solar PV system [4-5]. There for photovoltaic (PV) parameters monitoring is very important for the implementation and optimum utilization of solar energy as electricity source [6].

In large scale PV power station, a monitoring and control system is necessary to monitor and control the system operation. The PV power station often consists of photovoltaic array strings, storage batteries bank, power conditioning unit and electrical loads appliances. In the operation of such station especially with large size (kilowatt or megawatt scales), the system performance should be carefully monitored and a proper decision must be taken in time [6, 7]. For example, if one cell or branch of cells in one module is shadowed, broken, or have a problem, a hot-spot phenomena will occur and the PV cell or module may be damaged, it also reduces the overall system efficiency. The development of photovoltaic systems is accompanied by a rapid adaptation of measurement and control systems to the latest trends in digital techniques and computer-aided measurement [8].

The specialized photovoltaic (PV) data acquisition systems have been recognized as inevitable tools in the PV performance monitoring. Since many years, different data acquisition systems have been used in different equipment, to evaluate PV performance [9]. Photovoltaic solar panels are increasing in popularity and users need accurate information of their solar energy installation. Currently, most residential solar panel systems only provide energy information on a monthly basis and do not allow individual panel monitoring. PV solar panel has at least 25 years warranty, whereas inverters only come with an 8-10 years

warranty. That means that some time in the 8-10 years range the inverter will fail and the system will stop producing energy. With a monitoring system in place the installer or home owner will know immediately that the system has been compromised. Otherwise it could be weeks or months before the home owner looks at their energy usage statement from their utility company and realizes that their solar electricity system is no longer producing energy.

PV monitoring systems usually require a vast number of parameters to be recorded: namely temperatures, humidity, irradiances, voltage and current of the PV battery. When PV panel placed on a roof top, a solar module will heat up, resulting in its temperature going up to 80°C depending on whether air gaps are present between the module and the roof to exploit natural ventilation. Presence of water or moisture content due to dew formation on the PV battery bank, would result in short circuit of the battery terminals and it will lead to deposition of some chemical on the battery terminals, this bring the need to monitor and control the humidity in the PV system power bank. PV system performance depends on the presence of solar radiation on the PV panel for electric current to be generated, so solar radiation play a vital role in the PV system [10].

Another important element of photovoltaic system is the battery, when the temperature of the battery bank exceeds certain degrees it would affect the life span of the battery, so temperature monitoring and control need to be associated with PV system battery for better performance evaluation. The battery is necessary in such a system because of the fluctuating nature of the output delivered by the PV arrays. Thus, during the hours of sunshine, the PV system feeds directly the load and the excess electrical energy is stored in the battery. During the night, or during a period with low solar radiation, energy is supplied to the load

from the battery. The different state of charge/discharge currents and voltage of the PV storage battery at different operating conditions are needed to estimate the system operational performance, this would prevent the battery from overcharging and also critical deep discharge [10-11].

1.2 Motivation and Significance of the Study

The primary motivation behind taking up this research work was to provide a general background on photovoltaic monitoring system, discuss the various function requirements that one common to most PV monitoring system applications and developed personal computer based multi-channel PV monitoring system in order to examine most of the modern hardware and software options available to scientist and engineers.

1.3 Aim

The aim of this research work is to develop a Microcontroller-based Photovoltaic (PV) Monitoring system.

1.4 Objectives

The objectives set down for realization of the aim of the research work are as follows:

1. Develop electronic circuit with sensors that will interface the meteorological parameter with microcontroller to obtain the PV system meteorological and electrical parameters after every 5 minutes.
2. Develop a microcontroller program for the monitoring operation of the PV system.

3. Develop a program in PC to display the parameters obtained along with the time of observation, and to store the data obtained for a future use.

1.5 Methodology

1. In this research work, the photovoltaic system meteorological and electrical parameters can be obtained using electronic sensors and developed circuit. A simple voltage divider circuit is used to measure the PV system battery voltage, LTC6101 current sensor to obtain the load current of the PV battery. The PV system panel and battery temperature is measured using LM35 sensor and the panel irradiance is obtained with the aid of light dependant resistor which would be placed at the edge of the PV system panel. The humidity of the PV system is measured, using DTH11 sensor. All the developed circuit and sensors were interfaced with the microcontroller through Arduino board. Therefore, the obtained signals from the sensors are transferred to the microcontroller.
2. For the monitoring operation of the developed PV system, Atmega328 microcontroller is used, the program for the microcontroller was written in C language. The developed program is debugged and burnt in to the microcontroller chip in order to perform the intended function. Connection is made between the microcontroller board and the personal computer using universal serial board (USB).
3. LabView program was developed in personal computer using LabView block diagram and control panel window for the real time display of the obtained PV system parameters along with the time of observation. Also another option was provided for viewing the obtained data in the personal computer which is PC serial

monitor. The data storage was done in the personal computer (PC) and electrical erasable programmable read only memory (EEPROM) device, in which the data is saved in note pad document format.

1.6 Scope and Limitations of the Research Work

This research uses Atmega328 microcontroller with Arduino Board. An electronics circuit is developed with sensors which are interfaced with the microcontroller to obtain the PV system parameters (i.e. PV panel temperature, solar radiation intensity, PV battery voltage, temperature, humidity and load current) in real time, display and store in personal computer, a PV panel with battery would be connected next to the developed hardware. PV panels are used to charge a 12V battery, 20V measurement range was selected. The current measurement range was set to 0-30A. The temperature measuring range was set to 0-150°C and 0-100% for relative humidity measurement. As part of limitation in this research work, the developed system cannot alarm the user or isolate load from the photovoltaic system at critical load condition, it only measures and displays the PV panel and battery parameters to the user. Another limitation is that the two program developed for the display in personal computer, both programs cannot be ran at the same time, but only one at a time.

1.7 Dissertation Report Organization

The research report is divided in to five chapters, which deal with different aspects of the dissertation. Chapter one is the introduction, and the second chapter presents the literature review on related works. Chapter three is dedicated to materials and methods employed in the research. Chapter four dealt with results and discussions obtained from the work. Finally, chapter five serves as the conclusion and recommendations to the work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In order to develop an effective yet low cost photovoltaic monitoring system, a number of previous works, which are related to the PV monitoring system, have been reviewed. In addition the fundamental concepts of PV monitoring are presented.

2.2 Review of Fundamental Concepts of PV Monitoring System

Generally the PV system comprises of PV generator which is a set of series-parallel electrically interconnected solar panels. PV panels give the total installed power which is the sum of nominal peak power of each solar panel present in the PV installation. The PV generator is connected to an inverter which is connected to an AC/DC load and/or grid [12].

The schematic PV system diagram is shown in Figure 2.1

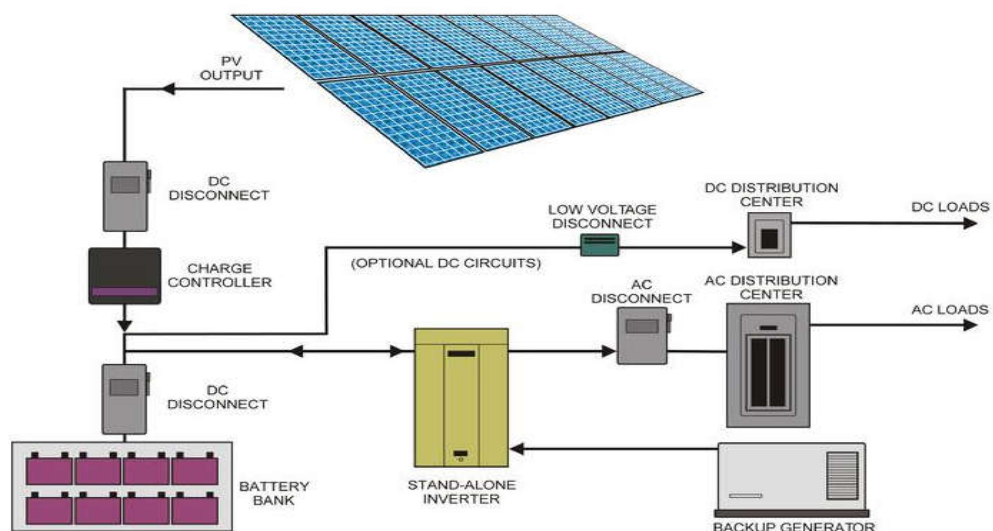


Figure 2.1 Typical Standalone PV Solar System Diagram [10]

There are many reasons for monitoring a system as expensive and long-term as a PV installation. A careful consideration should be given to the purpose behind the monitoring before developing a specification, and the ethos should be to measure only those variables that are necessary, and the minimum frequency required to give meaningful results [13]. The reasons for monitoring PV system fall into three main categories:

- User feedback
- Performance verification
- System evaluation.

2.2.1 User Feedback

This can range from a simple LED on the inverter lid or a user display in a domestic hallway, to a large interactive wall display in the foyer of a corporate building. The common function of all the displays is giving the users an indication that the system is functioning and, the benefits that this brings. A PV system appears, to the uninformed user, as doing nothing at all. A clear display gives much added value to the system, especially if combined with some graphic or text explaining the PV system operation [14].

2.2.2 Performance Verification

A PV system may have been financed on the basis of its electric power output, and so the user needs to measure the output and compare it to the claims for the system [12]. It may also be the case that the electrical power production has to be measured, in order to be sold, or that some ‘green certificates’ may be evaluated. The complexity and expense of such metering is determined by the number and accuracy of the measurements to be made [14].

2.2.3 System Evaluation

For an unusual system it may be worthwhile to measure the detailed operation of the system in order to understand the functioning of its components in detail. This was frequently performed in the 1980s and 1990s when systems were often funded by grants, and the main purpose of building the system was to improve knowledge and understanding. However, these three types of monitoring are not mutually exclusive. A display for user feedback is also necessary in a large system being fully monitored or a system where the output is being measured [13-14].

2.3 Basic Concept of LabView, Microcontroller and Sensors

LabView, microcontroller and sensors are basic tools in development of photovoltaic monitoring system; the LabView is software that contains a comprehensive set of tools for acquiring, analyzing, displaying, and storing data, as well as tools to help you troubleshoot the code you write, the microcontroller serve as central processing unit and sensors are used as means of obtaining the PV system monitoring parameters.

2.3.1 LabView Software

LabView software manages communication between central processing unit and the input/output (I/O) modules. Measurement and automation explorer (MAX) software tool is used for the configuration of data acquisition hardware device and the software. This tool creates tasks, channels, scales, interfaces and virtual instruments. The serial instrument or device includes software utilities and hardware drivers for communication, and also includes the documentation on the stop bits, parity bits, baud rates, and packet size that the

instrument used. In LabView programming, computer processors can execute the code when the graphical icons are joined and wired together, and then directly compiled to machine code. A block diagram functions in the data flow path that actually dictates when and in what order the program will execute. All inputs data must be available at a node for execution, and then it carries out data to its output and supplies to the next node in the path. We also used express voltage and current (VI) that simplifies common programming tasks and algorithm creation [13].

Data acquisition (DAQ) assistant express VI is used on the block diagram and configures it to execute the function. The DAQ assistance express VI prompts to select the channels you want to send and receive data to I/O module and configure parameters like terminal configuration, scales, sample rate, triggering, and synchronization. After completing the configuration, the LabView development environment writes the necessary codes (represented by the express VI) which are actually the task of reading real outer signals into inner files for analysis. In the front panel we configure and customize the control parameters to communicate with serial port and in the block diagram window we connect the blocks for serial connection [15].

2.3.2 Microcontroller

Microcontroller is one of the basic parts of a computer system. Which is much smaller form of a personal computer and mainframe computers; microcontrollers are built from basic elements of the same. Simply put, the computer will produce a specific output based on input received and the program worked. Like most computers, microcontrollers are tools that work on the instructions given to him. That is, the most important part and the principal

of a computerized system is the program itself is created by a programmer. This program instructs the computer to do a long thread of simple actions to perform more complex tasks desired by the programmer [14].

2.3.3 Sensors

In the broadest definition, a sensor is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output. A sensor is a type of transducer; sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple generates a known voltage (the output) in response to its temperature (the environment). A mercury-in-glass thermometer, similarly, converts measured temperature into expansion and contraction of a liquid, which can be read on a calibrated glass tube [15].

Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, besides innumerable applications of which most people are never aware. With advances in micro machinery and easy-to-use micro controller platforms, the uses of sensors have expanded beyond the most traditional fields of temperature, pressure or flow measurement. Applications include manufacturing and machinery, airplanes, aerospace, cars, medicine, and robotics it is also included in our day-to-day life [16].

A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. Some sensors can also affect what they measure; for instance, a room temperature thermometer inserted into a hot cup of liquid cools the liquid

while the liquid heats the thermometer. Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages. Technological progress allows more and more sensors to be manufactured on a microscopic scale micro sensor reach a significantly higher speed and sensitivity compared with macroscopic approaches [15].

Based on the surveyed literature in this research, the main constituents of typical PV monitoring system are categorized into six main aspects, i.e.

- Monitoring parameter
- Data acquisition System
- Data sampling interval
- Sensors
- Controller
- Display

2.4 Monitoring parameter in a Photovoltaic System

In general, a photovoltaic system integrates solar modules, batteries and regulators for the case of stand-alone systems, inverters for the case of grid connection, AC and DC wiring, electrical security devices, and protection devices. International standards set the parameters that must be measured and monitored. Specifically, the IEC61724 standard titled “Photovoltaic system performance monitoring – guidelines for measurement data exchange and analysis” describes the general guidelines for the monitoring and analysis of the

electrical performance of photovoltaic systems [15]. Table 2.1 presents some parameters measured in PV system.

Table 2.1: Fundamental PV System Parameters Measured and Type of Sensors Used [15]

| S/N | Parameters | Sensor Type | Units |
|-----|-------------------------------|-------------------------------|------------------|
| 1. | Ambient Temperature | T-type thermocouple | °C |
| 2. | Battery Bank Temperature | T-type thermocouple | °C |
| 3. | PV Cell Temperature | T-type thermocouple | °C |
| 4. | Horizontal Solar Radiation | 80SPC, Pyranometer | W/m ² |
| 5. | Solar Radiation on the Plane | 80SPC, Pyranometer | W/m ² |
| 6. | Solar PV Array Current | HXS 20-NP Current Transducers | Amperes |
| 7. | Solar PV Array Voltage | Direct to data Logger DT80 | DCVolts |
| 8. | Battery Bank Voltage | Direct to data Logger DT80 | DC Volts |
| 9. | Battery Bank Current In / Out | HXS 20-NP Current Transducers | Amperes |
| 10. | Load Voltage | Direct to data Logger DT80 | DC Volts |
| 11. | Load Current | HXS 20-NP Current Transducers | Amperes |

2.5 Typical Data Acquisition System Functional Requirements

Every data acquisition or logging application, from manually recording weather patterns in the 15th century to logging the experiment parameters of a fusion reactor test in the 21st century, can be broken down into a set of five common functional requirements, illustrated in figure 2.2 below.

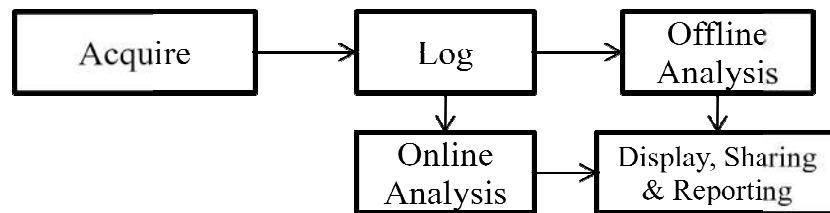


Figure 2.2 Functional Requirement of Data Acquisition System

Acquiring is the process of actually measuring the physical parameters and bringing them into your logging system. Online analysis consists of any processing done to the data while you are acquiring. It includes alarms, data scaling and sometimes control among others

logging or storing, the data is an obvious requirement of every data acquisition system. Offline analysis is everything done with the data after it has been acquired in order to extract useful information from it. The final functional block is made up display, reporting and data sharing. These are all the “miscellaneous” requirements that fill out the functionality of a data acquisition system [15].

2.5.1 Stand Alone PV System Data Acquisition

For a standalone PV system data acquisition are used to obtain the PV system parameters which include meteorological and electrical parameters.

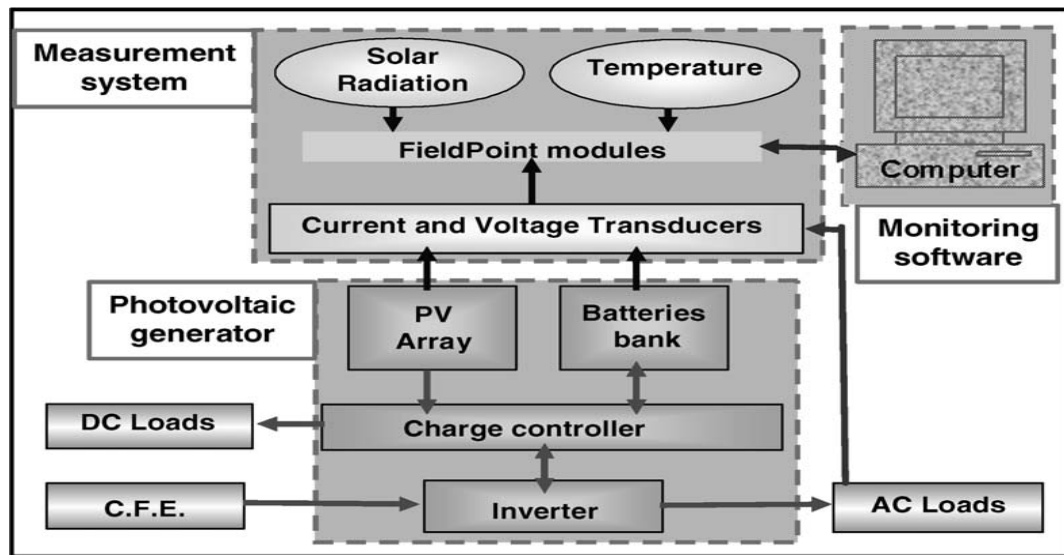


Figure 2.3 Schematic Diagram of Stand Alone PV System Data Acquisition [16]

To obtain PV system parameters using data acquisition systems, the organization of information flow in the system is an important aspect in designing and operating the measurement [16]. The functional components of a basic stand alone PV system data acquisition are shown in Figure 2.3.

- Transducers and sensors;
- Conditioners or circuits standardizing the level of transducer signal to the range of the input voltage of the analog-to digital converter (ADC);
- Analog-to digital converters (ADCs) to convert analog into digital signals.
- Devices for visual display of measurement results (display of digital measurement instruments, oscilloscopes or a computer monitor).
- Computer with dedicated software and memory resources.

Portable data acquisition applications must meet a number of strict requirements that are not present in traditional laboratory systems [16]. These systems are used in harsh environments that must be considered when selecting the type of equipment, such as extreme temperatures, humidity, dust, shock and vibration. For example, in photovoltaic applications, equipment must withstand temperature ranges that vary between -40°C and 85°C for PV modules in the worst case [15-17]. Other concerns include whether this equipment is capable of supporting the mix of the particular sensors that will be used, as well as if there is adequate memory storage to support the test. Invariably, the accuracy of field measurements is highly dependent upon the sensors being used. For most sensors that have been calibrated in the laboratory and installed in the field, their accuracies are in the range of 0.01– 1% of full scale are typical. Signal conditioning, such as gain and filtering, and the data acquisition sampling speed are other important considerations when determining the accuracy of the data acquisition system [18]. Figure 2.1 highlights the basic data acquisition system for PV system.

An automatic Data Acquisition System (DAS) is required for monitoring. The total accuracy of the monitoring system shall be determined by a calibration method such as given in IEC 61724. The monitoring system should be based on commercially available hardware and software which is properly documented with user's manuals and extensive technical support available [18].

2.6 Data Sampling Interval

Different sampling intervals have been used in previous works, ranging from as low as one second or less up to an hour. However, according to IEC61724 standard, sampling interval should be selected based on the parameter recorded [19]. The sampling interval for parameters which have larger time constants, an arbitrary interval may be specified between 1 min. and 15 min. Special consideration for increasing the sampling frequency shall be given to any parameters which may change quickly as a function of system load. All parameters shall be continuously measured during the specified monitoring period [19].

2.7 Sensors

Sensors are electronic devices that are used to obtain physical information and convert into electrical signal. In the typical PV monitoring system electronics sensors are used to obtain parameters that are required for the monitoring system, these parameters which include irradiance, temperature, humidity, voltage and current.

2.7.1 Irradiance Sensing

The in-plane irradiance is measured in the same plane as the photovoltaic array by means of the calibrated reference devices or light dependant resistor. This actually makes use of photo resistor or light dependent resistor (LDR) or photocell. LDR is a resistor whose resistance decreases with increasing incident light intensity; in other words, it exhibits photoconductivity. Solar radiation is partly absorbed, scattered and reflected by molecules, aerosols, water vapor and clouds as it passes through the atmosphere [20].

Another sensor for measuring irradiance is pyranometer, a pyranometer is used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength. The pyranometers are used in meteorology, climatology, climate change research, solar cell research and building engineering physics. They can be installed horizontally in meteorological stations.

The total amount of solar radiation falling on a horizontal surface (i.e. the direct solar beam plus diffuse solar radiation on a horizontal surface) is referred to as global solar radiation. Direct solar radiation is observed from the sunrise to sunset, while global solar radiation is observed in twilight before sunrise and after sunset, despite its diminished intensity at these times. The solar irradiance is expressed in Watts per meter square (W/m^2). Direct sunlight has a luminous efficacy of about 93 lumens per Watt of radiant flux. Bright sunlight provides luminance of approximately 100,000 lumens per square meter at the Earth's surface [21].

The total amount of energy received at ground level from the sun at the zenith is 1004 Watts per square meter, which is composed of 527 Watts of infrared radiation, 445 Watts of visible light, and 32 Watts of ultraviolet radiation. At the top of the atmosphere sunlight is about 30% more intense, with more than three times the fraction of Ultraviolet (UV), with most of the extra UV consisting of biologically-damaging shortwave ultraviolet [20-21].

2.7.2 Temperature Sensing

The ambient PV module temperatures are measured at a location that is representative of the array conditions, using temperature sensors located in the photovoltaic station. The temperature of photovoltaic system can be measured using electronic sensors, such as thermistor or LM35 sensor depending on the need of the design, in which the sensor would be placed at the PV module or PV power bank side [21]. But LM35 sensor is more of use, it has been utilized to measure the temperature of solar energy installation because of its advantage of high precision integrated circuit with output voltage of the sensor that is linearly proportional to the Celsius temperature and it does not require any external calibration. The accuracy of these temperature sensors, including signal conditioning, must be better than 1°C in order to determine the temperature of the reference cell or the reference modules [22].

In some cases, cooling systems are designed to keep the panels within certain temperatures. For example, solar power plants in extremely hot climates may pass a cool liquid behind the panels to remove away heat and keep the panels cool.

Using weather data, including historical temperature and solar irradiation information, engineers can estimate how much energy a PV power plant might generate over its lifetime. Solar panels work best in certain weather conditions, but since the weather is always changing and as engineers are installing solar panels all over the world in different climate regions, most panels do not operate under ideal conditions [23]. That is why it is important for engineers to understand how panels react to different weather conditions. With this knowledge, they can design to improve the efficiency of solar panels that operate in non-optimal conditions.

2.7.3 Humidity Sensing

As far as the efficiency of the solar cell is concerned, efficiency is termed as the amount of the light that can be converted into usable form of electricity. The presence of high humidity on the solar cell of the PV module will lead to decrease in electricity that could be produced at the output of solar module [24]. After observing such a drastic change when it comes to change in humidity level, the required solar panels should be designed in such a way that it could be made to have less effects of humidity level on the power ratings. Different sensors such as digital weather meter, electronic capacitor sensor LM331, STH10 sensor etc are used to measure the relative humidity of the PV system; the sensors are placed at the PV module or power bank side to obtain the humidity of the PV station.

2.7.4 Voltage and Current Sensing

The voltage and current parameters may be either direct current (DC) or alternating current (AC). The accuracy of the voltage and current sensors, including signal conditioning, must

be better than 1% [25]. The AC voltage and current may not need to be monitored in every situation. The two main methods to measure current consist of using shunts or current transducers. The use of shunts is very simple and does not require an extra power supply but does require a high sample rate monitoring for measuring AC [26].

The use of current transducers requires a power supply and can measure both AC and DC [27]. The price for both methods depends on their accuracy and range, which requires an in-depth study to determine the price for each case. Similarly, the voltage transducer or voltage dividers can be used to measure the DC voltage. The cost will be higher for the voltage transducer, but require an accuracy assessment. In the case of AC voltage, voltage transducers are required, unless the data logger is prepared to accept AC signals [28].

2.8 Controller

In every monitoring system, controller plays the vital roles of handling the data, from the sensor to end users. Hence, a proper selection of the controller is of paramount importance. In previous works, monitoring was usually done by using microcontroller or data acquisition card module. Even though data acquisition card or module are more expensive compared to microcontroller, they are easier to program and have been used in many reported systems [29]. For microcontroller, the resolution of the Analog to Digital converter (ADC) is usually an important factor, as it can influence the accuracy of the monitored data.

A microcontroller is a compact stand-alone computer, optimized for control applications. Entire processor, memory and the I/O interfaces are located on a single piece of silicon, it takes less time to read write to external devices [30]. The microcontroller receive acquired

analog signal from the sensors, convert it to digital and transmit this digital signal to serial level converter for serial transmission to the personal computer through serial port and receive using HyperTerminal program for display and logging.

PIC (peripheral Interface Controller) is the IC which was developed to control peripheral devices, alleviating the load from the main CPU. The PIC, like the CPU, has calculation functions and memory, and is controlled by software. However, the memory capacity is low, depending on the kind of PIC. The maximum clock operating frequency is about 20MHz and the memory capacity (to write a program) ranges from 1K to 4K words [29]. The clock frequency determines the speed at which the program is read and an instruction is executed. The through output cannot be judged with the clock frequency alone, it changes with the processor architecture [30].

2.9 Display

To add value to the monitoring system, a PC-based display feature for monitoring is added to the system, this allows users to observe real time data of the monitoring parameters [31]. Program is developed in personal computer for visual display of the collected data, and further analysis such as graphical presentation of the data and data stored for a record purpose [32]. LabView is a software package that provides the functional tools and user interface for data acquisition, LabView plays a vital role in data acquisition process. The real time display of the data is possible with the aid of LabView software and also capable of storing, processing, and displaying the collected data [33]. In most cases, one or more sensors transmit analogue readings to the data acquisition card in the computer. These analogue data are then converted to individual digital values and are made available to

LabView, at which point they can be displayed to the user [34]. Although LabView is capable of some data analysis functions, it is often preferable to export the data to separate sheet for detailed analysis and graphical presentation [35].

2.10 Review of Similar Works

The rapid development of the use of photovoltaic power system over the last decades has resulted in many PV monitoring system being installed throughout the world. However, this effort requires, as a first step, a detailed knowledge of the meteorological data of the PV plant site; as a second step, operational values from similar PV system are necessary to increase the technology reliability.

A microcontroller-based data acquisition system (DAS) in which values of total and diffuse solar radiation intensities are captured by a microcontroller, using an electronic conversion module was present in [36]. The transmission of recorded values to a PC was carried out using a RS-232 serial interface. The data acquisition was achieved by electronic sensors, which are interfaced with the microcontroller. The software operates with a time step of 50 seconds, thereby reading and storing into a data base the total and diffused solar radiation values. The data base was designed to store the values of measured solar radiation intensities and allowed their interrogation via internet. In this manner, the PC also acts as a server computer for distance monitoring.

Research titled “PV-standalone monitoring system performance using LabView” was present in [37]. Two PV panels of 150W rating each were used. Each panel feeds a variable resistive load separately and simultaneously. The constructed LabView engine displayed

environmental parameters and the associated electrical variables (voltage, current and power) on dedicated graph windows continuously in a real time manner. The developed system revealed and stored the pronounced impact of dust, the variation of temperature and the irradiation changes on the PV panel power output behavior.

The PV parameters measured in this work [38], were temperature, humidity and solar radiation. The system was quite accurate with minimum percentage error, but has an obvious limitation in that it does not involve the use of labView software that would provide the tools needed to create and display measurement, so that the inspiration of solving problems and productivity acceleration was minimal. This result to inability of the system to plot the result obtained from the computer memory for further analysis.

The research conducted at United Arab Emirate climate Measurements included global radiation on tilted surface, current and voltage readings of PV panel, module temperature, and ambient temperature [39]. All data acquired from measurements were stored in a personal computer. Experimental results showed that PV module efficiency drops by 3-4% due to high range of PV module temperature (50-60°C). PV module has also been characterized by change in voltage and current. It also showed change in power output due to high ambient temperature on the site.

In the research titled “Monitoring and data analysis of a PV system connected to a grid for home applications” [40] Two PV system were used, one connected to grid and the other one connected to home appliances, the daily performance of the two systems were recorded. Balance and surplus of energy in the systems were observed during dry and summer seasons when high solar radiation was recorded. During the rainy season, with thunderstorms, solar

radiation was low and grid cut-off occasionally occurred. It was found that the battery size of the PV system connected to the grid was reduced by a factor of 0.5 to 0.7 compared to the PV stand-alone counterpart for similar load behaviors.

A similar study in [41] presented a data acquisition system for monitoring photovoltaic (PV) water pumping systems. The data transmission serves to collect field's parameters such as water flow rate, global irradiation on an inclined and horizontal surface, surface voltage and current of photovoltaic field and ambient temperature. Sensors were used in this work to obtain the physical and electrical parameters, various existing techniques were used especially satellite, radio, GSM (global system of mobile communication) and GPRS (general packet radio service). The results were displayed in personal computer (PC) in graphical representation, the collection of plots and interpretation using different combinations of scatter plots and time series plot were obtained.

A microcontroller-based DAS for the characterization of PV modules under real meteorological test conditions was present in [42]. The DAS communication channel is a TTL/RS-232 transceiver that permits the serial interfacing between a microcontroller with Transistor-Transistor Logic (TTL) voltage levels and a computer (RS-232 voltage levels). The basic element of the DAS hardware is an electronic load based on MOSFET. The microcontroller was the central element of the designed DAS card, executing the electronic load variation, the analog-digital conversion from the solar irradiance, the communication with the 1-Wire temperature sensor and the data transmission to and from the computer via RS-232 interface. By using different buttons on a computer graphical interface, it was possible to visualize the results of the module characterization.

In [43] a microcontroller-based data acquisition system was used on a remote PV plant. The measurement system used a silicon-cell pyranometer as a solar radiation sensor. From the sensor, data was collected by an internal A/D converter of the microcontroller and stored in a serial I2C EEPROM until uploaded to a portable computer. Keeping the DAS in a low-power mode, which was only interrupted when measurements are to be taken or when a computer is connected to retrieve the stored data, it is possible to minimize the power consumption. An on-chip timer provided a way to change operational conditions, where by changing the low-power wait mode at 10-min intervals to sample and store the data. At the end of each data collection period, the acquired data was transmitted to the computer through a RS-232 serial interface.

In [44] a data acquisition system applied to a PV plant that was capable of delivering 5kW of electrical power was described. Temperature, irradiance, array voltage and current data are acquired, processed and then transmitted. The system comprised of sensors, DAS, wireless access point and computer, enabling users to access the array parameters via a wireless connection. Three current sensors with a maximum current value of 50A and a sensitivity of 37.8 mV/A, were connected to the dc array output, while irradiance and temperature sensors are placed around the array. For voltage acquisition, a voltage divider was used, which gave 10 mV for every one volt of solar panel output. LM35 temperature sensor with sensitivity of 10mV/°C was used to measure the ambient temperature of the solar panel. The irradiance was sensed using LDR. The microcontroller serial interface is connected to an EGSR7150 modem in order to convert format data from serial to Ethernet data. Furthermore, the acquired data was also sent to the access point of the connected user computer in the form of a Wi-fi signal.

In [45] a set of sensors was used for measuring both meteorological data and electrical parameters (i.e. temperature, humidity, voltage and current) of the photovoltaic system. The collected data were first conditioned using precision electronic circuits and then interfaced to a PC using a data acquisition card. The LabView program was used to further process, display and store the collected data in the PC disk. The system operator can easily process the measured parameters using any LabView build-in function available. This system has advantages of rapid development and flexibility in the case of changes, while it can be easily extended for controlling the renewable energy system operation.

In [46] the data was recorded in first shift encoded binary format one track of audio cassette (CC-1). In this way one C90 tape was able to record 21 data channels with 8 bit precision continuously for more than 7 days with a channel sampling interval of approximately 101s. In some ways the philosophy of the system is similar to that of multichannel strip chart recorder in that the data was recorded continuously and all the data was stored without pre-selection. The obvious advantage of over strip chart recorder is that the data may be quickly transferred into a computer. The advantage of recording without pre-selection is the availability of information for an unforeseen diagnostic need, as it happens in the event of component failure in the device being monitored. While the system described is less flexible than commercially produced loggers, the marginal cost is comparatively low. Such a system is advantageous when the initial development can be spread over a number of loggers.

The implementation of a web-based wireless monitoring system for grid-connected PV converter was presented in this work [47]. Solar radiation, temperature, PV voltage and current, grid voltage and grid current were obtained using data acquisition methods which

consist of different electronics sensors. Besides having data acquisition and control function which can monitor the system remotely, the system was also equipped with web-based function which made it accessible at any place and any time via the internet. Implementation result shows that the system was able to function with good performance. The recommendations made in this work are; firstly the data obtained from the monitoring is useful for future reference to determine the efficiency and stability of the PV system as it may reduce over time. Secondly, the data collected can also be used for fault detection. Thirdly, faulty notification to user by using messaging system may be added to the developed system to improve the robustness of the system.

A research work on PV solar system using a novel procedure based on virtual instrumentation was presented in [48]. The measurements and processing of the data were made using high precision I/O modular field point (FP) devices as hardware, a data acquisition board (PCI6023E) as software and the package of graphic programming, LabView. The system was able to store and display the values of current and voltage, and simultaneously trace characteristics (current-voltage, power-voltage, power-charge resistance), present the measured parameters (during the data acquisition) in Tables, continuous acquisition and save data into files for future processing. The equipment was capable of real time signal measurement, giving information about the performance of the PV power plant, as well as of the energy quality generated by it. This new system boasts of high accuracy measurements coupled with the commercial viability of low cost. The result obtained the best fitting results using the Levenberg-Marquardt algorithm for a robust non liner least squares method with bisquare weights.

In [49] the system consists of data acquisition system, Zigbee and RS-232 communication modules and computer that permit user to collect data wirelessly. 8-bit 40-pin Atmel AT89C51 type microcontroller was used. After collecting data wireless communication module Zigbee and serial communication module RS232 were used to transmit collected data to user computer. The data acquisition system consists of a microcontroller AT89C51 and some of its peripheral equipments as ADC analog to digital converter ADC0831, LCD (Liquid Crystal Display), and some communication modules as Zigbee and RS-232. Zigbee allows system transmission of data wirelessly. Compared to other implementations, this model uses less energy and meets the goal of data acquisition system that is high speed, and real time calculation.

In [50] a set of sensors were installed to monitor the electric current and voltage of the energy generated by the PV system, the energy stored and the energy used by the loads that may be connected to the system. Other parameters like solar radiations and temperatures of the photovoltaic module were monitored. Interface provides information on PV plant operation, displayed as digital values, slide bars and graphs. Finally, a measurement and communication hardware was installed to interface the system developed with a conventional computer. A PC-microcontroller interface based software and hardware was implemented as a wired monitor and control of PV system. In this way, the performance of the overall system in real rural conditions could be evaluated efficiently. The experimental results showed that the logical operation of the proposed system is straightforward and the results are obvious, and clear.

Five parameters extraction mainly based on outdoor measurements is present in [51]. The model was able to describe the I-V and P-V characteristic of a photovoltaic module for any operating condition of temperature and solar irradiance, single diode model was used and it gave their values at reference and real condition. These values are then used within the model to calculate the five parameters, using MATLAB software. The open circuit I-V and P-V curves, obtained from the simulation of the PV module designed in MATLAB environment explains in details its dependence on the irradiation levels. The results obtained from the MATLAB model showed excellent correspondence to manufacturer's published curves; the consistency between the data and the parameters given by manufacturers (Current, Voltage and Power) was good. This work provides a clear and concise understanding of the I-V and P-V characteristics of PV module, which will serve as the model for researchers in the field of PV modeling.

Based on the related researches reviewed above, the research gaps identified are; most of the PV monitoring parameters measured in these researches are temperature, light intensity or PV voltage/current. Also in the above researches low emphasis was paid on the PV battery side which is the back bone of the PV system, other limitations identified are related to real time display, data storage and power consumption.

2.11 General Trends in PV Monitoring System

Different technologies and mechanisms for PV monitoring exist, which depend on the availability of materials, method and needs of the researcher. In order to have a comprehensive understanding of PV monitoring system, Table 2.2 highlights the techniques/mechanisms employed by researchers in PV monitoring system.

Table 2.2 Summary of Techniques and Mechanisms for PV Monitoring

| Wok done by | Data transfer mechanism | PV system type | Controller | Monitoring parameters | Monitoring method | Software used |
|--------------------------------------|-------------------------|-----------------|---------------|--|-------------------|-------------------|
| Carrington <i>et al.</i> , (1981) | DAQ Card | Stand alone | Not mentioned | temperature, air-heat pump | C90 tape | Not mentioned |
| Sopitan <i>et al.</i> , (2001) | Wire:RS232 | Grid-connected | DAQ Unit | current, voltage & power | PC | MATLAB/LabView |
| Al-Moham'd <i>et al.</i> , (2002) | DAQ Card | Stand alone | PIC8052 | temp., pressure, humidity wind speed | PC | C++ Language |
| Aissa <i>et al.</i> , (2004) | Wire:RS232 | Stand alone | DAQ | temp., irradiance, voltage & current | PC | LabView |
| Andrei <i>et al.</i> , (2007) | TTL:RS232 | Stand alone | PIC16F877a | temperature & irradiance | PC | GUI/Labview |
| Rosiek, & Batlles (2008) | Wireless/GSM | Weather station | Atmega16 | temperature, humidity & irradiance | Web | LabView |
| Laurentin <i>et al.</i> , (2009) | Wire:RS232 | Stand alone | Atmega128 | temperature & irradiance | PC | C++ /Visual Basic |
| Avishet <i>et al.</i> , (2009) | Wire | Stand alone | Not mentioned | temp., irradiance, voltage & current | PC | LabView |
| Berberkis <i>et al.</i> , (2010) | Wire:RS232 | Stand alone | PIC16F690 | temperature, voltage & current | PC | LabView |
| Zahran <i>et al.</i> , (2010) | Wire/Wireless | PV power plant | ATMRGA16 | temp., irradiance, voltage & current | Web | LabView/Sever |
| Sadro <i>et al.</i> , (2011) | RS232/GSM | Stand alone | PIC16F877 | temperature & irradiance | PC | LabView |
| Fabrizio <i>et al.</i> , (2012) | RS232 | Stand alone | Atmega9323 | temperature, humidity & irradiance | PC | LabView |
| Ibrahim & Munaf (2012) | Wireless | Greenhouse | PIC16F877a | temp., irradiance, voltage & current | Web | Not mentioned |
| Chour <i>et al.</i> , (2012) | Wire | Stand alone | Not mentioned | temp., irradiance, voltage & current | PC | LabView |
| Mahjoubi <i>et al.</i> , (2012) | Wireless | Stand alone | Atmega128 | temp., irradiance, voltage & current | Web | Not mentioned |
| Kautroulis <i>et al.</i> , (2013) | DAQ Card | Stand alone | PIC16F877 | temp., humidity, voltage & current | PC | LabView |
| Kapil <i>et al.</i> , (2013) | Wire/USB | Stand alone | Not mentioned | temp., irradiance, voltage & current | PC | LabView |
| Ike, (2013) | RS232 | Stand alone | Atmega16 | temperature, voltage, current & power | PC | Not mentioned |
| Pietruszko <i>et al.</i> , (2013) | Wire | Grid-connected | PIC16023E | temp., irradiance, voltage, current | PC | Not mentioned |
| Chokri <i>et al.</i> , (2013) | RS232 | Stand alone | Not mentioned | temp., humidity, irradiance, voltage & current | PC | LabView |
| Maheshwari <i>et al.</i> , (2013) | Wire:RS232 | Weather station | PIC89C51 | temp., irradiance, voltage & current | PC | Not mentioned |
| Bala <i>et al.</i> , (2013) | USB-6009 | Stand alone | Not mentioned | voltage and current | PC | LabView |
| Zaran <i>et al.</i> , (2013) | Wire:RS232 | Stand alone | Atmega16 | temp., irradiance, voltage & current | PC | GUI/LabView |
| Parashar <i>et al.</i> , (2014) | RS232 | Grid-connected | AT89C51 | voltage and current | PC | Visual Basic |
| Fuentes <i>et al.</i> , (2014) | RS232 | Remote PV plant | PIC16F8677 | irradiance and temperature | PC | LabView |
| Guizhong <i>et al.</i> , (2014) | DAQ Card | Stand alone | PIC1716L | temp., irradiance, voltage & current | PC | Labwindow/CVI |
| Trillo-Mentro <i>et al.</i> , (2014) | Wire | Grid-connected | RDMS | irradiance and temperature | PC | S-Lar Software |
| Sharif, (2015) | Wireless | Grid-connected | Atmega16 | temp., irradiance, voltage & current | Web | LabView |

In the research reviewed in table 1 above, the main constituent characteristics of a typical PV monitoring system developed by different researchers are categorized into; the type of the PV system, monitoring parameters, monitoring software, controller and data acquisition mechanisms. The PV system can be a grid-connected or stand alone, for the grid-connected PV system comprises of PV panel, a DC/AC converter that capably connected to the grid, this system is used for power generation in places or sites accessed by the electric utility grid while the stand alone PV system is not connected to a grid, is only supplying a specific electrical load [36]. Different parameters are monitored in PV system such as temperature, irradiance, voltage and current etc. In PV monitoring system, the software used for data analysis, processing and display is another key aspect of PV monitoring. The LabView software creates tasks, channels, scales, interfaces and virtual instruments, when the graphical icons are joined and wired together, and then directly compiled to machine code [23]. But in Visual basic software, an event driven language with an integrated development environment allow it to perform some special functionality as rapid application development of graphical user interface and data base access etc. MATLAB software is used in PV monitoring but this requires mathematical model expirations and assumptions [10].

Microcontroller are used as central processing unit in developments of PV monitoring system; Atmega and Arduino have advantages of the possibility of changing the number of sensors and also have analog and digital I/O pins [44]. The PIC16F877 family is more popular due to their low cost, wide availability, free development tools and reprogramming (serial programming) in flash memory. The original PIC was built with 16 bit CPU and the CP1600. The CPU was good, but CP1600 has poor I/O performance [2]. To obtain PV system parameters, sensors are interfaced with microcontroller and this has an advantage of

low cost and easy access to information in remote area, but in the data acquisition card (DAQ), it's feature is unique in circuit design and functions for data acquisition and control, including 16-channel analog and digital input, and 16-channel digital output, which meets the monitoring system requirement.

2.12 Future Research Trends in the Subject Area

In future research in photovoltaic monitoring system would be to obtain both the PV panel and PV battery metrological and electrical parameters wirelessly and provide a user-friendly Web interface to download, browse, share, and organize data. In addition, this will provide a Web service application layer to be used to develop customized Web pages for presenting PV power system information to computer users with advantages of low-cost and low power consumption. A faulty notification to user by using messaging system may be added to the developed system to improve the robustness of the PV system not only by monitoring but, to also allow the user to take precautions before any disaster. Also monitoring the state of PV battery charging, discharging and equalization, would increase the efficiency of the PV monitoring system.

In this research work, it aims to develop a microcontroller based photovoltaic monitoring system, which is portable, flexible and low-power consumption, multi-channel that would obtain up to six PV system parameters (irradiance, temperature of the PV panel, humidity, temperature, voltage and load current of the PV battery bank) with real time display of the obtained data in the PC (personal computer) by the use Arduino program and LabView software.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Introduction

This chapter discusses the methods and materials used in this research. Different methods, techniques and materials used for the achievement of this work are presented in this chapter.

3.2 Model Equation of the PV System

To develop an accurate equivalent circuit for a PV cell, it is necessary to understand the physical configuration of the elements of the cell as well as the electrical characteristics of each element. The ideal equivalent circuit of a PV cell is a current source in parallel with a single-diode is shown in figure 3.1.

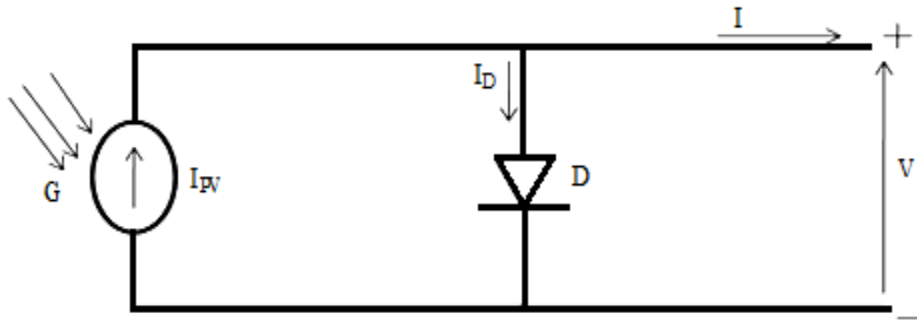


Fig 3.1 PV Cell Model with Single-Diode

The equation for the output current is given by:

$$I_{PV} - I_D$$

Where

$$I_D = I_0 \exp\left(\frac{V}{V_A V_r}\right) - 1 \quad (3.1)$$

Then equation (1) becomes

$$I_{PV} - I_0 \exp\left(\frac{V}{V_A V_r}\right) - 1 \quad (3.2)$$

I_{PV} is the current generated by the incidence of light and I_0 is the diode reverse bias saturation current;

$V_T = \frac{kT}{q}$ is the thermal voltage of a PV module having N_s cells connected in series; q is the electron charge; k is the Boltzmann constant; T is the temperature of the p-n junction and A the diode ideality factor.

A PV cell can at least be characterized by the short circuit current (I_{SC}); the open circuit voltage (V_{OC}) and the ideality factor A . The output of current source is directly proportional to the light falling on the cell. The short current is given as,

$$V = 0, I_{SC} = I = I_{PV} \quad (3.3)$$

Likewise, for the same irradiance and p-n junction temperature conditions, the open circuit voltage (V_{OC}) is the greatest value of the voltage at the cell terminals and it can be written as:

$$V_{OC} = A \times V_T \ln \left(\frac{I_{SC}}{I_0} + 1 \right) \quad (3.4)$$

And at the same conditions, the output power is given by:

$$I_{SC} - I_0 \exp \left(\frac{VA}{V_T} - 1 \right) \quad (3.5)$$

More accuracy and complexity can be introduced in to the model by adding a series resistance in the circuit, from equation of current through the junction resulting:

$$I_0 \exp \left(\frac{V + IR_s}{V_T} \right) - I_{SC} = I \quad (3.6)$$

In the absence of illumination of the cell, is obtained:

$$-I = -I_0 \exp \left(\frac{V + IR_s}{V_T} \right) - 1 \quad (3.7)$$

This justifies the name given to the current I_d of "dark current" of photocell. Short-circuit current I_s , respectively no-load voltage V_{OC} of a cell are dependent on the level of illumination. For a given incident radiant power P_r , electrical power transferred to load R of a photocell is:

$$I = I_0 \exp\left(\frac{V - V_r}{V_t}\right) - I_s \quad (3.8)$$

The condition of zero derivatives for the power at maximum power point equation can be mathematically expressed as

$$\frac{\partial P}{\partial V} \Big|_{(I_{mp}, V_{mp})} = 0 \quad (3.9)$$

Using the above condition in equation (3.2), introducing (3.4) and (3.6) and then simplifying the equation, the transfer function of equation (3.7) can be expressed as:

$$\frac{I_{mp} V_{mp}}{I_0 V_t} \left[\frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} + \frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} \right] = 0 \quad (3.10)$$

Therefore, the transfer function becomes,

$$\frac{I_{mp} V_{mp}}{I_0 V_t} \left[\frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} + \frac{I_{mp} V_{mp}}{I_0 V_t} \right] = 0 \quad (3.11)$$

$$\frac{I_{mp} V_{mp}}{I_0 V_t} = \frac{I_{mp} V_{mp}}{I_0 V_t} + \frac{I_{mp} V_{mp}}{I_0 V_t}, \quad \frac{I_{mp} V_{mp}}{I_0 V_t} = \frac{I_{mp} V_{mp}}{I_0 V_t} \frac{I_{mp} V_{mp}}{I_0 V_t} \text{ and } A = \frac{I_{mp} V_{mp}}{I_0 V_t} + \frac{I_{mp} V_{mp}}{I_0 V_t}$$

The state space representation of equation (3.8) can be expressed as:

$$\dot{\theta} = \frac{I_{mp} V_{mp}}{I_0 V_t} + \frac{I_{mp} V_{mp}}{I_0 V_t} \frac{I_{mp} V_{mp}}{I_0 V_t} - \frac{I_{mp} V_{mp}}{I_0 V_t} \theta \quad (3.12)$$

Also, the maximum value of this power is obtained at a point M of the current-voltage

$\frac{\partial P}{\partial V} = 0$, are given by the equations:

$$P_{out} = P_{in} - P_{loss} + P_{generation} = P_{in} + P_{generation} - P_{loss} \quad (3.13)$$

In the conditions of maximum electrical power generated on the terminal, P_M the conversion efficiency is:

$$PMP_r \quad (3.14)$$

Therefore, equation (3.10) serves as the model for the developed system.

3.3 Block Diagram of the System

The block diagram and signal flow of the developed PV monitoring system is presented in figure 3.2, the developed circuit with sensors obtain the PV system parameters, i.e., PV panel temperature and battery temperature, battery humidity, PV panel solar radiation intensity and electrical parameters (i.e., current and voltage) of the PV battery. A crucially important component is a program that provides the appropriate set of instructions for the microcontroller to perform the desired task, the obtained data were sent to personal computer for display and storage. Finally, the developed physical model would be connected to the PV system to monitor the PV panel and battery meteorological and electrical parameters of the system.

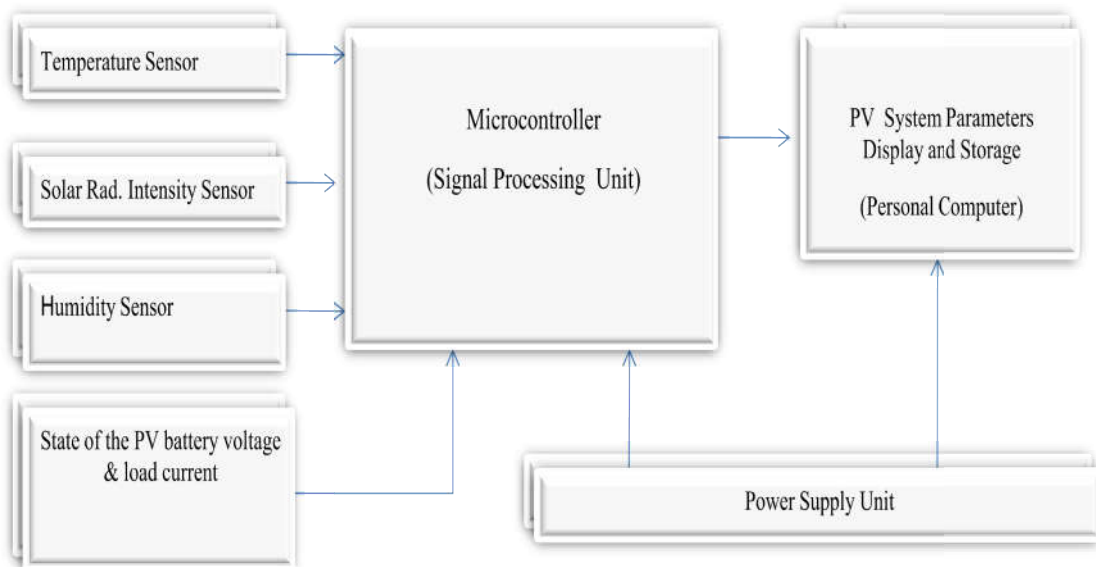


Figure 3.2 Schematic Structure of Microcontroller-Based Photovoltaic Monitoring System

3.3.1 Microcontroller Unit

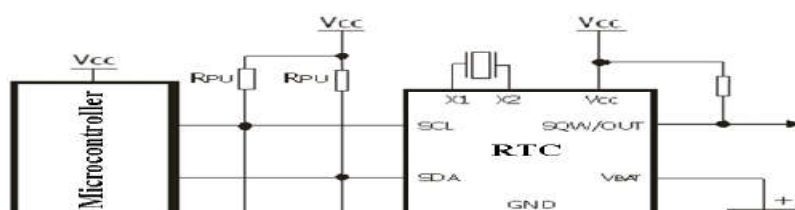
In terms of controller requirement, the system requires a single chip microcontroller with adequate ADC port and equipped with sufficient ADC resolutions for accurate readings. Furthermore, the chosen microcontroller must have adequate processor speed to process data within some seconds. For this work Atmega328 microcontroller chip with Arduino board is chosen, as it satisfies all the above requirements while being of low-cost. The Atmega328 microcontroller board has the following features:

- High-performance, Low-power AVR 8-bit Microcontroller
- Advanced RISC Architecture
- High Endurance Non-volatile Memory segments
- 32 Programmable I/O Lines
- DC Current per I/O Pin 20mA
- 0 - 16 MHz for Atmega16
- Two 8-bit Timer/Counters and One 16-bit Timer/Counter.
- Real Time Counter with Separate Oscillator
- Four PWM Channels
- 8-channel, 10-bit ADC
- Byte-oriented Two-wire Serial Interface

- Programmable Serial USART
- Master/Slave SPI Serial Interface
- On-chip Analog Comparator
- External and Internal Interrupt Sources
- Operating Voltage 5V
- Input Voltage (recommended) 7-12V
- Input Voltage (limit) 6-20V
- Low Power Consumption.
- Length 68.6mm
- Width 53.4mm
- Weight 25g

All these features make the microcontroller board very suitable and high performance solution for the monitoring system.

Most microcontroller models have internal EEPROM, with a memory capacity of 256 bytes. The internal EEPROM is adequate for storing initialization parameters or retaining measured values during an operational sensing. Thus, a critical factor associated with data acquisition, is the microcontroller internal memory capacity. To overcome this limitation, a 16GB external EEPROM memory is included in the present system. In the developed system, an option was made for an EEPROM model which provides large storage capacity and a real time clock RTC that is a low cost clock/calendar referenced by an external crystal at a frequency of 32.768 Hz. The connection scheme between devices using the Inter-integrated interface is shown in Figure 3.3



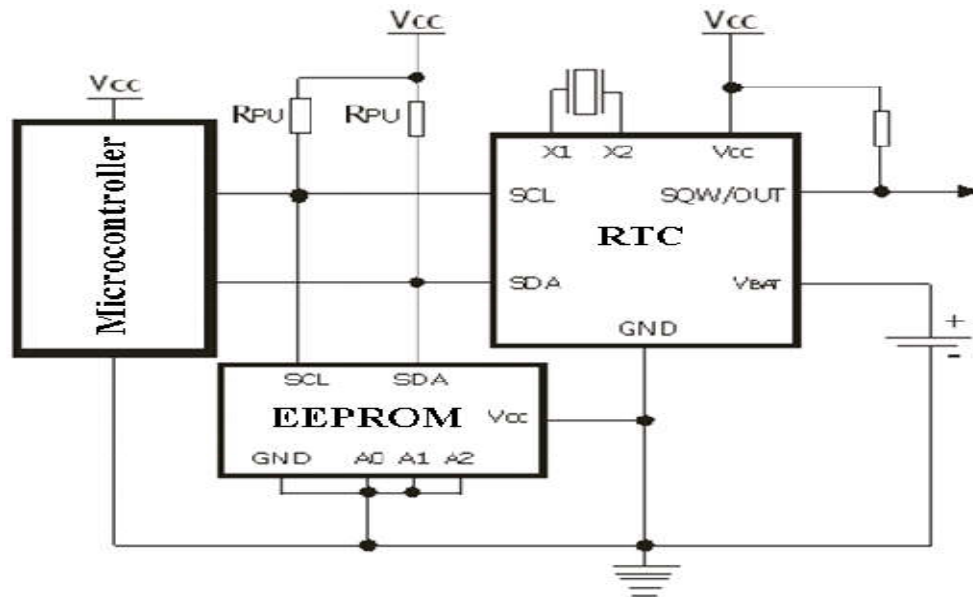


Figure 3.3 Connection Scheme between Devices Using the Inter-Integrated Circuit

The inter-integrated circuit (I^2C) bus is designed with the goal of connecting integrated circuits and peripheral devices from different manufacturers on the same circuit using two pins. Microcontrollers, memories and external RTC can be included within the context of this device.

3.3.2 PV Panel Temperature Sensing Unit

The temperature of the PV panel is obtained by the use of electronic sensor LM35, which was placed at the edge of the panel. The sensor provides the measured temperature ($^{\circ}C$) output, and sensor communicates with a host microcontroller over a 1-wire bus. The LM35 thus has an advantage over linear temperature sensors calibrated in $^{\circ}Kelvin$, as the user is not required to subtract a large constant voltage from its output to obtain convenient

Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of $\pm 1/4^\circ\text{C}$ at room temperature and $\pm 3/4^\circ\text{C}$ over a full -55 to $+150^\circ\text{C}$ temperature range.

But others sensors like t-type thermocouple is a junction formed from two dissimilar metals, a temperature difference will cause a voltage to be developed that is temperature dependent, (that voltage is caused by something called the Seebeck effect). Thermocouples are widely used for temperature measurement because they are rugged and reliable, and they can be used over a wide temperature ranging -269°C to $+1260^\circ\text{C}$. However, this thermocouple sometimes malfunctions in atmosphere with very low temperature.

The equation 3.1 shows the relationship between temperatures of the PV panel is given as.

$$T_c = [\text{NOCT} - T_{cn}] G + T_a \quad (3.15)$$

Where, T_a is the ambient temperature and NOCT is normal operating cell temperature of PV panel and is usually between $43-47^\circ\text{C}$. T_{nc} is the nominal cell temperature and is normally about 298 K and T_c is the cell actual temperature.

3.3.3 PV Panel Irradiance Sensing Unit

To obtain data for solar radiation intensity, a light dependant resistor (LDR) is placed on the PV panel side edge. A light dependent resistor (LDR), photoconductor, photo resistor, or photocell is a component used commonly in electronics which has a resistance that decreases as the intensity of the light hitting its surface increases, and vice versa.

A photo resistor is made of a high resistance semiconductor. In the dark, a photo resistor can have a resistance as high as several mega-ohms (MΩ), while in the light; a photo resistor can have a resistance as low as a few hundred ohms. If incident light on a photo resistor exceeds a certain frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electrons conduct electricity, thereby lowering resistance. The resistance range and sensitivity of a photo resistor can substantially differ among dissimilar devices and the solar irradiance is expressed in watts per meter (W/m²).

The relationship of solar radiation intensity with PV system panel, taking into account the characterization and parameters of the module, the I-V, P-V and efficiency of the module η may be determined as

$$\eta = V_{ocm} I_{scm} F/G \quad (3.16)$$

Where, V_{ocm} and I_{scm} are the open circuit voltage and short circuit current of the module. G is the intensity of solar radiation; F is the fill factor which is approximated to 0.75.

3.3.4 PV Battery Temperature and Humidity Sensing Unit

The temperature and relative humidity of the PV battery site in this research is measured using DHT11 sensor; this sensor would be placed at the battery site. DHT11 temperature and humidity sensor is a composite sensor it contains a calibrated digital signal output of the temperature and humidity. DHT11 uses a simplified single-bus communication.

DHT sensor utilizes exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability. Its sensing elements are connected with 8-bit single-chip computer. This sensor have small size, low consumption and long transmission distance, these enable DHT11 to be suited in all kinds of harsh environment with operating range of 0-100% and accuracy of $\pm 2\%$.

3.3.5 Voltage Sensing Circuit

A simple voltage divider circuit is used in this research to obtain the PV battery voltage, in which it is placed between the positive and negative terminal of the battery. In electronics, a voltage divider (also known as a potential divider) is a linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). Voltage division refers to the partitioning of a voltage among the components of the divider. An example of a voltage divider consists of two resistors in series or a potentiometer. It is commonly used to create a reference voltage, or to get a low voltage signal proportional to the voltage to be measured, and may also be used as a signal attenuator at low frequencies. For direct current and relatively low frequencies, a voltage divider may be sufficiently accurate if made only of resistors; where frequency response over a wide range is required, such as in an oscilloscope probe, the voltage divider may have capacitive elements added to allow compensation for load capacitance. The resistance divider in this work is shown in Figure 3.4

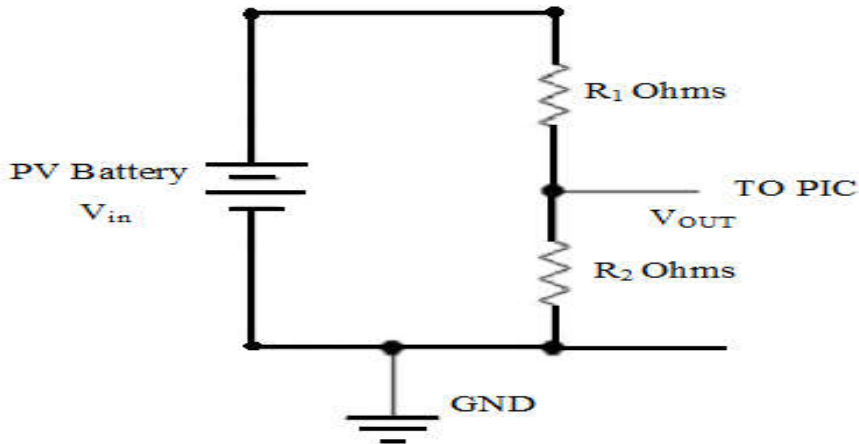


Figure 3.4 Voltage Divider Circuit for PV Battery Voltage Measurement

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in} \quad (3.17)$$

If $R_1 = R_2$ then

$$V_{out} = \frac{1}{2} \times V_{in} \quad (3.18)$$

Between 0 and 1 is possible. That is, using resistors alone it is not possible to either invert the voltage or increase V_{out} above V_{in} .

3.3.6 Current Sensing Circuit

A current sensing circuit is developed to measure the PV battery current as shown in figure 3.5; this circuit comprises of a current sensor LTC6101, limiting resistor and connection to the PV battery terminals. The advantages of the selected current sensor LTC6101 are the excellent accuracy, good linearity, low temperature drift, optimized response time, wide frequency bandwidth, no insertion losses, high immunity to external interferences and current overload capability. The output of this IC chip is connected to the microcontroller for signal processing and PV battery current display.

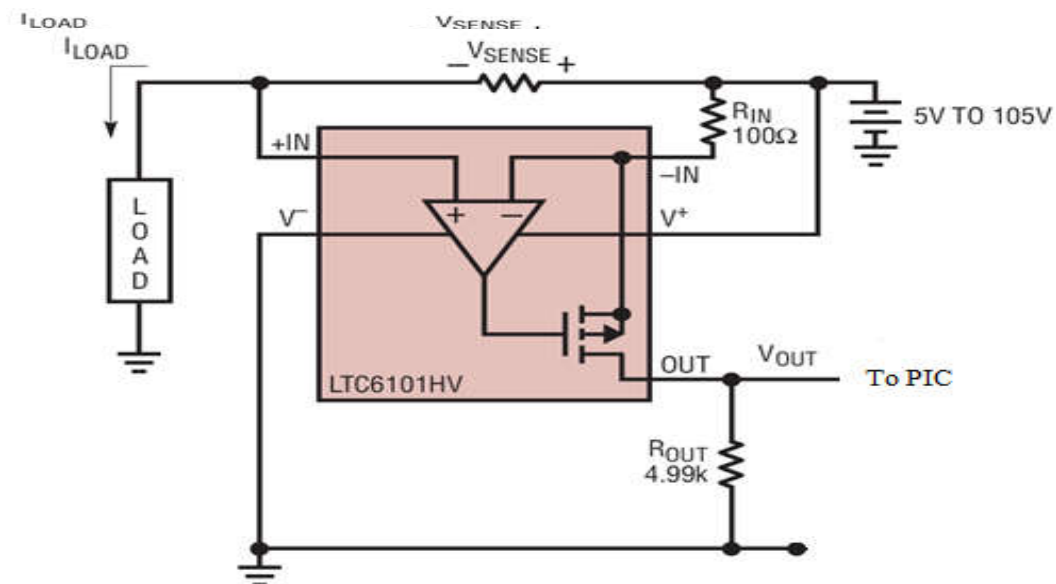


Figure 3.5 Current Sensing Circuits with LTC6101 Current Sensor [52]

$$R_{out} = R_{in} \times V_{in} \quad (3.19)$$

Where V_{out} is voltage which is equivalent to PV battery current

The LTC6101 is versatile, high voltage, high side current sensor. Design flexibility is provided by the excellent device characteristics; 300 μ V Max offset and only 375 μ A (typical at 60V) of current consumption. The wide operating supply range and high accuracy make the LTC6101 ideal for a large array of applications from automotive to industrial and power management. A maximum input sense voltage of 500mV allows a wide range of currents to be monitored. The fast response makes the LTC6101 the perfect choice for load current warnings and shutoff protection control. With very low supply current, the LTC6101 is suitable for power sensitive applications.

3.4 Software Development

There are two software algorithms that are used in this work, the first one; for the microcontroller Arduino program for display in the PC, the second one is LabView program for simulation and display. The integration of these two algorithms provides two ways of viewing the PV system parameters i.e. Arduino serial monitor and LabView environment. The microcontroller program is developed using Arduino package software. This program is written in C/C++ language, the developed system data are collected with the aid of sensors

that are interfaced with the microcontroller unit and transferred to personal computer via a serial/USB cable. The program display format start with displaying the research title flow by the date, time and thus monitoring parameters with units in tabular form, the sample interval is done after every five minute before another reading would be obtained.

In the PC, processing is done on those data for monitoring and data saving for system documentation, the developed program was edited and debugged to ensure that it works as expected in the system before it was burnt in to the microcontroller chip; the complete program is shown in appendix 1. The second program is for the LabView, which was carried out using LabView block diagram; this enables the user to view the incoming data from the sensor in the LabView control panel in the personal computer.

The LabView program, manages communication between CPU and the I/O modules. Measurement & automation explorer (MAX) software tool is used for the configuration of data acquisition hardware device and the software. This tool creates tasks, channels, scales, interfaces and virtual instruments. In LabView programming, computer processors can execute the code when the graphical icons are joined and wired together, and then directly compiled to machine code.

A block diagram functions in the data flow path dictates when and in what order the program will execute. All inputs data must be available at a node for execution, and then it carries out data to its output and supplies to the next node in the path. The developed LabView blocks diagram in Figures (3.6, 3.7, 3.8, 3.9 and 3.10) illustrate the design.

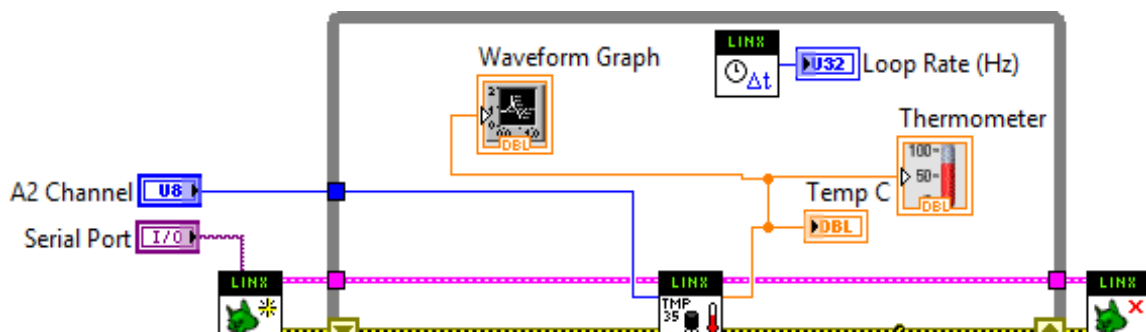
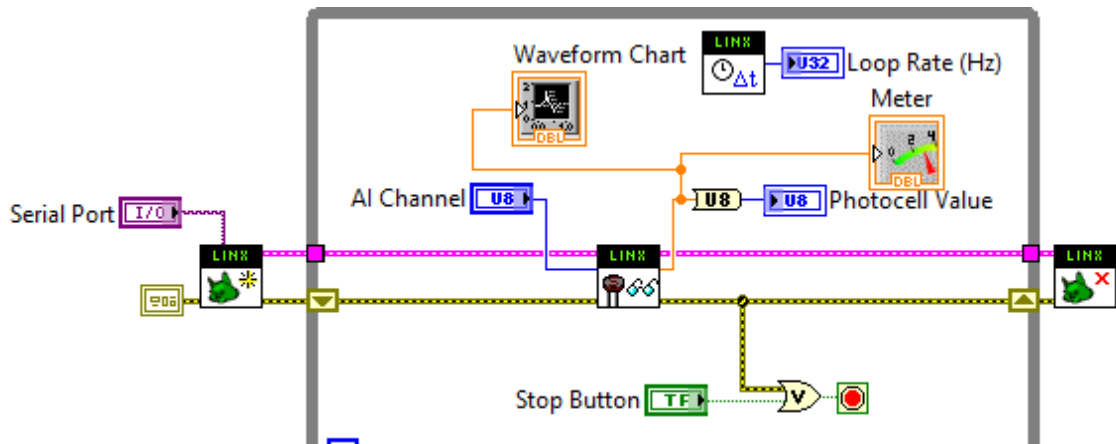


Figure 3.6 PV Panel Temperature Measurement Block Diagram in LabView Program



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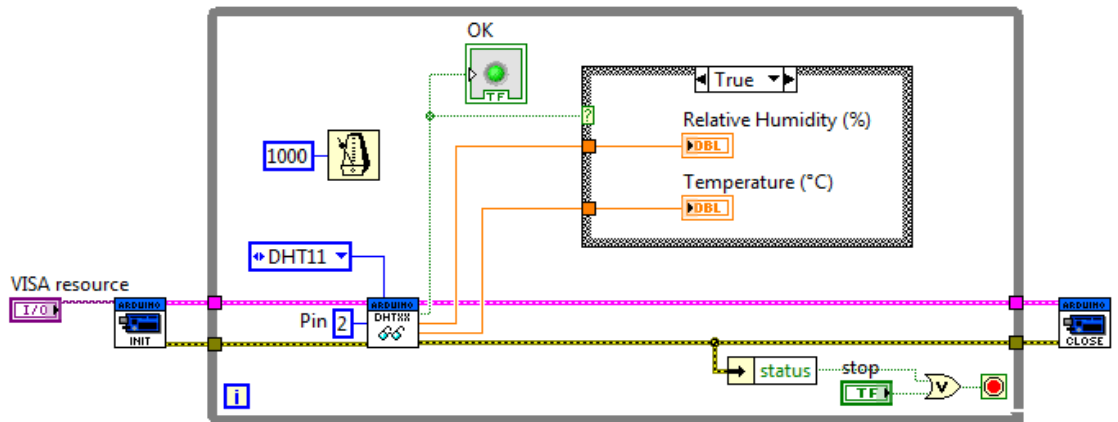


Figure 3.8 PV Battery Temperature and Humidity Measurements in LabView

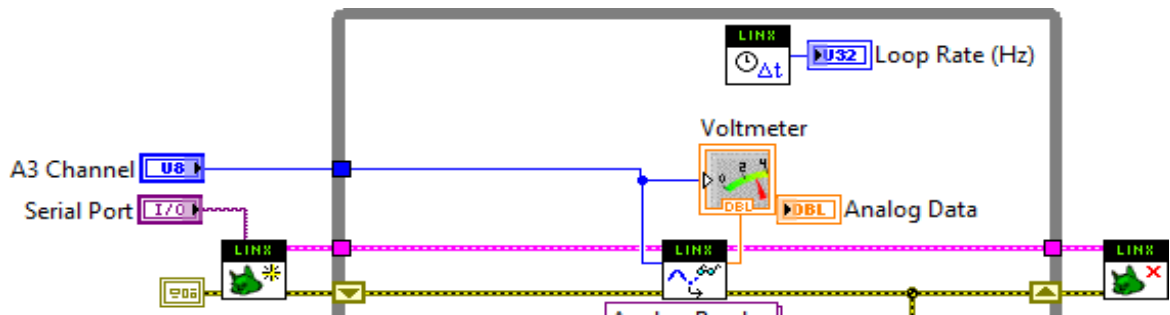


Figure 3.9 PV Battery Voltage Measurement in LabView

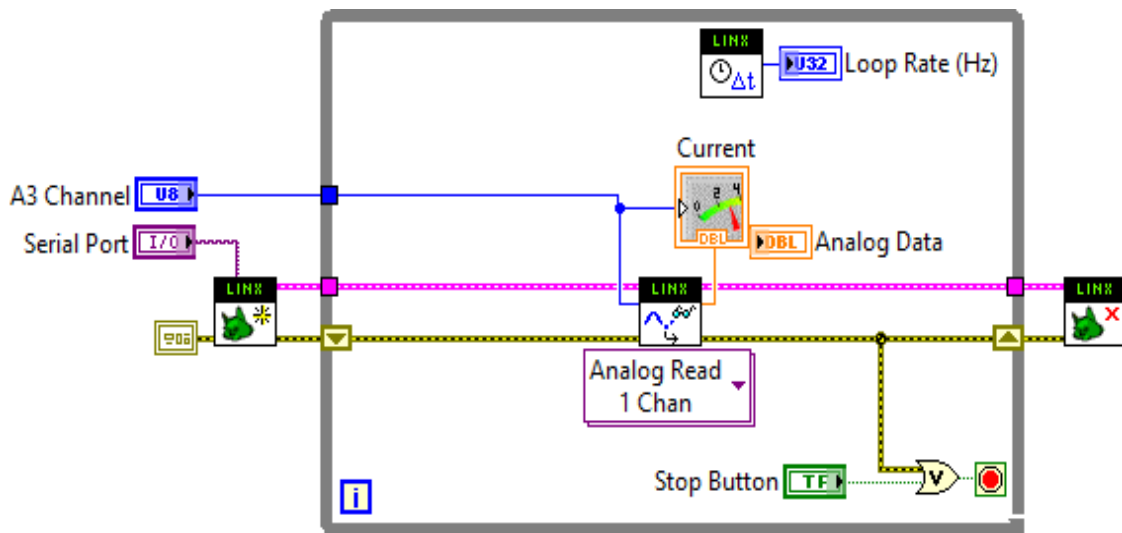


Figure 3.10 PV Battery Current Measurement in LabView

3.4.1 Microcontroller Algorithm Flowchart

The microcontroller functions in the system as a data logger device and a control circuit. The microcontroller is an 8-bit device and works in a very extensive way to collect system data, transfer these data to the computer, and to receive the operation commands from the computer and execute it. It is attached to the analog sensors' via analog multiplexer and collects the sensors data periodically. The flowchart of the PV monitoring system is shown in Fig 3.11

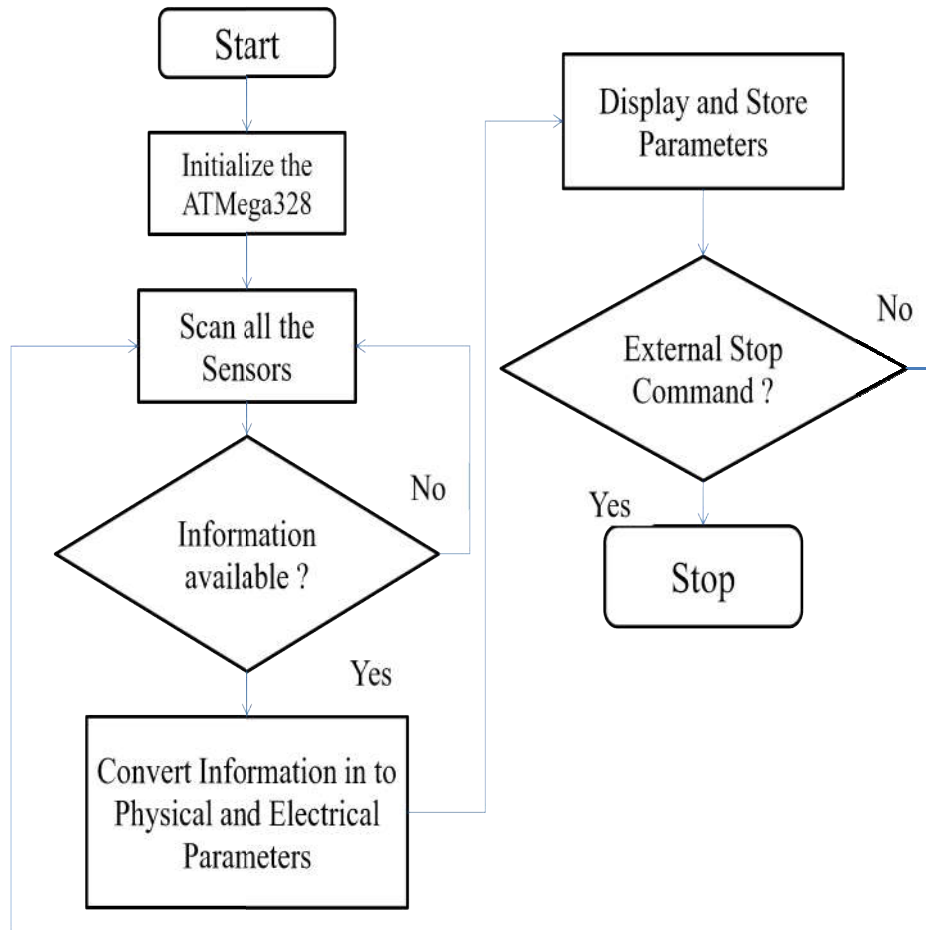


Figure 3.11 Flow Chart Algorithm for PV Monitoring System

The algorithm starts with microcontroller peripheral initialization, then flow by the scanning of the various sensors reading and storing them in its RAM and transmits this data to the computer via the serial interfacing.

3.5 Hardware Implementation

The microcontroller board program was developed to monitor PV system parameters and display in personal computer. The microcontroller stands as the processing unit for the measurement circuitry and constitutes a major part of the monitoring system. It is part of the

hardware circuitry that connects to the PC via a serial port (USB cable). Part of its functions is to read and format the data periodically before getting to the Arduino software in the PC for display.

As part of the functional requirements for the monitoring system, we expect that the software would measure/monitor the following:

- The PV panel ambient temperature.
- The light intensity of the PV panel.
- The PV battery humidity
- The PV battery temperature
- The PV battery voltage
- The PV battery load current

The monitoring circuitry connected to the microcontroller constitutes components that carry out all the necessary measurements and signal conditioning. The voltage measurements are generally carried out using a simple potential divider method through a series of $1k\Omega$ resistors to drop the system voltage level to 5V, an acceptable input to the microcontroller with a design current of about 10mA. Temperature measurement is carried out using a LM35 precision centigrade sensor, being able to give voltage readings from 0°C to beyond 150°C . Light intensity measurement is carried out using a light dependent resistor (LDR) circuitry. Current measurement is carried out using a current sensor and the humidity measurement is carried out using a DTH11 sensor.

The microcontroller board is interfaced to the personal computer via serial interface. The sensors are connected to the microcontroller board. All the interfacing circuits are built in that board to support the system operation.

3.6 PC Interface

Serial Interfacing is actually done via the Rx (D0) and Tx (D1) pins of the microcontroller which by default route through the USB port. Information transferred is understood by the computer and made available on the configured COM port. The RxTx Arduino library enables access of information on the serial port in the Arduino program.

The process of information acquisition is made possible via a serial Port Listener action listener which is triggered each time there is information available on the port. This information is encoded as a string before processing begins. Before information transmission, the microcontroller is able to send multiple readings by making use of a delimiter between each of the readings.

The PC interface is equipped with a tool that allows the user to view data obtained from the sensors in real-time operation. The data would be acquired with respect to time of observation, for greater flexibility in achieving the tests; the data can be further stored in personal computer.

3.7 Power Supply Unit

For this system specification, the developed system was connected to the personal computer; both the sensors and the microcontroller board obtain, their supply from the personal

computer which is 5V D.C, since all the interface circuits are connected to the personal computer using universal serial board (USB). A separate battery source supplies the power required by the chip, hence enables uninterrupted operation in the event of main power source failure.

3.8 Assembling of the Prototype Monitoring System

The developed module was based on the Arduino Uno board, in which all the sensors used are connected directly to this board to acquire the required PV parameters data. The program writing for this operation was debugged and burn in to the microcontroller in this board, others supporting circuit are all connected to the developed system and finally connection was made between the developed system and personal computer using USB for the display. To obtain the PV system battery temperature and humidity the sensors are position at the PV battery side, as shown in Figure 3.13, for the battery voltage and load current connection was made between the developed system and the PV system battery. The temperature and solar radiation intensity sensor are position at the PV panel side as shown in Figure 3.14 to obtain the temperature and irradiance of the PV system panel. Figure 3.12 shows the prototype developed in this research.

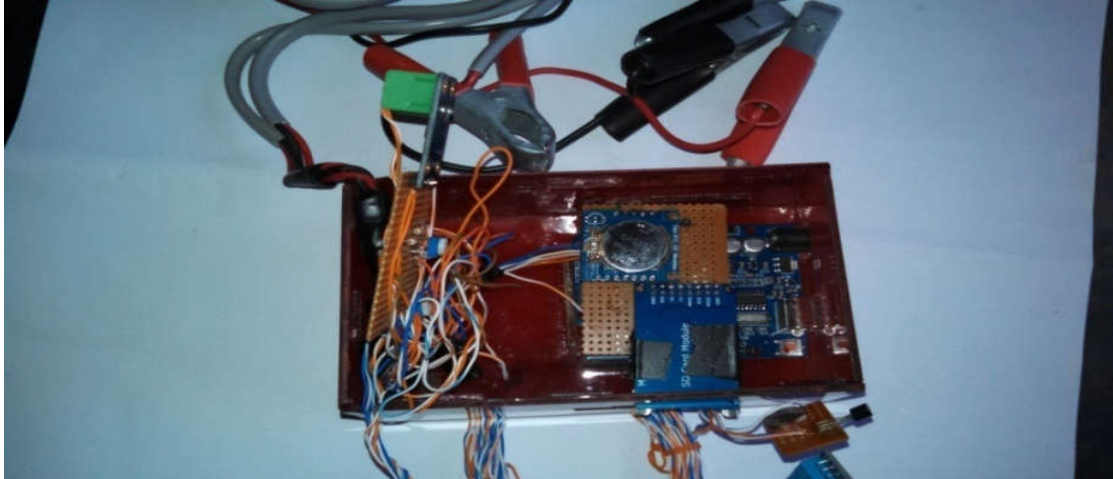


Figure 3.12 Developed PV Monitoring System Prototype Assemble



Figure 3.13 Developed Monitoring System Connected with PV System Power Bank



Figure 3.14 Developed System Connected with PV System Panel

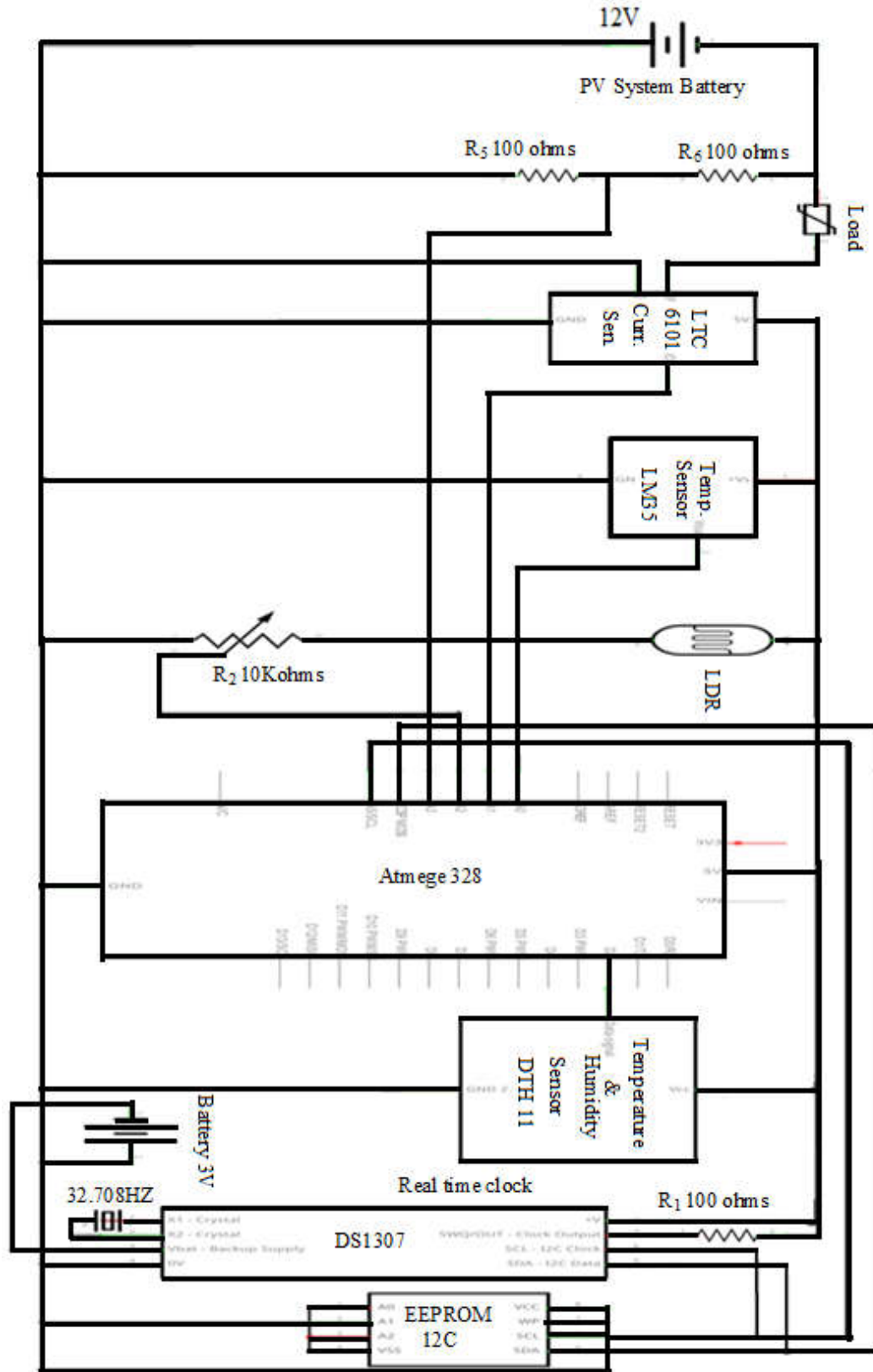


Figure 3.15 Circuit Diagram of the Developed PV Monitoring System

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The developed PV monitoring system results are presented in this chapter which include discussion on the results obtained from the developed system.

After assembling the developed system hard ware experimental test was conducted at meteorological station located at Abubakar Tafawa Balewa University Bauchi, the developed system and meteorological station instruments were used to monitor the temperature, solar radiation intensity, and humidity. Data was obtained for both the meteorological station and developed system at sampling interval of five minute at the same time and location during the sunny and cloudy weather condition.

The experimental test conducted will demonstrate the performance of the developed system in relation to the standard commercial instrument and to verify the accuracy of the developed system. Second test was conducted on the stand alone PV system, in which both the meteorological and electrical parameters of the PV system was monitored and recorded, which is the aim of this research work.

4.2 Results

The results during testing period indicate how the developed PV monitoring system measures and records data correctly in comparison with the data measured by the meteorological station. Figures 4.1 and 4.2 show the irradiance daily profile using the data

obtained from the developed system and that of meteorological station located at Abubakar Tafawa Balewa University Bauchi during a sunny and cloudy day respectively.

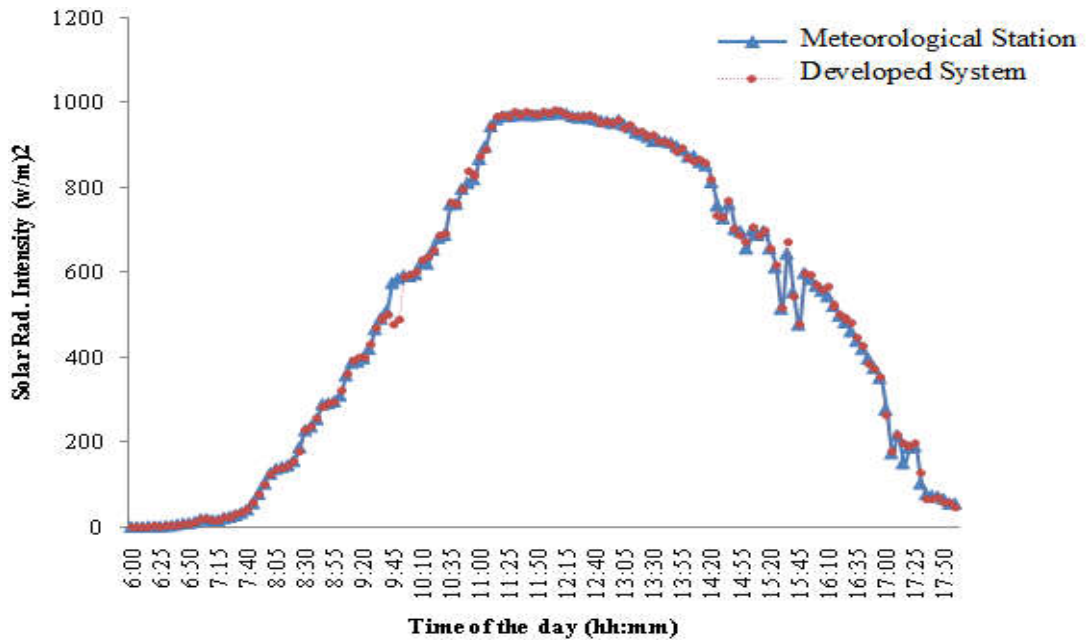


Figure 4.1 Irradiance Data Obtained Using the Developed System and that Obtained by Meteorological Station at Abubakar Tafawa Balewa University Bauchi on 21/03/2016 which is Sunny Day.

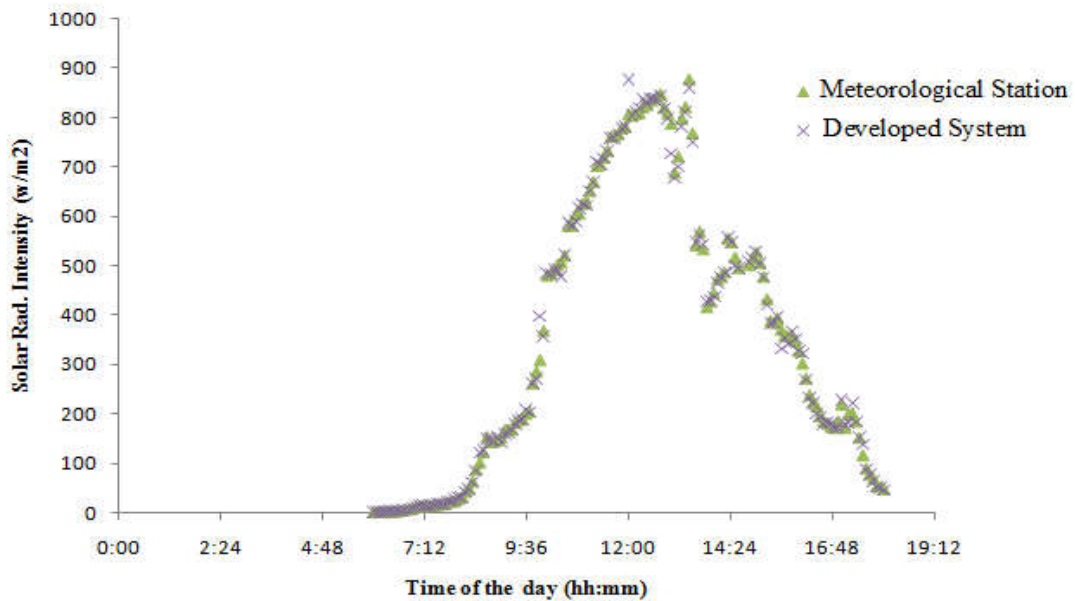


Figure 4.2 Irradiance Data from the Developed System and that Obtained from Meteorological Station at Abubakar Tafawa Balewa University Bauchi on 27/03/2016 which is a Cloudy Day.

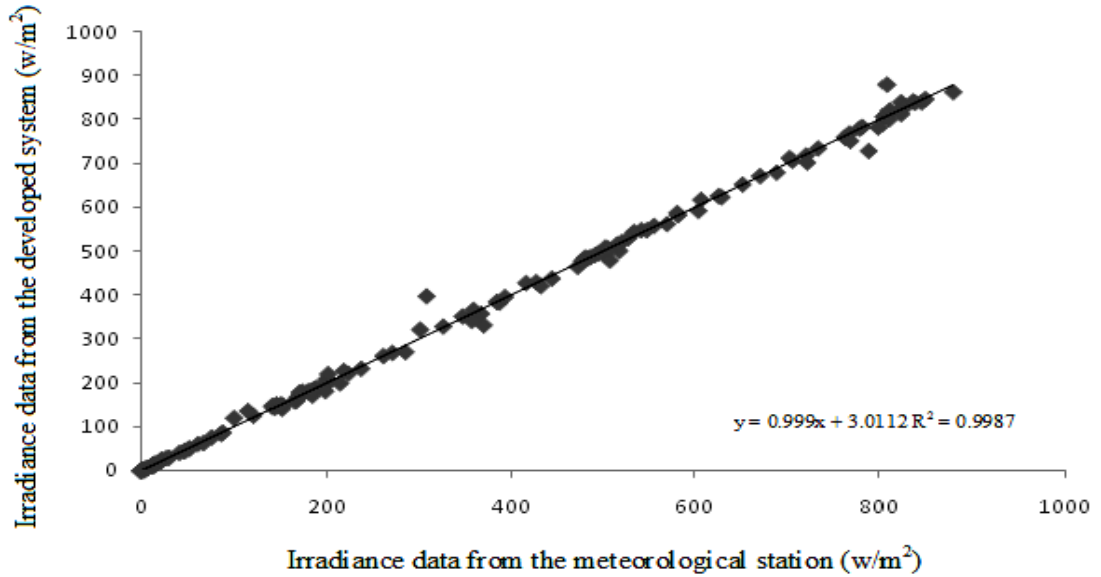


Figure 4.3 Solar Radiation Intensity Data Registered by the Developed System against the Meteorological Station.

The Figure 4.3 above illustrate measurement of irradiance registered by the developed system and that of reference meteorological station to verify the fitness of the developed system, majority of the experimental points are located on a straight line which illustrates minimal dispersion.

The results are further analyzed based on root mean square error (RMSE) and mean bias error (MBE). The RMSE gives a measure of the dispersion of the experimental data and it is defined as.

$$RMSE = \sqrt{\frac{\sum (X_{estimated} - X_{measured})^2}{N}} \quad (4.1)$$

Where $X_{estimated}$ the data is measured by the developed system, and $X_{measured}$ is the obtained from the meteorological station.

The MBE gives a measure of the difference between the estimators' expected value and the true value of the parameter being estimated, it is expressed by the following equation;

$$(X_{\text{estimated}} - X_{\text{measure}}) / 2N \quad (4.2)$$

Table 4.1(a) and (b) shows the statistical results obtained by comparing the data obtained from meteorological station and that of the developed system sunny and cloudy condition using the RMSE and MBE which is express in percentage.

Table 4.1 Sunny Day

| | Developed system/Metrological station data |
|----------|--|
| RMSE (%) | 1.024881 |
| MBE (%) | 0.043292 |

Table 4.2 Cloudy Day

| | Developed system/Metrological station data |
|----------|--|
| RMSE (%) | 2.869432 |
| MBE (%) | -0.963482 |

After demonstrating the good performance of the developed system in relation to measurements obtained from meteorological station for irradiance measurement, the system was also used for temperature, humidity, voltage and current measurements, which shows that the developed system performed satisfactorily. Figure 4.4 illustrates the developed system temperature data, in comparison to data obtained from meteorological station.

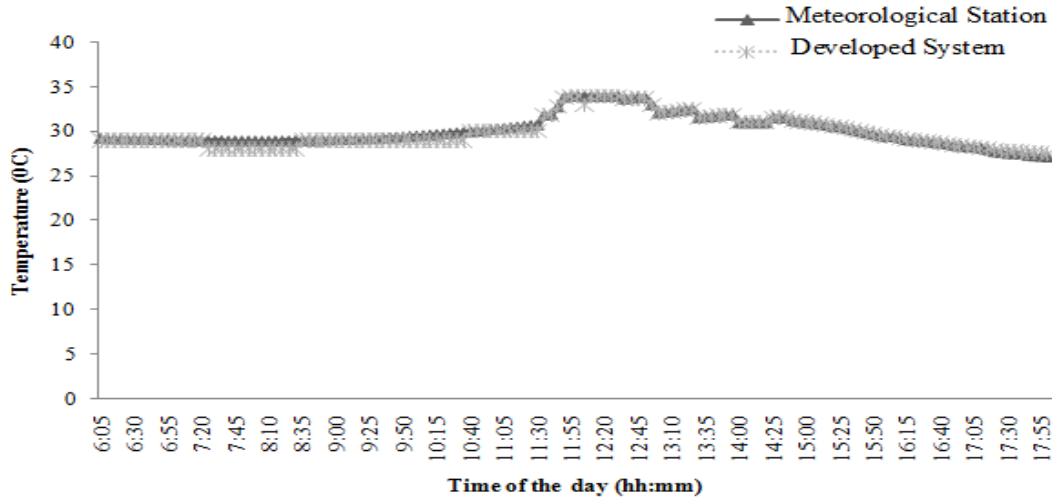


Figure 4.4 The Temperature Data Obtained from the Developed System and that obtained from Meteorological Station on a Sunny Day.

The statistical analysis of the obtained data in Figure 4.4 is express in root mean square RMSE and mean bias error MBE which is shown in table 4.3.

Table 4.3 Sunny Day

| | Developed system/Metrological station data |
|----------|--|
| RMSE (%) | 1.998 |
| MBE (%) | 0.412 |

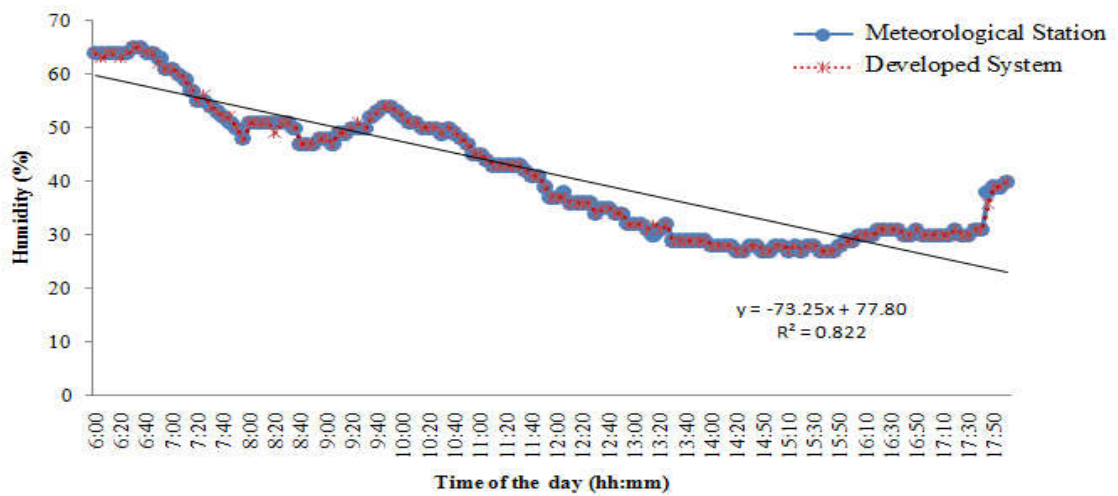


Figure 4.5 Humidity Data obtained from the Developed System and that Obtained from Meteorological Station on a Cloudy Day.

The statistical analysis of the obtained data in Figure 4.5 is expressed in root mean square RMSE and mean bias error MBE is shown in table 4.4.

Table 4.4 Cloudy Day

| | Developed system/Metrological station data |
|----------|--|
| RMSE (%) | 1.872 |
| MBE (%) | -0.297 |

4.3 Measurement of a Standalone PV System Parameters

The new developed PV monitoring system was used to monitor the electrical performance parameters of standalone PV system, after demonstrating the good correlation that exist between the developed system and the data obtained from meteorological weather station and accuracy of developed system at different environmental conditions. Figures 4.6 illustrate the performance of the system monitoring on a standalone 120° North-East direction PV panel with 12V, 150Ah battery located at Bauchi, Nigeria (Long 10.28164; Lat 9.79096) on 31st March, 2016 from 6:00am to 6:00pm which happens to be a sunny day. The parameters monitored are PV panel irradiance, temperature, PV battery humidity, temperature, voltage and load current.

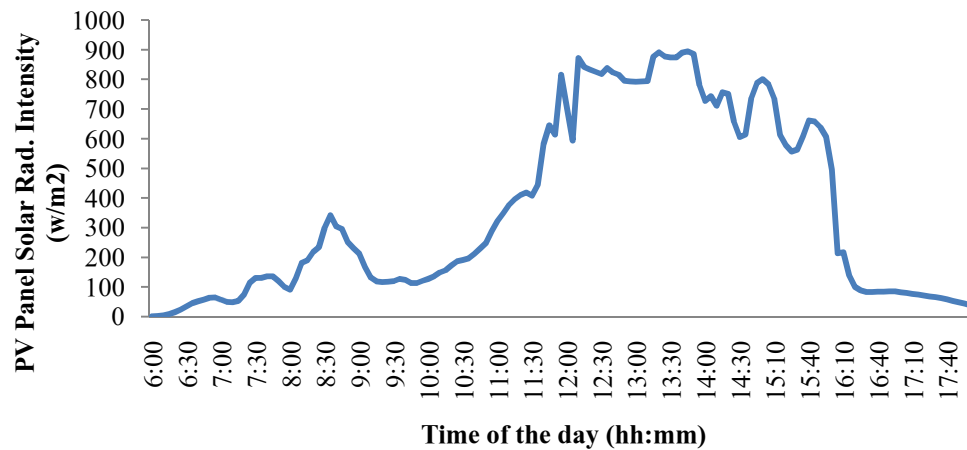


Figure 4.6 (a) Daily Profile Irradiance Monitored by the Developed System for a Standalone PV System Panel on Sunny Day.

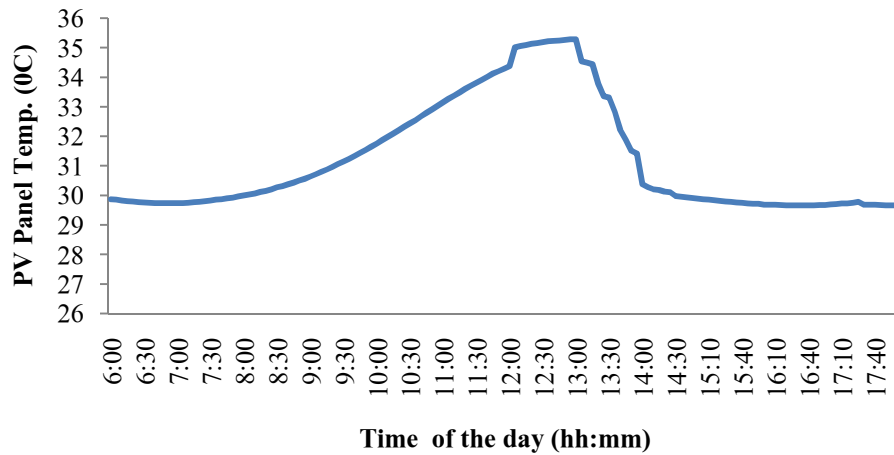


Figure 4.6 (b) Temperature Profile of the PV Panel Recorded by the Developed PV Monitoring System for a Standalone PV System Panel on Sunny Day.

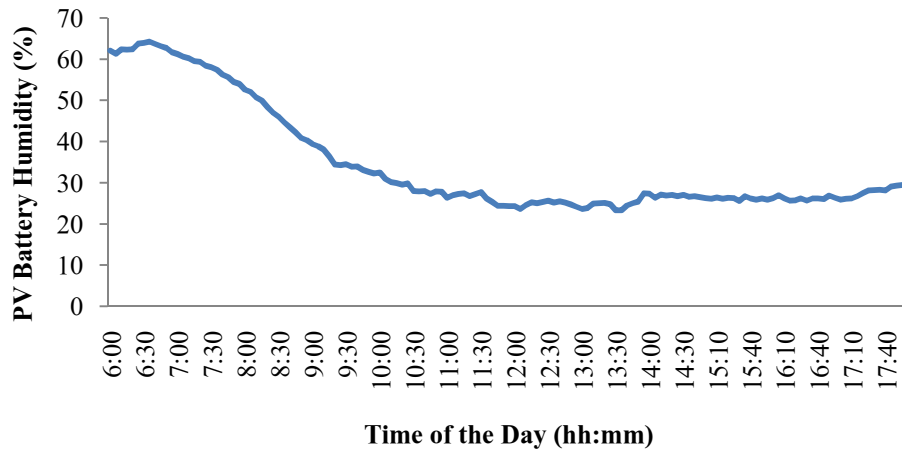


Figure 4.6 (c) Humidity Profile of the PV System Battery Monitored by the Developed PV System for a Standalone PV System on Sunny Day

Also the PV battery temperature variation was monitored and recorded using the developed PV monitoring system; the graph of the temperature data monitored is shown in Figure 4.6 (d).

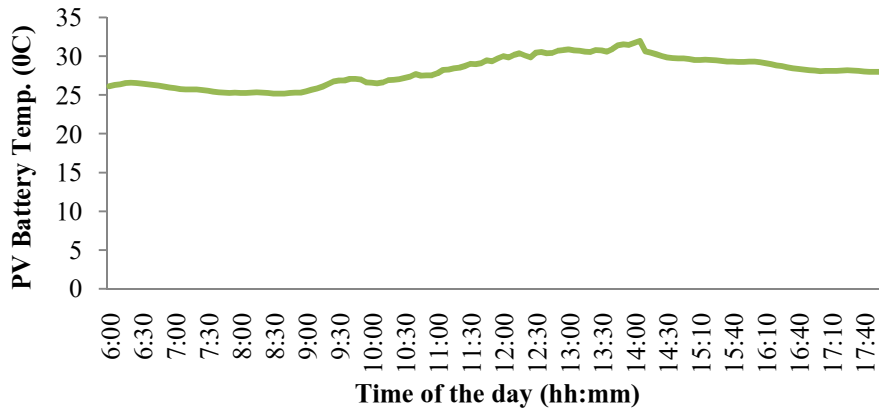


Figure 4.6 (d) Temperature Profile of the PV Battery Recorded by the Developed PV Monitoring System on Sunny Day.

The stand alone PV system battery voltage and load current were monitored by the developed system. A stand alone 12 Volts 150Ah battery was used; the daily PV battery voltage variation is recorded as real time display in personal computer. Figure 4.6 (e) display the graph of the voltage variation, an inverter with two 60watt bulb loads was connected to the battery in which load current variation was recorded by the developed PV monitoring system as shown in Figure 4.6 (f).

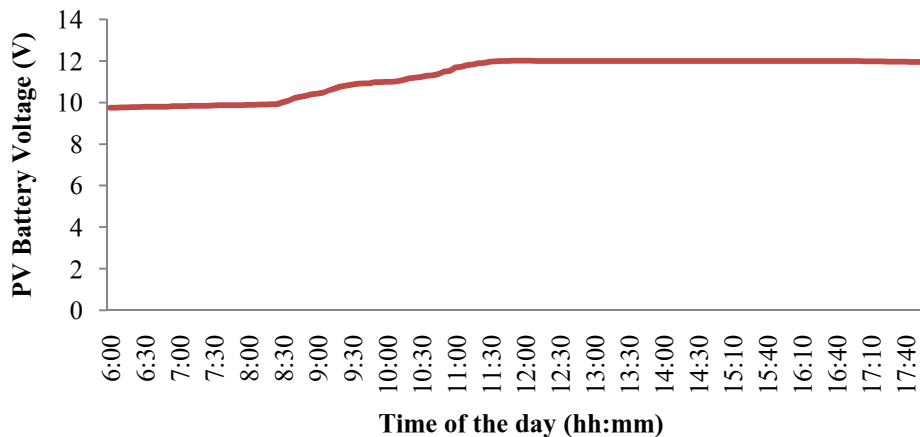


Figure 4.6 (e) Standalone PV Battery Voltage Measurements Using the Developed PV Monitoring System.

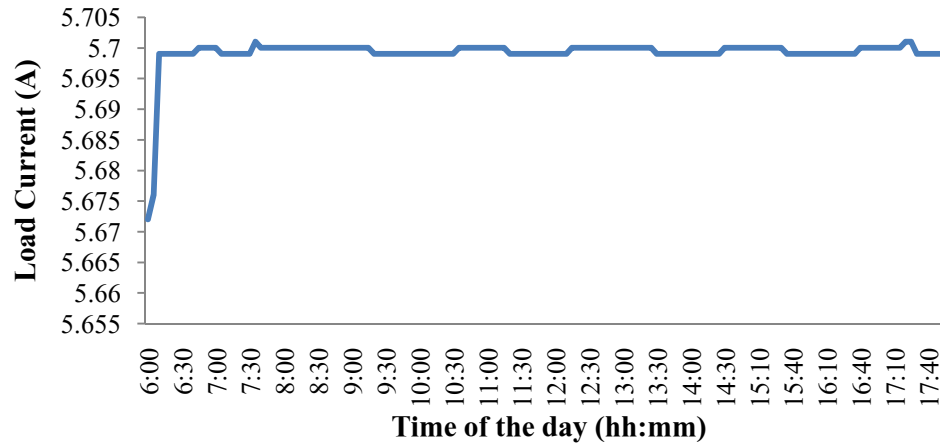


Figure 4.6 (f) Standalone PV Load current Variation Along with the Time of Observation Using the Developed PV Monitoring System.

4.4 Discussions

As shown in Figures 4.1 and 4.2 above, the daily profile of irradiance experimental test was conducted to verify the accuracy of the developed system during the sunny and cloudy day; this experiment was set at meteorological station at Abubakar Tafawa University Bauchi. Data was obtained from the meteorological station at the same time with the new developed PV system after every five minute interval the developed system data have a good correlation with the meteorological stations data as shown in Figure 4.3. The results obtained were further analyzed using the root mean square error and mean bias error, as shown in Tables 4.1 and 4.2 which show that the developed system performance is comparable with the one obtained from measuring devices of meteorological station.

After demonstrating the accuracy of the developed system in measuring environmental parameters, the system was used to monitor standalone PV system parameters as shown in Figures 4.6. The PV system panel receives low irradiance in the early morning and late evening, but in the case of humidity is vice versa. Figure 4.6 (e) and (f) illustrates the PV

system battery performance in relation to battery voltage and load current, the voltage and load current state of PV system is very important parameter in PV monitoring system, because if the load connected to the PV system is large the current drawn will be high, above the rating of the system.

In this developed system PV battery voltage and load current variation is recorded and displayed in Arduino serial monitor and also in LabView control panel window as shown in appendix. During the testing, the system developed was found to be reliable and able to monitor all the intended parameters with good accuracy, and able to withstand high temperatures and other harsh climatic conditions.

The experimental test was conducted at PV battery as shown in Figure 4.6 (e) which shows that PV battery received charging during the sun raised, which lead to battery voltage up to it maximum stage during the day time. This shows that to have maximum PV battery voltage, the battery need to charge by the voltage and current generated from the PV panel which is mostly from 12noon of the day after the sun raised.

Another important parameter associated with PV system is current drawn from the system; an experiment was conducted with this developed PV monitoring system to monitor the load current variation as shown in Figure 4.6 (f). The current drawn from the PV system was completely monitored using this developed system; this would provide the user with information about the load current drawn from the PV system, so as to prevent the load connected to PV system from drawing high current above the PV system rating.

From the entire experimental test conducted with this developed system shows that the system is functioning with good performance and using this developed PV monitoring system would increase the efficiency and performance of the PV system in general.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter high-light the major finding of the research and inferences made from them, the recommendations, including suggestions on areas for further work are also present in this chapter.

5.2 Conclusion

The main goal of this research is to increase decision effectiveness in PV power system through developing a portable and real-time multi-channel system for monitoring PV system parameters. A microcontroller based photovoltaic monitoring system is presented in this work, which is used to obtain important PV parameters, process and display them on personal computer.

The main attractiveness in this developed system is multitasking capability and two ways of displaying the obtained data, i.e. Arduino serial monitor and LabView environment. These two ways of displaying the data, provides the user with of options of graphical user interface to handle the data in different form. The developed software can be used for large PV system power generation plant with this implemented hardware.

From the experimental results conducted in this work, It's shown that this developed system data obtained have good correlations with the standard commercial instruments used in meteorological stations and laboratory with 0.043% mean bias error for solar radiation

intensity channel, 0.0412% of temperature channel, -0.297% for humidity measurement channel and for PV battery voltage is 0.024%, this shows good performance of the developed system. And this shows that the knowledge of all metrological and necessary electrical parameters associated with PV system are very important to be monitored, because in one way or the other can vary the output of PV system. And using this developed PV monitoring system would increase the efficiency and performance of the PV system in general.

5.3 Recommendations

The recommendations made in this work are:

- The smart automatic control that would isolate load from the photovoltaic system during low power output from the PV system was recommended for future work.
- A faulty notification to user by using messaging system may be added to the developed system to improve the robustness of the PV system monitoring.
- In future research in photovoltaic monitoring system, that would monitor PV parameters wirelessly and provide a user-friendly Web interface to download, browse, share, and organize data.
- Monitoring charging, discharging and equalization of the PV battery will increase the efficiency of the PV monitoring system.

The limitations of this research are:

- The developed system cannot isolate load from the photovoltaic system at critical load condition, it only measure and display the PV panel and battery parameters to the user.

- The two programs developed for the display in personal computer, both programs cannot be run at the same time; only one can be run at a time.
- The temperature sensor LM35 malfunctions due to long wire resistance, therefore DS1802 temperature sensor was recommended

5.4 Contribution of Work to the Body of Knowledge

This research PV monitoring system contributes to the body of knowledge in the following area itemized below.

- The results obtained from this developed system show good correlation of the obtained data with standard commercial instruments of 0.043% mean bias error for solar radiation intensity channel, 0.0412% of temperature channel, -0.297% for humidity measurement channel and for PV battery voltage is 0.024%.
- The real time display of the obtained PV system parameters, with two programs (Arduino and LabView) in personal computer provide the user with more graphical user interface to handle the data in different forms.
- The multi-channel capability of measuring up to six PV system parameters which include both the meteorological and electrical parameters, makes this developed system more effective PV monitoring system.

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APPENDIX I

DEVELOPED C LANGUAGE PROGRAM IN ARDUINO



The image shows a screenshot of the Arduino IDE interface. The window title is "AGAWA | Arduino 1.6.3". The menu bar includes "File", "Edit", "Sketch", "Tools", and "Help". The toolbar contains icons for saving, running, uploading, and downloading. The main editor area displays the following C code:

```
AGAWA $
void setup()
{
  Serial.begin(9600);
  Serial.println();
  Serial.println("Microcontroller Based PV Monitoring System");
  Serial.println("By: Yunusa Yusuf Agawa");
  Serial.println("Supervised By: Dr. S. B. Ibrahim");
  Serial.println("Department of Electrical Engineering");
  Serial.println();(Bayero University Kano);
  Serial.println("\tHumidity (%) \tBatt. Temp. (C) \t \tPanel Temp (C) \t \tSolar Intensity (lum)");

  dht.setup(2); // data pin 2
}

void loop()
{
  delay(dht.getMinimumSamplingPeriod());

  float humidity = dht.getHumidity();
  float temperature = dht.getTemperature();

  float Vin = analogRead (analogInPin); /* Tells the Arduino to read the pin and stores the value in "Vin" */

  float Temperature=(500*Vin)/1023; /* Converts the voltage value into temperature and stores it into the "Temperature"
16 Arduino Uno on COM15
```

APPENDIX II

MICROCONTROLLER PROGRAM

```
// EmonLibrary openenergymonitor.org, Licence GNU GPL V3
#include <SPI.h>
#include <SD.h>
#include <Wire.h>
#include "RTClib.h"
#include "EmonLib.h"
#include "DHT.h"
DHT dht;
// Include Emon Library
EnergyMonitor emon1;      // Create an instance
RTC_DS1307 rtc;
char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday", "Thursday", "Friday",
"Saturday"};
const int chipSelect = 4;
float energy;
float tempC;
File logfile;
const int tempPin= A0; // Analog input pin that the potentiometer is attached to
const int lightpin= A2; // Analog input pin that the potentiometer is attached to
const int voltpin=A3;
const int curpin=A1;
unsigned long int FIVEMIN= (1000UL);
void setup()
{
  Serial.begin(9600);
  pinMode(SS, OUTPUT);
  rtc.begin();
  SD.begin(chipSelect);
  Serial.println();
  Serial.println("Microcontroller Based PV Monitoring System");
  Serial.println("By: Yunusa Yusuf Agawa (SPS/MEE/12/00044)");
  Serial.println("Supervised By: Dr. S. B. Ibrahim");
  Serial.println("Department of Electrical Engineering");
  Serial.println();
  Serial.println("Time\t\t\t\tSolar Rad (W/M2)\t Panel Temp (C) \t \tBattery Volt (V)\tHumidity (%)\tBatt.
Temp. (C)\t\tLOAD CURRENT (mA) ");
  dht.setup(2); // data pin 2
  emon1.voltage(2, 234.26, 1.7); // Voltage: input pin, calibration, phase_shift
  emon1.current(1, 111.1); // Current: input pin, calibration.
  logfile = SD.open("datalog.txt", FILE_WRITE);
  if (! logfile) {
    Serial.println("error opening datalog.txt");
    // Wait forever since we cant write data
    while (1);
  }
  if (! rtc.isrunning()) {
    Serial.println("RTC is NOT running!");
    // following line sets the RTC to the date & time this sketch was compiled
    rtc.adjust(DateTime(2016, 3, 14, 3, 47, 20));
    // This line sets the RTC with an explicit date & time, for example to set
```

```

// January 21, 2014 at 3am you would call:
// rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));
}
logfile.println(" ");
logfile.println("Microcontroller Based PV Monitoring System");
logfile.println("By: Yunusa Yusuf Agawa (SPS/MEE/12/00044)");
logfile.println("Supervised By: Dr. S. B. Ibrahim");
logfile.println(" ");
logfile.println("Time\t\t\tSolar Rad (W/M2)\t \tPanel Temp (C) \t \tBattery Volt (V)\tHumidity (%)\t\tBatt.
Temp. (C)\t\tLOAD CURRENT (mA) ");
}
void loop()
{
delay(dht.getMinimumSamplingPeriod());
//DHT
float humidity = dht.getHumidity();
float temperature = dht.getTemperature();
//Panel Temp
float volts= analogRead(tempPin);
tempC =((5.0 * volts * 100.0) / 1024.0); /* Converts the voltage value into temperature and stores it into the
"Temperature" variable (in °C)*/
//Light
float vol = analogRead (lightpin);
float light = (1000*vol)/1024;
//Voltage
float volt= analogRead (voltpin);
float voltage= (20*volt)/1024;
//Current
float cur= analogRead (curpin);
float curr= ((5.0* cur)/1024);
float current= (((curr - 2.498)* 1000)/6.5);
DateTime now = rtc.now();
Serial.print(now.day(), DEC);
Serial.print("/");
Serial.print(now.month(), DEC);
Serial.print("/");
Serial.print(now.year(), DEC);
Serial.print(" (");
Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
Serial.print(") ");
Serial.print(now.hour(), DEC);
Serial.print(":");
Serial.print(now.minute(), DEC);
Serial.print(":");
Serial.print(now.second(), DEC);
Serial.print(" ");
Serial.print("\t");
Serial.print("\t");
Serial.print(light, 1);//solar intensity
Serial.print("\t\t\t");
Serial.print(tempC);//panel temperature
Serial.print("\t\t\t");
Serial.print(voltage);//Battery Volatage
Serial.print("\t\t\t");
Serial.print(humidity, 1);//Battery/envir
Serial.print("\t\t\t");

```

```

Serial.print(temperature, 1); // Battery temp
Serial.print("\t\t");
Serial.println(current, 2); // Battery Discharge Current
delay(10); // delay in between reads for stability
logfile.print(now.year(), DEC);
logfile.print("/");
logfile.print(now.month(), DEC);
logfile.print("/");
logfile.print(now.day(), DEC);
logfile.print(" ");
logfile.print(now.hour(), DEC);
logfile.print(":");
logfile.print(now.minute(), DEC);
logfile.print(":");
logfile.print(now.second(), DEC);
logfile.print(" ");
logfile.print("\t\t");
logfile.print(light, 1);
logfile.print("\t\t\t");
logfile.print(tempC);
logfile.print("\t\t\t");
logfile.print(voltage);
logfile.print("\t\t\t");
logfile.print(humidity, 1);
logfile.print("\t\t\t");
logfile.print(temperature, 1);
logfile.print("\t\t\t");
logfile.println(current, 1);
logfile.flush();
delay(FIVEMIN);
}

```

APPENDIX III

PV MONITORING PARAMETERS DISPLAYED IN PC SERIAL MONITOR

Microcontroller Based PV Monitoring System
 By: Yurusa Yusuf Agawa (SPS/MEE/12/00044)
 Supervised By: Dr. S. B. Ibrahim

| Date | Time | Solar Rad (w/m2) | Panel Temp (c) | Battery Volt (V) | Batt.Humidity (%) | Batt. Temp. (C) | Batt.LOAD CURRENT(A) |
|----------|----------|------------------|----------------|------------------|-------------------|-----------------|----------------------|
| 2016/3/6 | 13:00:53 | 134.8 | 35.16 | 9.26 | 27.0 | 36.02 | 5.1 |
| 2016/3/6 | 13:02:56 | 134.8 | 30.76 | 9.07 | 26.0 | 36.04 | 5.2 |
| 2016/3/6 | 13:04:59 | 134.8 | 31.74 | 9.05 | 27.0 | 36.22 | 5.4 |
| 2016/3/6 | 13:06:2 | 134.8 | 31.74 | 9.05 | 27.0 | 36.62 | 6.0 |
| 2016/3/6 | 13:08:6 | 134.8 | 29.79 | 9.07 | 27.0 | 36.88 | 6.1 |
| 2016/3/6 | 13:10:9 | 134.8 | 35.64 | 10.02 | 27.0 | 37.02 | 5.0 |
| 2016/3/6 | 13:12:12 | 134.8 | 37.60 | 10.02 | 28.0 | 37.04 | 5.0 |
| 2016/3/6 | 13:14:15 | 134.8 | 36.13 | 10.03 | 27.0 | 37.09 | 5.6 |
| 2016/3/6 | 13:16:18 | 134.8 | 29.30 | 10.03 | 27.0 | 37.11 | 5.7 |
| 2016/3/6 | 13:18:21 | 134.8 | 37.11 | 10.04 | 27.0 | 36.03 | 5.8 |
| 2016/3/6 | 13:20:24 | 134.8 | 30.27 | 10.07 | 27.0 | 36.05 | 5.7 |
| 2016/3/6 | 13:22:28 | 134.8 | 36.62 | 10.05 | 27.0 | 36.09 | 5.8 |
| 2016/3/6 | 13:24:31 | 135.7 | 37.11 | 10.08 | 27.0 | 36.21 | 5.8 |
| 2016/3/6 | 13:26:34 | 134.8 | 29.79 | 10.12 | 27.0 | 36.22 | 6.0 |
| 2016/3/6 | 13:28:37 | 135.7 | 35.16 | 10.13 | 27.0 | 36.42 | 6.1 |
| 2016/3/6 | 13:30:40 | 135.7 | 37.11 | 10.16 | 27.0 | 36.52 | 6.2 |
| 2016/3/6 | 13:32:43 | 134.8 | 29.79 | 10.18 | 27.0 | 36.87 | 6.0 |
| 2016/3/6 | 13:34:46 | 135.7 | 36.13 | 10.22 | 27.0 | 36.42 | 6.3 |
| 2016/3/6 | 13:36:50 | 134.8 | 35.64 | 10.23 | 27.0 | 36.31 | 6.4 |
| 2016/3/6 | 13:38:53 | 134.8 | 36.13 | 10.27 | 27.0 | 36.12 | 6.1 |
| 2016/3/6 | 13:40:56 | 134.8 | 36.13 | 10.27 | 28.0 | 36.06 | 6.2 |
| 2016/3/6 | 13:42:59 | 134.8 | 37.11 | 10.29 | 27.0 | 36.02 | 5.9 |
| 2016/3/6 | 13:44:2 | 134.8 | 37.11 | 10.32 | 27.0 | 36.45 | 5.8 |
| 2016/3/6 | 13:44:2 | 134.8 | 37.11 | 10.44 | 27.0 | 36.79 | 5.7 |
| 2016/3/6 | 13:46:5 | 134.8 | 36.13 | 10.58 | 27.0 | 36.86 | 5.6 |
| 2016/3/6 | 13:48:9 | 135.7 | 29.79 | 11.01 | 27.0 | 37.05 | 5.8 |
| 2016/3/6 | 13:50:12 | 134.8 | 30.27 | 11.01 | 27.0 | 37.04 | 5.5 |
| 2016/3/6 | 13:52:15 | 134.8 | 34.67 | 11.02 | 27.0 | 37.27 | 5.3 |
| 2016/3/6 | 13:54:18 | 134.8 | 37.11 | 11.04 | 27.0 | 36.88 | 5.2 |
| 2016/3/6 | 13:56:21 | 135.7 | 30.27 | 11.06 | 27.0 | 37.32 | 5.3 |
| 2016/3/6 | 13:58:24 | 135.7 | 35.16 | 11.09 | 27.0 | 37.76 | 5.4 |
| 2016/3/6 | 14:00:27 | 134.8 | 33.20 | 11.10 | 27.0 | 36.0 | 5.2 |
| | | | | | | 36.0 | 5.3 |

APPENDIX IV

PV MONITORING PARAMETERS DISPLAYED IN LABVIEW CONTROL PANEL WINDOW

