

**LOW COST DATA LOGGER AND MONITORING SYSTEM FOR A  
SMALL SOLAR PV ENERGY SYSTEM**

by

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## Abstract

A data logger and monitoring system are very crucial for a smooth, efficient and robust operation of PV solar energy system. Datalogger and monitoring system enables the proper operation and contributes to identifying system malfunctioning before any major breakdown. In this thesis, a low-cost, user-friendly, reliable datalogger and monitoring system has been developed mainly for a pico solar home system in a rural area of a developing country. This ESP 32 microcontroller based datalogger stores all monitoring parameter in a micro SD card and displays that on a local webpage in HTML format. Data can be downloaded directly from the webpage to analyze and verify the system operation. The developed datalogger hardware prototype uses only three sensors for temperature, voltage, and current sensing. An Android app is also developed for cell phone to display all parameters in real time basis for an efficient monitoring which can also able to send an alert text message to maintenance personnel for any issues in battery charging. The overall cost of this prototype is only around C\$ 50.

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## List of Abbreviation

SHS-Solar Home System

PV- Photovoltaic

DC- Direct Current

Wp- watt-peak

LED- Light Emitting Diode

USB- Universal Serial Bus

mAh- Milli Ampere Hour

kWh- Kilowatt-Hour

IDE- Integrated Development Environment

HTML- Hypertext Markup Language

ADC- analog to digital

DAC- digital to analog

SPI- Serial Peripheral Interface

SDK- Software Development Kit

DoD- Depth of Discharge

LDR-Light Dependent Resistor

## Chapter 01: Introduction and Literature Review

### 1.1 Introduction:

Energy or electrical power plays an important role in this modern civilization and the proper development of a nation depends on the availability of energy for industries and human civilization. So, energy or power is a vital element for the socio-economic development of a country. Due to the huge urbanization and technological development, the world energy consumption is increasing very rapidly. According to the U.S Energy Information Administration (EIA) statistics, global energy consumption will increase by 28% between 2015 to 2040. It will increase from 575 quadrillion British thermal units (Btu) in 2015 to 663 quadrillion Btu by 2030 and then to 736 quadrillions Btu by 2040 [1]. Figure 1-1 depicts world energy consumption from the year 1990 to 2040.

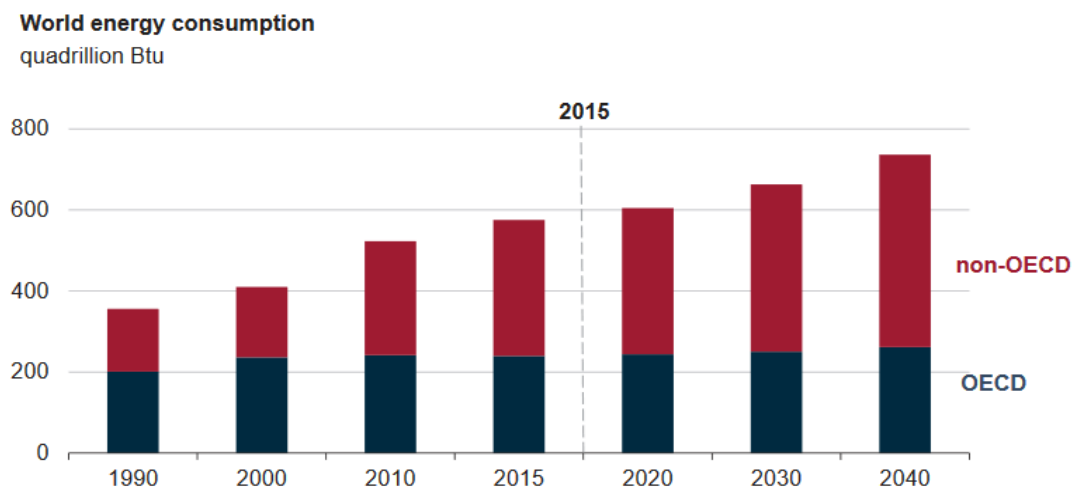
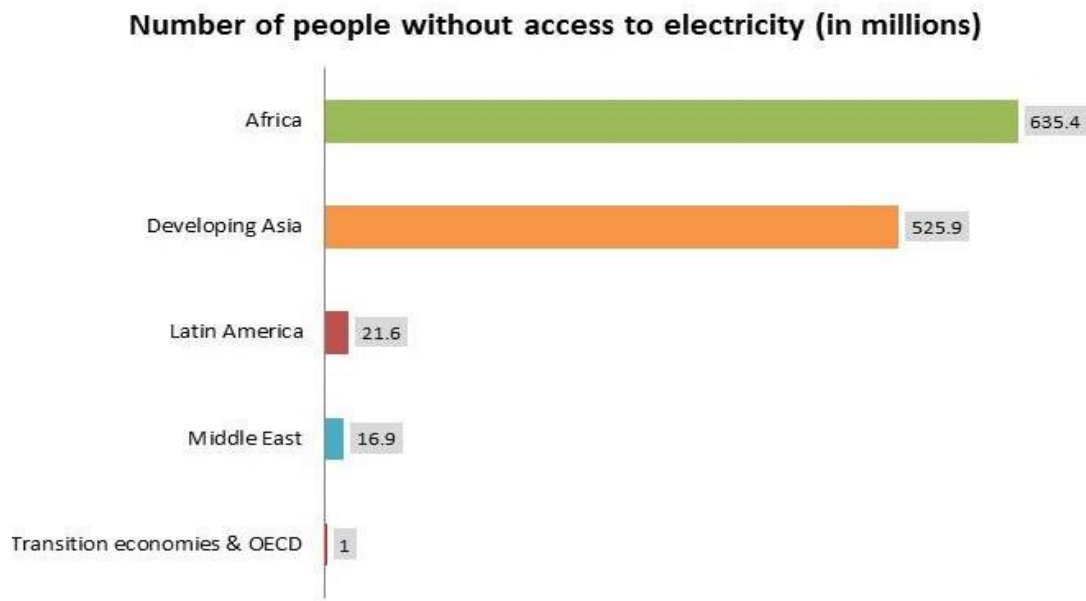


Figure 1- 1 : World Energy Consumption [2].

This energy consumption is mainly based on fossil fuel and oil. The world total reserve of this fossil fuel will deplete within the next two or three decades. The mono dependency policy on fossil fuel must reduce for the greater sustainability of human beings. Moreover, this type of fuels is creating greenhouse gas emission and carbon footprint issues. So, for the existence of the human world, a reliable and easy affordable alternative energy needs to be found. Also, the accessibility of electricity for all people of the world must be ensured. Power or electricity is required for both economic and social development of humans all over the globe.

Currently, over 20% of people living in the world today do not have access to electricity and many more have access to only very limited amounts of electricity. Especially, people who live in rural areas in developing countries, have lack access to modern energy services, that means these people not only have a low quality of life but also, they are deprived of basic services, such as healthcare and education. They fall into an energy poverty trap. This result, they are going through a poor living standard without access to electricity, and they can not change their lifestyle. Figure 1-2 shows a bar chart of people without electricity in the world.



**Figure 1- 2: Number of people without electricity in the world,2016 [3]**

To overcome this huge energy demand in the future and provide electricity to all, an efficient, cost-effective and environment-friendly solution is much more anticipated. To meet the extreme demand trend, primary energy sources will not be sufficient. So, renewable energy can mitigate the shortage by a clean, affordable and available energy source. Renewable energy has huge potential to meet the hike in energy demand and less carbon emission than the conventional sources. It is forecasted that within 2050 the total global energy demand will be covered by renewable energy.

In the last 10-20 years, renewable energy utilization has increased a lot in both developed or developing countries. Almost 71% of the total energy is generating from renewable sources in European countries. Renewable energy has drawn huge interest to meet the

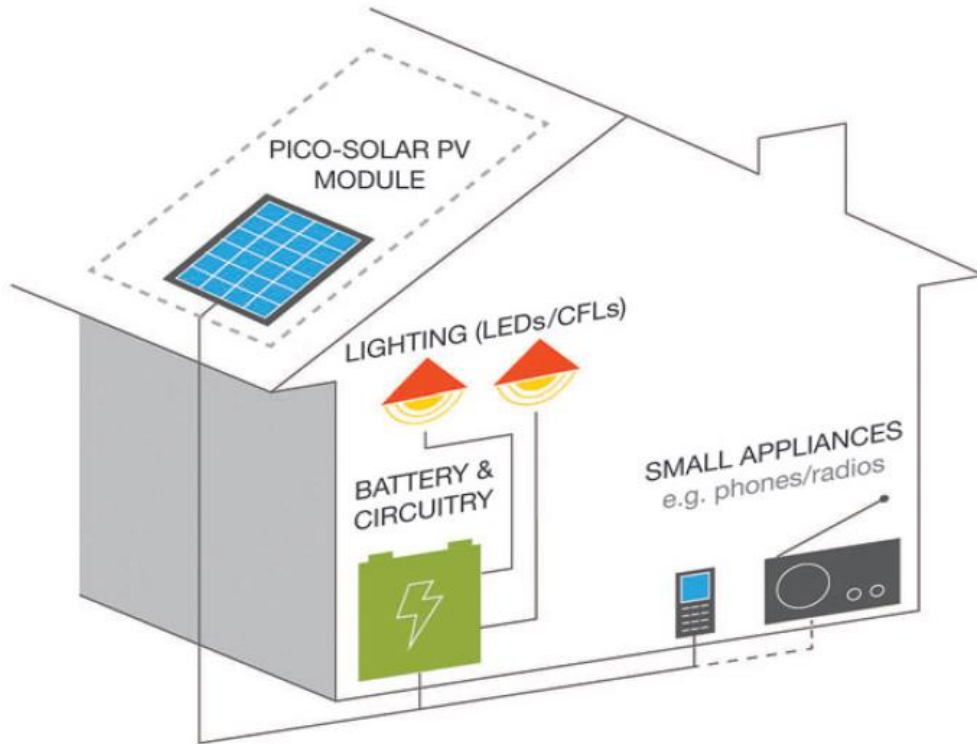
growing energy demand due to it is clean, affordable and available alternative source. The foremost sources of renewable energies are solar, wind, biomass, geothermal, tidal, hydro energy.

As renewable energy sources are getting more emphasize to overcome this energy shortage and future demand all over the world. Policy makers and Governments of different countries are implementing different projects and programs to provide electricity for all citizen. Many rural electrification programs based on the use of small-scale renewable energy system have been implemented over the past decades, but the progress rate is not yet sufficient to provide electricity for all. The number of rural electrification programs being implemented will need to be greatly increased and their scales expanded.

Solar is one of the most significant renewable sources which has the highest potential than any other sources of energy generation. The potential energy of solar is  $1.73 \times 10^{16}$  kW which can meet thousand times of total global energy demand. Currently, 301 GW energy is generating from solar all over the world. Solar Home System (SHS) is has shown a great impact as a rural electrification program in the rural areas of developing countries.

A Solar Home System comprises of a small solar PV (Photovoltaic) generator (typically one PV module), a battery charge controller and a battery. This small panel of the solar home system is called pico-solar system. Pico-solar systems are smaller than traditional

SHS. This system is mainly used to provide electricity to a remote user where on-grid distribution lines cannot be reached. Pico-solar system is vastly used for low power consumption appliances i.e. lighting, mobile cell charging and turning small DC fans in rural areas. The operation principle of pico-solar systems is the same as SHS, but it has an integrated charge controller unlike a separate charge controller unit in regular SHS. Pico-solar system has a wide range of different shapes and sizes and comes with portable design. Figure 1-3 shows a Solar Home System with Pico-Solar Panel.



**Figure 1- 3: Pico- Solar PV based Solar Home System [4]**



## **1.2 Literature Review:**

Technological advancement increased the global energy demand along with the growing world population. Government and researchers are giving more emphasis to the alternative or renewable energy sources. Solar energy is considered as the most promising and reliable source of renewable energy. To provide a reliable, consistent performance of photovoltaic (PV) system makes a demand for developing a monitoring system. There are many data acquisition and monitoring system available for the large plant which is expensive and complicated. Even there is no such data logging and control system for a small plant like pico-solar system for rural home electrification pregame. To overcome this problem, many researchers are conducting several projects to find a low cost and reliable solution for a pico-solar system.

Some of the proposals are reviewed as following for finding objective and goal to develop a new low-cost data logger and control system which can operate without any internet connection in a rural area of developing country.

### **1.1.1 Non-Commercial Systems:**

Ranhotigamage et al. [5], proposes the design and development of a monitoring system get information on the defected solar panels for timely repair and maintenance. The design, development, and trial work of a performance monitoring system of distributed solar panels along with automated data logging based on a low-cost wireless sensor network has been

reported to help the current situation. This system can be used up to 146 V and 15.5 A solar cell systems with an automatic selection of best resolutions. The overall cost of their system is \$175 CAD.

Lab-VIEW based real-time interface system in paper [6] presents, a detailed characterization of the performance and dynamic behavior of photovoltaic systems. They developed a software tool that integrates several types of instruments into a single system which can offer online measurements of all data sources and compare simulation results with monitored data in real-time. The proposed method provides a fast, secure and reliable system by making the system database-ready for performance analysis of PV systems. The integration methodology of robust simulation and monitoring data in real-time can be used to study the fault diagnosis of a PV system.

An Arduino based data logger using the open-source electronic platform was developed to solve the current problem of monitoring photovoltaic (PV) systems especially for remote areas or regions in developing countries [7]. This data logger meets the International Electrotechnical Commission (IEC) standards requirements with a resolution of 18-bits, including 8 analog inputs for measuring up-to 8 PV modules. They mentioned that this data logger can be customized for the specific needs of each project at low-cost and the cost is around \$90 CAD.

Jihua et al. [8] designed a remote intelligent monitoring system based on TinyOS for monitoring and management for PV power generation. This system had implemented remote monitoring and reverse control by the host computer, ARM gateways, wireless sensor networks, and other components.

A simple sensor-based microcontroller data acquisition system for monitoring the temperature data in solar installations is developed by Gad et al. [9]. The system can easily change the date, time of experiment start and end, sampling rate and deals correctly with corruption such as power failure. The proposed data acquisition system can handle up to 16 sensors, has user interface system (4 buttons LCD screen), own storage systems such as flash memory or SD card; therefore, it doesn't require any external computer to store the sensors data. This system automatically creates a new file on the SD card every day and records data on it and data can be handled and analyzed easily by any mathematical software such as Excel or MATLAB. The system monitors the sensors remotely by using the internet.

Shrihariprasath et al., presented their research in [10] to design and implement a Smart Remote monitoring system using IOT that can monitor the Solar PV PCU and stores data in the cloud database through an easily manageable web interface. The proposed system has a flexibility by using GPRS technology to interconnect the Solar PV Power Conditioning Unit to the Remote server.

Another designed with the help of LabVIEW and DAQ card is presented in [11]. The solar panel is connected to the battery and then with sensors. The proposed system is connected by four sensors with LabVIEW via DAQ hardware to acquire data. LabVIEW has shown a high performance in communicating with several devices simultaneously and high capability of displaying several variables behavior at a time.

An android based design of an electronic system for the measurement and control of the physical parameters like water temperature, solar collector's fluid temperature, solar radiation level, etc. to monitor and consequently optimize thermal-solar plant functioning is presented in [12]. The designed control unit can monitor and program the device functionality by means of a touch-screen graphical display that to check or correct operation and quickly reveal any fault, to manage and view locally the plant functioning by serial connection to PC with terminal role, and also remotely viewing and monitoring actions, by Android-based mobile devices, through RS485/Ethernet adapter and modem/router device connected to internet network.

Begum et al. [13] have implemented an Operation & Maintenance (O&M) system using predictive analytics and supervisory control and data acquisition (SCADA) with the help of internet cloud along with IoT devices, The ARM processor is used to acquire the sensor data and then converted to the required format to transfer over the internet. Google Compute Engine is used as the cloud end which is responsible for connecting to all the data

source nodes using a lightweight sensor messaging protocol MQTT (MQ Telemetry Transport).

Soham et al. proposed a conceptual system in [14] to monitor the state of a photovoltaic system through an IoT based network to control it remotely. The information from the sensors is transmitted via the mobile radio network. A GPRS module is employed to send data to the remote server. IoT application schematic has three layered starting with the sensing layer at the bottom which comprises of current sensors, voltage sensors, pyranometer for irradiance measurement and other sensors, this layer also includes microcontroller-based data processing of data acquired from the sensors. The microcontroller communicates with a wireless module to initiate and transmit data to the server. Layer 2 as envisaged is the network layer where data logging from the plant for real-time processing is done which includes a database for storage. Then after the network layer, this processed and stored data is used in the application layer. In this layer sophisticated web-based services are designed based on the data collected, processed and stored. Graphical user interfaces will help to monitor the performance of the plant, the console will also advise the administrator with decision-based on historical data that will significantly reduce the decision-making time.

Pereira et al. [15] proposed a Renewable Energy Monitoring System (REMS), a new concept of an open source and low-cost data acquisition and transmission system using

Raspberry Pi, multi-user cloud remote monitoring and Internet of Things, applied to decentralized RE plants. REMS architecture, based on the Internet of Things (IoT) and Cloud computing principles, consists of three main parts SanUSB microcontroller, Raspberry Pi (Rpi) Embedded Linux System (ELS) and Online Web Monitor for real-time cloud monitoring.

Table 1-1 represents a summary of developed non-commercial monitoring system up to now [53]-[84].

**Table 1- 1: Characteristics of Previous Monitoring Systems [16]**

Work was done by	Data transfer mechanism	Parameters	Monitoring method	Software/programming language
Mukaro and Carelse (1999)	Wired: RS232	None	PC	Turbo C++, ASSEMBLY
Pietruszko and Gradzki (2003)	Wired	$V_{pv}, V_{ac}, I_{pv}, I_{ac}, P_{ac}, E_{ac}, Z, f$	PC	Not mentioned
Koutroulis and Kalaitzakis (2003)	Wired: PCI bus	$V_{pv}, I_{pv}, V_b, I_b, W/G_v, W/G_c$	PC	LabVIEW
Kalaitzakis, Koutroulis, and Vlachos (2003)	Wireless: RF	$V_{pv}, I_{pv}, W/G_v, W/G_c, W/G_s, V_b, I_b$	Web	Java
Krauter (2004)	Wireless: Satellite	$P_{pv}, V_b, P_b, P_{ac}$	Web	Not mentioned
Papadakis, Koutroulis, and Kalaitzakis (2005)	Wireless: RF	$W/G_v, W/G_c, W/G_s, V_{pv}, I_{pv}, V_b, I_b$	Web	VB, SQL server 2000
Forero, Hernández,	Wired: RS232	$V_{pv}, I_{pv}, E_{pv}, P_{pv}, V_{oc}, I_{sc}, FF, \eta, P_{max}$	PC	LabVIEW

and Gordillo (2006)				
Soler-Bientz, Ricalde-Cab, and Solis-Rodriguez (2006)	Wired: RS232	$V_{pv}, I_{pv}, P_{pv}, V_b, I_b$	PC	LabVIEW
Gagliarducci, Lampasi, and Podestà (2007)	Wireless: GSM	$P_{pv}, E_{pv}, DC P_l, AC P_l, V_{pv}, \eta_{ave}, \gamma, \gamma_r, CL$	PC	LabVIEW
Rosiek and Batlles (2008)	Wireless: GSM/GPRS	None	PC	Not mentioned
Boonmee, Plangklang, and Watjanatepin (2009)	Wired	$V_{pv}, I_{pv}, P_{pv}, V_{ac}, I_{ac}, P_{ac}, E_{ac}$	PC	Not mentioned
Benghanem (2009b)	Wireless: RF	None	PC	LabVIEW
Benghanem (2009a)	Wireless	$V_{pv}, I_{pv}$	PC	MatLab
Benghanem (2010)	Wireless: TX5002, RX5002	None	Web	LabVIEW
Ayompe, Duffy, McCormack, and Conlon (2011)	Wired (RS485)	$E_{pv}, E_{ac}$	PC	Not mentioned
Anwari, Dom, and Rashid (2011)	Wired: RS232	$V_{pv}, I_{pv}$	PC	MPLAB, LabVIEW
Ranhotigama ge and Mukhopadhyay (2011)	Wireless: Zigbee	$V_{oc}, I_{sc}, P_{max}, V_{max}, I_{max}$	PC	Not mentioned
Wittkopf, Valliappan, Liu, Ang, and Cheng (2012)	Wired	$V_{ac}, I_{ac}, E_{ac}$	PC	Matlab
Carullo and Vallan (2012)	Wired	$V_{pv}, I_{pv}, V_{ac}, I_{ac}, P_{pv}, P_{ac}, E_{pv}, E_{ac}$	PC	LabVIEW

Park, Shen, Kim, and Rho (2012)	Wire/wireless: Ethernet	$V_{pv}, I_{pv}, P_{pv}, V_l, I_l, P_l, f, PF$	PC	Autobase
López, Mantiñan, and Molina (2012)	Wireless: Zigbee	$V_{ac}, I_{ac}, P_t, Q, S, V_{pv}, I_{pv}, P_{pv}$	PC	LabVIEW, C

### 1.1.1 Commercial Systems:

Geo Solo II PV monitoring system [17] is a commercial PV monitoring system by Green Energy Options Ltd. The Solo II PV is a stylish and elegant web-enabled In-Home Display which provides real-time information that triggers interest and provides an indication to turn on high-load appliances such as washing machines and dishwashers when more than 750W is being generated, helping you to make the most of your PV system. With the online service called Energynote is the internet bridge provided gives you access to our online service Energynote. Energynote provides in-depth, real-time generation data, hints and tips for your microgeneration as well as analysis of all historical data. It displays the total generation in kW, money earned from the Feed-In Tariff and the amount of CO<sub>2</sub> emission saved. Figure 1-4 represents a Geo Solo II PV monitoring system.

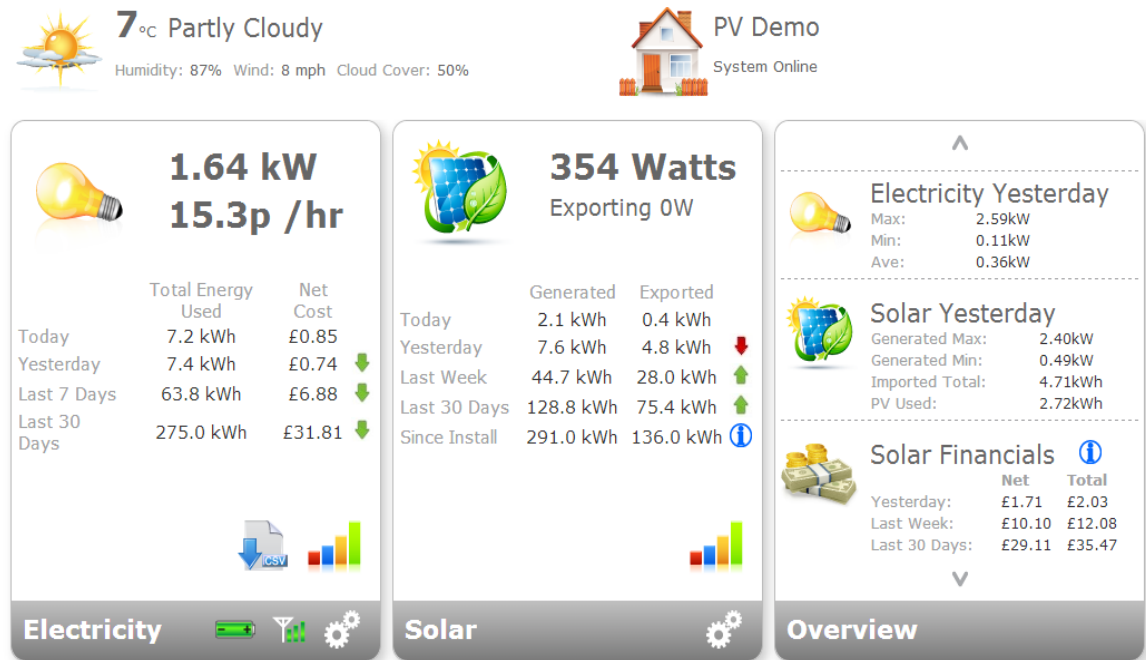




**Figure 1- 4: Geo Solo II PV monitoring system [15]**

Eco-eye has developed a monitoring system named Eco Eye Smart PV [18] which is a smart energy monitor, an essential piece of equipment for photovoltaic or microgeneration installations. With sensors on both the generated and demand cables, Smart PV provides full display and monitoring capabilities; displaying power generated, the power used and net power. It's onboard traffic light system instantly shows if the system has a surplus or are using power from the grid. Smart PV can log generated electricity as well as the demand for analysis on windows or mac computer by way of the memory card at four-second resolution.

Intuition-PV Solar PV Monitoring system [19] has been developed by OWL, allows monitoring of the PV generation, export and overall consumption of a property with solar panels. Intuition online dashboard gives access regardless of location as long as the user has internet access. Android and iPhone apps can give the user to access this system on-the-go. It shows live readings to 12-second intervals, and a historical account of the above; also informs when the user has improved usage habits or solar panels are performing better. User configurable tariff settings allow the unit to calculate how much the user spent over the course of a day, week, and month. FITS settings allow you to see the tangible impact your solar panels are having on your bills. Figure 1-5 represents Intuition-PV Solar PV monitoring system.



**Figure 1- 5: Intuition-PV Solar PV Monitoring system [19]**

SMA Data Manager M powered by ennexOS [20], a monitoring and controller with sunny portal developed SMA Solar Technology AG, which is shown in figure 1-6. This data manager optimizes communication, monitoring, and control of PV systems with up to 25 SMA devices. Based on the new IoT platform for energy management, ennexOS from SMA, the Data Manager M is the ideal professional system interface for electric utility companies, direct marketers, service technicians and PV system, operators. Particularly impressive is its innovative and highly efficient user interface, which has been standardized for both Data Manager M and the new Sunny Portal powered by ennexOS. A range of intuitive assistance functions for the Data Manager M, inverters and Sunny Portal powered by ennexOS significantly reduce the amount of time involved in commissioning and parameterization.

The basic scope of functions and interfaces offered by the new Data Manager M is coordinated with the associated functions in Sunny Portal powered by ennexOS and adapts to future requirements step by step. It's modular design and systematic support of industry standards such as Modbus/TCP, systems can be expanded to include additional components such as I/O systems or energy meters, from either SMA or other suppliers.



**Figure 1- 6: SMA Data Manager M powered by ennexOS [20]**

Swart et al. represent a comparison of advantages and disadvantages for some datalogger systems available in South Africa in [21]. Table 1-2 shows the comparison represented in their paper.

**Table 1- 2: Some Commercial Datalogger Available in South Africa [21].**

<b>Data logger</b>	<b>Advantages</b>	<b>Disadvantages</b>
PICOLOG 1012	<ul style="list-style-type: none"> <li>• Relatively cheap (€200)</li> <li>• Very user friendly interface</li> <li>• Repetitive unlimited samples with unique file names</li> <li>• Real time mathematical calculations</li> <li>• 12 input analogue / digital channels</li> <li>• 2 output digital channels</li> <li>• Remote download</li> </ul>	<ul style="list-style-type: none"> <li>• Time stamp per sample missing</li> <li>• Must be permanently connected to a PC</li> </ul>
DAQPro 5300	<ul style="list-style-type: none"> <li>• User friendly interface</li> <li>• Onboard memory for medium data storage</li> </ul>	<ul style="list-style-type: none"> <li>• Modestly prices (€800)</li> <li>• 8 input analogue channels</li> <li>• Limited number of samples</li> <li>• Mathematical calculations after data collection</li> <li>• One alarm output reduces input channels by 1</li> <li>• No remote download</li> </ul>
CAMPBELL Scientific CR800	<ul style="list-style-type: none"> <li>• User friendly interface</li> <li>• Onboard memory for extensive data storage</li> <li>• Remote download</li> <li>• 4 output digital channels</li> <li>• Resistance measurements</li> <li>• Pulse counter</li> </ul>	<ul style="list-style-type: none"> <li>• Very expensive (€1000)</li> <li>• 6 single-ended analogue input channels</li> <li>• Mathematical calculations after data collection</li> </ul>

Table 1-3 represents a price comparison of some commercial system available for PV monitoring and data logging.

**Table 1- 3: Price Comparison of Commercial PV Monitoring System [17]-[20].**

Sl. No.	Name	Manufacturer	Price (CAD)
1.	Geo Solo II PV	GEO	\$126.97
2.	Eco Eye Smart PV	Eco Eye	\$130.36
3.	Owl Intuition PV	OWL	\$135.45
4.	Solar Cache Wi-Link Kit Comprehensive Energy Monitor	DSM Energy Control Ltd.	\$659.02
5.	SMA Data Manager M powered by ennexOS	SMA Solar Technology AG	Not found
6.	Solarfox® Solar Display Systems	SOLEDOS GmbH	\$575.78

### 1.1.2 Findings of Literature Review:

After the literature review, it is found that the earlier monitoring systems were a wired system, they could provide a reliable solution but required a long data transmission cables. RS232 or RS485 cables were used for data transmission in wired monitoring systems. This physical system was expensive due to installation and maintenance cost. To overcome these shortcomings of the wired system, the wireless monitoring system is proposed.

For wireless data monitoring system, various type of data transmission technology has been applied to satellite, GSM, Zigbee, and other RF devices. Satellite data transmission is reported to be slow and installation is expensive. GSM based system is reliable and fast comparing with satellite but has low retransmission and data loss problem. On the other hand, the RF data transfer system is good to send data without the wire transmission line. The main disadvantages of RF system are high installation cost and required permission to set up. However, Wi-Fi is another alternative technology, which is a good wireless data communication system and has a higher data transfer rate. Wi-Fi data transmission has become popular however the cost of the Wi-Fi system is expensive and consumes lots of power.

Some low-cost and open source computer-based general data acquisition system is also proposed using a dedicated personal computer (PC) with USB or Serial RS-232 for communication. Moreover, LabVIEW™ based system for PV simulation and monitoring is also proposed. These data logger and monitoring system are mostly micro-controller based system using the cloud-based third-party server. This micro-controller based system is not cost effective as it requires a PC and internet connection for storing and monitoring data. Moreover, the Cloud-based system lacks the information security and privacy policy.

Currently, after the new era of internet, IoT based solutions are also proposed using Arduino and open source servers, for example, Thnikspeak and mobile apps like Blynk.

This type technology has become very popular and research is going on to make a low cost and easy to use the system, but the drawback of this type of data logger and monitoring system requires an internet connection which is not available in many rural areas.

To overcome the cost-effectiveness, data security and user-friendliness, this thesis propose a low-cost data logger and control system of the pico-solar system using ESP 32 with a local HTTP web server for data monitoring. This data logger will show the charging current and battery voltage, output power of the pico-solar system for rural area in a developing country. SD card will be used to store the historical data for analysis and troubleshooting of the PV system. Moreover, this data logger and monitoring system will increase the overall system efficiency by displaying the system parameter which also prevents the battery damage issue due to easy access through a local HTTP server without requiring an internet connection. Datalogger data can be downloaded locally from the web server using any internet browser like Mozilla Firefox, Internet Explorer etc. An Android App is also developed for monitoring all PV parameters.

### **1.3 Research Objectives:**

- Literature review on pico-solar energy systems.
- Load estimation and system sizing for a remote house in Bangladesh,
- Design of a low power and low-cost data logger for pico-solar energy system.
- Design of a cell phone App for data monitoring and analysis.

#### **1.4 Thesis Organization:**

Chapter 2 presents a detail of load estimation and system sizing for a remote house in Bangladesh. A model of the overall system design and simulation in HOMER Pro software is presented.

Chapter 3 discusses the design of a low power and low-cost data logger for pico-solar energy system. The details of hardware and software designed are discussed in this chapter.

Chapter 4 gives a detail discussion about designing a cell phone android App for data monitoring and analysis of PV energy system. It shows a real-time plot of all PV monitoring parameters.

Finally, the thesis concludes and provides recommendations and future work in chapter 5.

## **Chapter 02: Load Estimation and Sizing of Small PV System**



## **2.1 Introduction:**

Solar home system or standalone photovoltaic systems are becoming increasingly popular and low-cost solution for providing electricity for remote areas especially in the developing countries. This pico-solar system is changing the socio-economic condition of small villages of the third world countries where the on-grid connection is not available. As these countries often suffer for the shortage of electricity and some area are not covered by the grid distribution system because of distance and remote location, so Solar Home System (SHS) is playing an important role for rural electrification projects. People are facing difficulty in lighting up their houses in the night, they usually used kerosene to light up their house. Kerosene is both expensive and not environment-friendly, it emits CO<sub>2</sub> and pollutes the environment. However, due to the vast deployment of SHS, the residents of this remote areas are improving their lifestyle with the help of affordable and environment-friendly solar energy. The solar home system is very easy and low cost to implement in a remote area and it contains only three major parts of a solar panel, charge controller, and a battery. This small solar system which is called pico-solar system can provide lighting and run some small home appliances. The size of the panel and the battery depends on the user's demand for electricity. This chapter will discuss the detail of load estimation and system sizing of the pico-solar system. Moreover, modeling and optimization of this total system will also be simulated using HOMER.

## 2.2 System Description:

Solar home systems (SHS) are helping off-grid and remote homes of mainly developing countries across the world to access electricity and changing their life and promoting a better future. Currently, almost 1.2 billion people do not have access to electricity in the world and most of them are developing countries like Bangladesh [23]. Even in India, one-third of the population do not have electricity and some of them are suffering from power shortage. The solar home system is one of the major alternate sources to provide electricity for these peoples.

A typical rural house is shown in figure 2-1 in Shreemangal, Syhlet, Bangladesh which is disconnected from any grid line for its remote location. This type of house consists of one or two rooms and they did not have any electrical lighting system in the night time before the Solar Home System was installed.



**Figure 2- 1: A Rural House with Solar Home System in Sreemangal, Sylhet, Bangladesh.**

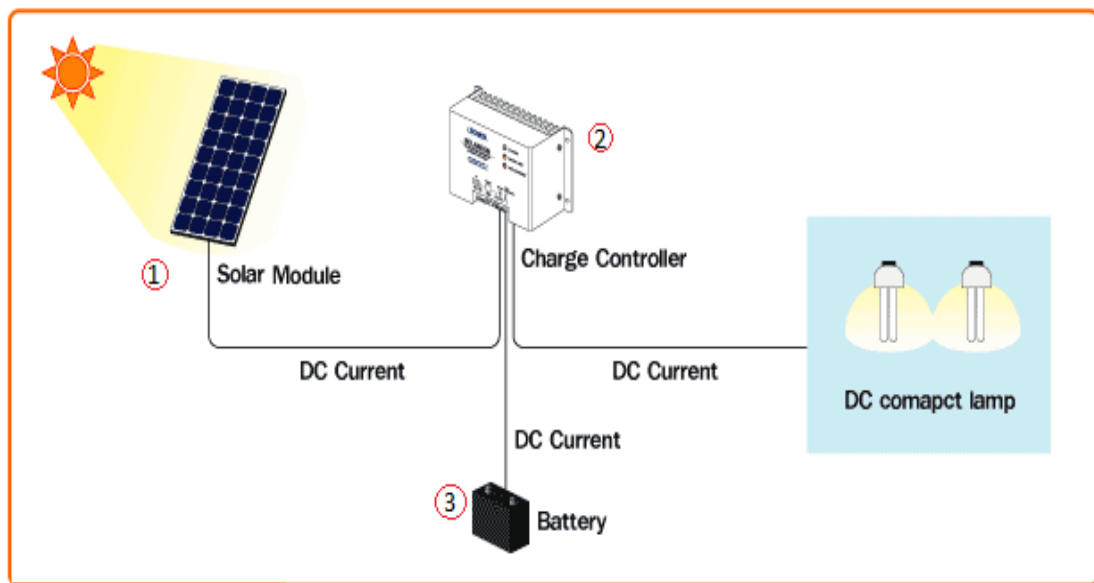
SHS can not provide that much power like grid connections to run color television or refrigerators but this system is capable to provide enough lighting and operating small home appliances like a small dc fan and charging mobile phones. A 20 watt-peak (Wp), the solar home system can provide 50 watt-hours (0.05 kWh) per day which is run by 3 small LED lights and a cell phone charger very effectively. A pico-solar panel of 20 Wp is shown in the figure 2-2. The benefits of using this SHS are huge compared to kerosene for lighting up houses and this system is safer and more reliable.



**Figure 2- 2: A Rooftop pico-solar panel of a rural house in Sreemangal, Sylhet, Bangladesh.**

Figure 2-3 presents different components of a Solar Home System. A SHS consists of mainly three major parts. They are the following:

- 1) Pico-solar panel
- 2) Charge controller and
- 3) Rechargeable battery



**Figure 2- 3: Different Components of Solar Home System [22]**

1) Pico-Solar Panel:

Solar home systems use photovoltaic (PV) cells and this PV cells are made from semiconductor materials such as silicon and generate DC electricity from sunlight. A different number of cells according to the size of PV are connected together and sealed in a waterproof case which called PV panel. Figure 2-4 presents a small PV panel which is

called Pico-Solar panel. These pico-solar panels range from 0.1 Watt-peak to 20 Watt-peak.



**Figure 2- 4: Pico-Solar Panel Set Up on the House Roof**

PV cells and panels are described by their capacity called watt-peak (Wp) rating and the generation depend on this capacity considering standard conditions and weather. Generally, 20 Wp or 30 Wp PV systems are using for the solar home system but a system with higher capacity are also available depending on the load like 40,50,60,100 and 130 Wp.

## 2) Charge Controller:

The solar charge controller is a controller that is used to control the charging of the solar appliances and also battery. The function of the controller is to regulate the voltage and current from the solar PV panel to the battery in order to prevent overcharging and also

over-discharging. Many technologies have been included in the design of a solar charge controller. For example, MPPT charge controller included maximum power point tracking algorithm to optimize the production of the PV cell or panel. Figure 2-5 shows a charge controller for SHS.

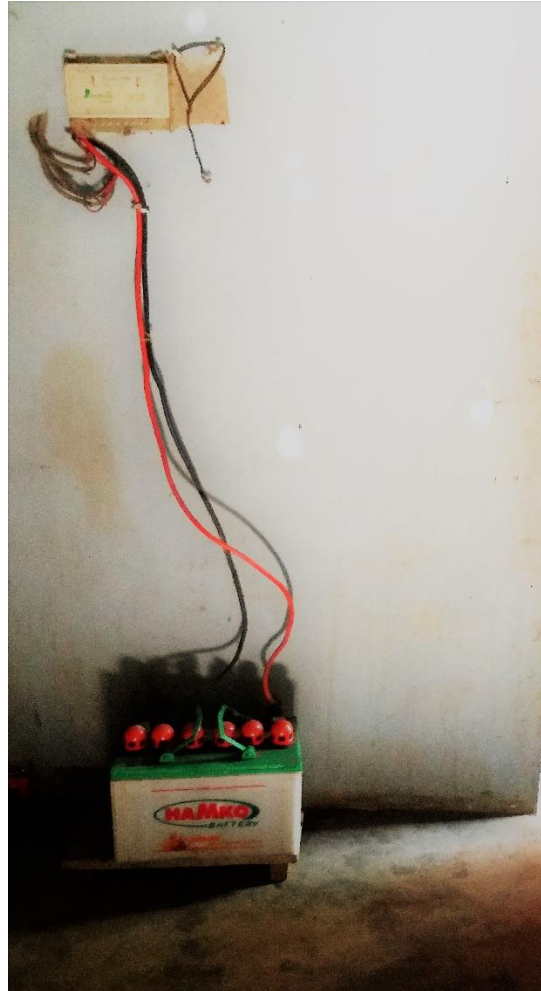


**Figure 2- 5: Pico-Solar Charge Controller Setup in the House Wall**

### 3) Rechargeable Battery:

Mainly rechargeable batteries are used to store electricity from the energy of sun using solar PV panel. The battery is used to store charge or electricity throughout the day so that it can provide the backup energy required to light up at the night or even on any cloudy day. This rechargeable battery is providing a stable voltage for the DC small appliances. Normally, a lead acid battery is used to store electricity and run small DC lights and fans. Figure 2-6 shows a rechargeable lead-acid battery for SHS. Nowadays, lithium-ion

batteries are also becoming popular for this purpose due to longer lifespan and fewer maintenance issues than a lead-acid battery.



**Figure 2- 6: Rechargeable Battery setup in the house of SHS**

### **2.3 Load Estimation:**

Load estimation or calculating the amount of energy required by a house is an important factor for selecting solar panel for Solar Home System. The total energy consumption or electrical load by adding the total demand for that house per day. SHS which uses a pico-

solar panel generates DC electricity for small DC appliances only. There is no need to use the inverter for SHS as all appliances operate on either DC 12 Volt or 5 V via USB port like LED light, a smartphone charger, and sometimes small Black & White television. So, the load estimation can be done by summing up all the electrical load or the DC demand of the house and based on this total load the size of the panel is determined for a SHS.

In SHS, low power appliances are used to operate on DC voltage which is totally different from the AC grid supply provided by power generation and distribution company. Nowadays, mostly used light devices like smartphones, radios, tablet computers are using a DC power supply. Actually, these appliances convert AC power supply to DC when they plugged into the main socket of 110 V or 240 V in the house. An adapter is used to convert this AC supply to DC and reduces voltage level which is compatible with these appliances.

Figure 2-7 shows a small panel with low-end DC appliances like LED lights.



**Figure 2- 7: Solar Home System with DC Load and Controller. [26]**



A pico-solar panel produces DC electricity, so there is no need to use an adapter or converter for the conversion from AC to DC to run appliances using this panel. Most of the pico-solar systems operate at 12 V. There are some other types of a smaller system called solar lanterns are operates at 5 V DC and provides a USB outlet to run this type of appliances. Figure 2-8 shows this type of system which is used for charging a small LED light and mobile phone charging. It has a small battery which stores solar energy to provide power for light or charging a mobile phone. In the recent development of technology, appliances with this 5 V of operation has got huge attention in the industry.



**Figure 2- 8: Pico- Solar Panel for USB light and Mobile Charger [27]**

This low operating voltage appliance made it easy to use pico-solar or solar home system, but the amount of current required to operate these appliances is also important. The required amount of current to operate the appliances should not drain the battery of the pico-solar system. It is a vital factor of SHS that the battery should not drain completely

by any appliances of the system. To protect and make the proper utilization of the pico-solar panel and battery, the user should understand the amount of current required by an appliance and should not completely drain the battery. For example, if a system is used to run only LED light and smartphones for hour hours but if a tablet computer which has four times higher capacity of the battery, is used to charge by the same system then it will drain the battery completely within an hour. Most of this SHS do not have any monitoring facility to track the State of Charge (SoC) of the battery and battery charging information. Some commercial monitoring systems are available but very expensive and not suitable for this SHS. So, for the longevity and overall safety of the entire system, it is very important to understand the system capability and load current requirement and calculate the total load for the SHS.

### **2.3.1 Theoretical Calculation:**

Load estimation or calculation of power consumption can be accomplished by multiplying the operating voltage with maximum current. For any appliance, it can be found out how much power it draws and the operation hour of that appliances to calculate watt-hours (Wh). Using this method, the load estimation can be performed to determine the exact size of the pico-solar panel for a specific house.

This load calculation should be accurate and precise to avoid the oversizing or under-sizing of a panel of SHS. For a battery-based system like SHS, it is useful to calculate the Watt-hour of all appliances. In table 2-1, different power requirement and run time of small appliances are presented based on a particular solar panel.

**Table 2- 1: Energy requirements of different appliances [28]**

Appliance	Power rating (Wp)	Based on pico-solar system with 5 V battery with 1500 mAh capacity	Notes
LED light (100 lumens)	1	5 hours run time	
LED light (20 lumens)	0.18	30 hours run time	
Small radio	1–10	5–15 hours (approx.) run time	Power draw varies slightly with volume
Mobile phone	2	100% charge System will fully charge up to two basic phones or one smartphone	Battery capacity typically varies between 600 mAh for rudimentary phones and 1500 mAh for smartphones
E-reader (basic e-reader device)	3	Up to 100% charge System will charge most e-readers, but may not achieve full charge	Battery size slightly larger than smartphones. E-readers with battery capacities above 1500 mAh will only partially charge
Tablet computer	10	25% charge (approx.) Will only provide partial charge for most tablets which tend to have battery capacities of around 6000mAh	This system will only provide a partial top up for tablet computers Tablets can be recharged with a larger pico-solar system with a module of 5–10 Wp and larger battery capacity above 6000 mAh

Load data or power consumption appliances of a pico-solar panel can be found on the manufacturer’s data sheet. Panel manufacturer provides all information related to load power requirement and operating hours. Usually, they provide LED light with this type of SHS. The average daily load can be calculated by the below formula:

$$\text{Daily load} = \text{wattage} \times \text{time in use} \quad [29]$$

$$DL = \text{Watt} \times \text{Time}$$

For example, a load of 10 watts can run for 2 hours then

$$DL = 10 \text{ watt} \times 2 \text{ hours} = 20 \text{ watt-hours.}$$

So, for a 10-watt pico-solar panel for running LED light and smartphone charging option and if the battery is 1000 mAh, then the system can run the LED light unit if the charge of the battery is available. The total run of this system depends on the load. If the system is used to recharge the smartphone's battery which has a capacity of 600 mAh, then there will be only 400 mAh left to run a LED light with 100 mAh capacity. So, it can run the LED light only for four hours. Moreover, if the system needs to charge another smartphone then it will only be charged partially and there will be no energy left to operate the LED light. In order to understand the system's capabilities to provide sufficient energy and the runtime of all appliances, load estimation needs to be done first.

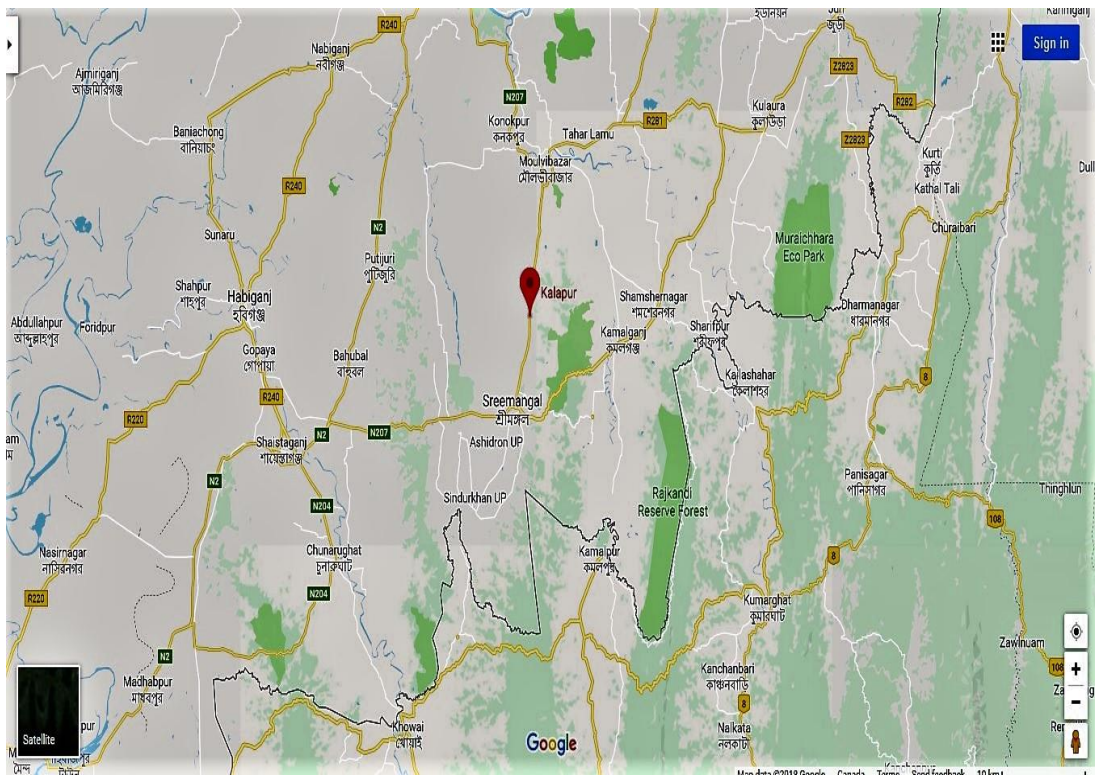
Table 2-2 represents different SHS with their capacity, battery and load wattage depending on different user and load for the rural electrification program run by UNDP and other local organization. Usually, the panel manufacturer provides all those components for setting a SHS in a rural area of developing countries. Moreover, the Government of this countries provides a subsidy for setting up SHS in the remote villages.

**Table 2- 2: Capacity and Load Estimation of Different Solar Home System**

Sl No.	System Capacity, Wp	12v Battery, Ah	Load	Instruments Provide by Supplier
1	20	30	3x3W LED light	Panel, Battery, Charge Controller, LED Lights
2	30	30	3x3W LED light	
3	40	40	3x3W LED light	
4	50	50	4x3W LED light	
5	60	60	4x3W LED light, 15" TV	
6	65	80	5x3W LED light, 15" TV	
7	75	80	6x3W LED light, 15" TV	
8	85	85	7x3W LED light, 15" TV	
9	90	100	7x3W LED light, 15" TV	
10	100	100	7x3W LED light, 15" TV	

### 2.3.2 Practical Data of a Remote Project Area:

For a real-life data acquisition, a remote area was selected from Bangladesh. The name of the village was Kalampur, Srimangal of Maulvibazar District in the Sylhet Division of Bangladesh which is in  $24.3010^{\circ}$  N,  $91.6955^{\circ}$  E coordinate. Figure 2-9 shows the location of the remote area on a map using google map's satellite view. The average daily global solar radiation is  $4.78 \text{ kWh/m}^2$  [24]. Five solar home systems were visited, and data was collected from different houses in that remote area.



**Figure 2- 9: Geographical Location of Project area in Sylhet, Bangladesh.**  
(adapted from google map)

In the time of visiting different SHS project for this thesis work, it is found that most of the Solar Home Systems use 20 W pico-solar panel. The panel comes with three LED lights of 3 W capacity, a charge controller for the battery, mobile phone charging point and a 12 V rechargeable battery.

Moreover, some larger SHS are also found in this visit for example of 75 Wp and 130 Wp solar panels. These panels are used for larger houses or small villages shop where the load requirement is high compared to the traditional house lighting system. A 75 Wp system uses 80 Ah of lead-acid battery to store solar energy and it supports the larger load of six LED tube lights each of 3W, one 5W mobile charging point and one black and white (B&W) television (TV) which is 10W. The other SHS is 130 Wp which consist of a 130Ah rechargeable lead-acid battery. This system is used to run seven LED tube light of 3W, one mobile charging outlet of 5W also one 15” black and white television of 10W. The details of the load and runtime are given in Table 2-3.

**Table 2- 3: Load and Runtime for the 75 Wp and 130 Wp SHS. [31]**

Sl. No.	Panel Size	Battery Size	Load	Qty.	Watts	Total Watts	Hours/Day	Wh	Total Wh
1	75 W	80Ah	LED Light	6	3	18	5	90	135
			Mobile Charger	1	5	5	3	15	
			TV(B&W)	1	10	10	3	30	
2	130 W	130Ah	LED Light	7	3	21	5	105	150
			Mobile Charger	1	5	5	3	15	
			TV(B&W)	1	10	10	3	30	

## 2.4 System Sizing:

For an optimal and cost-effective solution of using Solar Home System, system sizing plays a vital role. To minimize the cost of the panel size and the battery capacity should select properly and efficiently. Panel and battery size can be determined by considering the amount of available solar irradiation, system efficiency, derating factor, battery DoD (Depth of Discharge) and the number of autonomous days the system needs to operate while solar light from the sun is very less in a cloudy day or bad weather.

A load requirement of a rural house is presented in table 2-4, which was selected to be designed for SHS. Three LED lights of 3 W each is required to light up the house. LED lights are desired to run in the evening from 6 PM to 10 PM and a total duration of 4 hours.

A mobile phone charger is also required to operate by this system.

**Table 2- 4: Load estimation and system sizing for a SHS. [31]**

Sl. No.	Load	Qty.	Watts	Total Watts	Hours/Day	Wh	Total Wh
1.	LED Light	3	3	9	4	36	51
2.	Mobile Charger	1	5	5	3	15	

### 2.4.1 PV Panel Sizing:

The size of Photovoltaic solar panel can be calculated based on the total load estimation or energy requirement of a SHS. The estimated total load of the selected SHS is 51 Wh as

mentioned in table no. 2-4. So, the panel should generate some extra energy to meet the daily energy requirement of that house sufficiently. The approximate panel size can be calculated from the total load divided by the time duration of peak solar energy available and considering the overall system inefficiencies.

So, the panel size will be as below:

$$\begin{aligned}
 \text{Panel size (m}^2\text{)} &= \frac{\text{Total kWh use by appliances per day}}{(\text{solar hours per day}) \times \text{efficiency factor}} \quad [28] \\
 &= \frac{\text{Total kWh use by appliances per day}}{(\text{solar radiation per day}) \times \text{efficiency factor}} \\
 &= \frac{0.051 \text{ kWh/day}}{4.78 \text{ kWh/m}^2\text{/day} \times 0.056} \\
 &= 0.1905 \text{ m}^2
 \end{aligned}$$

From the above calculation, a panel with a minimum area of 0.1905 m<sup>2</sup> is required to meet the energy requirement. Here efficiency factor 0.056 is based on the overall system losses and inefficiencies like panel (10%), battery (70%), controller (80%) and wiring. An annual average solar radiation of 4.78 kWh/m<sup>2</sup> is considered per day based on the solar irradiation data found from **NREL's National Solar Radiation Database [25]**.

So, according to the load requirements, the panel size is selected to a standard 20 Wp pico-solar panel and the area of the panel is 0.2056 m<sup>2</sup>.



### 2.4.2 Battery Capacity:

The capacity should be selected in a way so that the battery would have sufficient capacity to store the energy generated by the solar panel and able to run all appliances as required by the user. The standard battery size for the pico-solar system is 3.6 V and 12 V depending on the system type and load.

Battery capacity can be calculated as below:

$$\begin{aligned} \text{Battery capacity in Amp-hours (Ah)} &= \frac{\text{energy requirement in Wh per day} \times \text{days of autonomy}}{\text{battery DoD} \times \text{system voltage (V)}} [2] \\ &= \frac{60 \text{ Wh per day} \times 3 \text{ day}}{0.80 \times 12 \text{ V}} \\ &= 18.75 \text{ Ah} \end{aligned}$$

Here, the load requirement is 60 W for the selected solar home system and battery DoD is 80%.

Practically, it is more preferred to select a battery with larger capacity to reduce the probability of battery draining to run all the appliances and considering more days of autonomy during the cloudy weather.

Considering future load hike and to make an efficient system, the SHSs are designed to select both panel and battery size so accurately. To overcome customer requirement and other system related issues like unavailability of solar energy, the size of the practical panel and battery size has been selected as 20 Wp and 30 Ah so that the system can support more appliances and longer hours as required.

To design the system of all components and their specifications of 20 watt-peak SHS are tabulated below:

**1. Panel:**

<b>Manufacturer</b>	<b>SolarLand</b>
Model	SLP020-12U
Cell type	Polycrystalline
Rated power	20 Watt
Nominal voltage	12 Volts
Open Circuit Voltage, Voc	21.6 Volts
Voltage at Pmax, Vpm	17.2 Volts
Short Circuit Current, Isc	1.31 Amp
Current at Pmax, Ipm	1.16 Amp
Length	22.68 in
Width	14.06 in
Weight	6.17 lbs

**2. Charge Controller:**

Manufacturer	Techno Sol
Model	TSCC-1210
Capacity	12 V and 10 A

### 3. Battery:

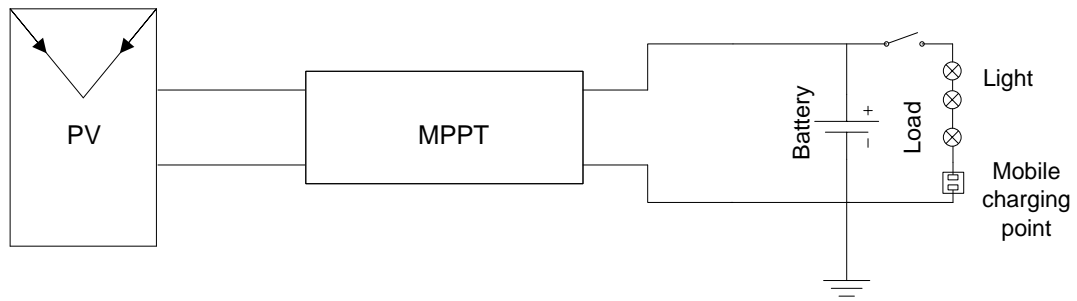
Manufacturer	Hamko
Model	HPD30T
Terminal Voltage	12 Volt
Capacity	30 Ah
Charging rate at C10	3
Dimension	301x170x190 MM

### 4. LED Tube Light:

Manufacture	Solarland
Model	SLL-L1903D
Operating current	400 mA
Input power	3 W
Lamp Flux	270 Lm
Dimension	300x23x28.5 mm.

### 2.1 System Block Diagram:

Figure 2-10 represents the overall system with three tube light and one cellphone charging point.

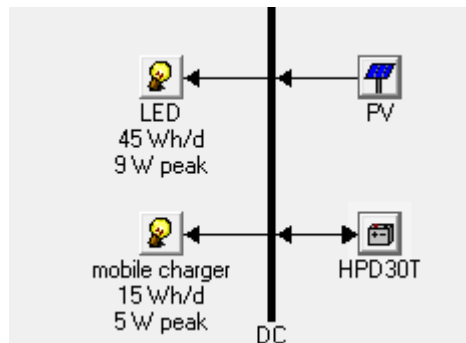


**Figure 2- 10: System Block Diagram.**

## 2.5 System Simulation:

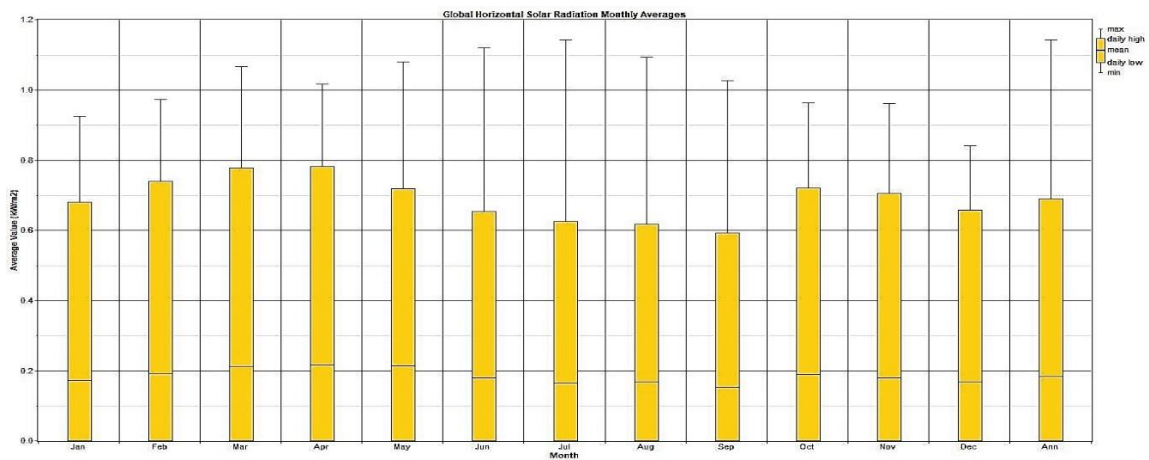
Three different Solar Home System (SHS) has been modeled and analyzed for optimal result in HOMER software [30]. HOMER is a microgrid software from HOMER Energy, developed by National Renewable Energy Laboratory, which is used to design and optimizing of microgrid system of renewable energies. System models are simulated by HOMER for all possible combination depending on the user consideration. The software examines all combinations of the modeled system and then sorts the combination results according to the optimization variable of choice.

### 2.5.1 SHS Model # 1:



**Figure 2- 11: System Modeling of 20 Wp SHS in HOMER**

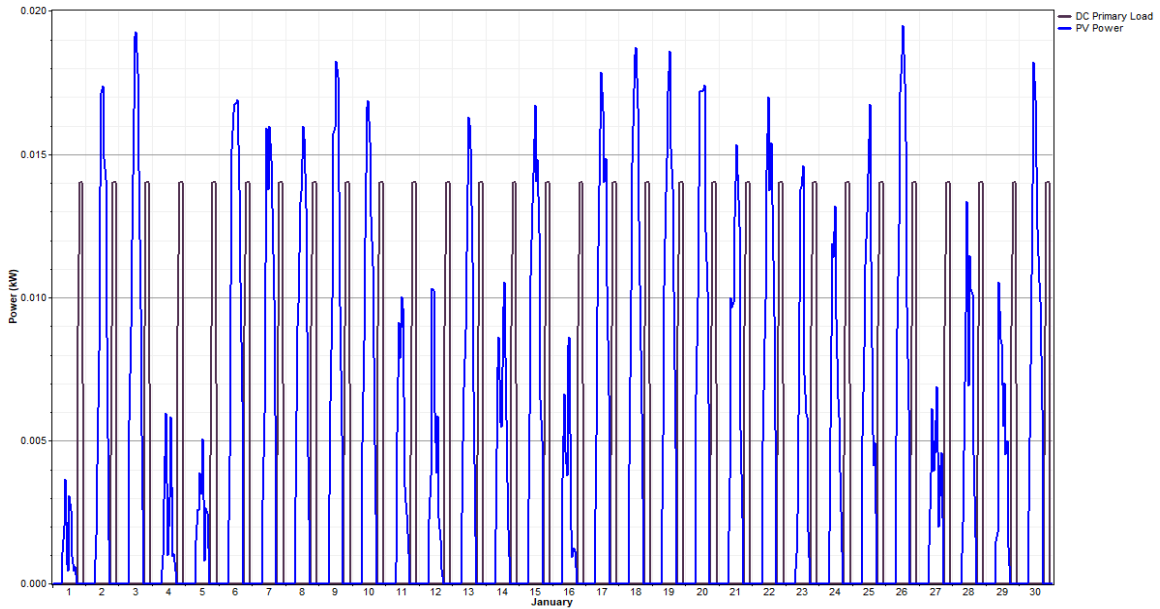
A 20 Wp SHS is presented in Figure 2-11, which consist of 20 Wp pico-solar panel with 30 Ah of battery and a load of three LED tube light and one mobile phone charger. LED tube lights are 3W each and these lights are running for 4 hours from 6 P.M. to 10 P.M. each day. A mobile charger of 5 W is also used to charge the phone for 3 hours each day. So, the average load and peak load for LED light are 36 Wh/d and 9 W respectively. For mobile phone charger, the average load is 15 Wh/d and peak load is 5 W.



**Figure 2- 12: Global Horizontal Solar Radiation Monthly Average in Srimangal, Sylhet. [30]**

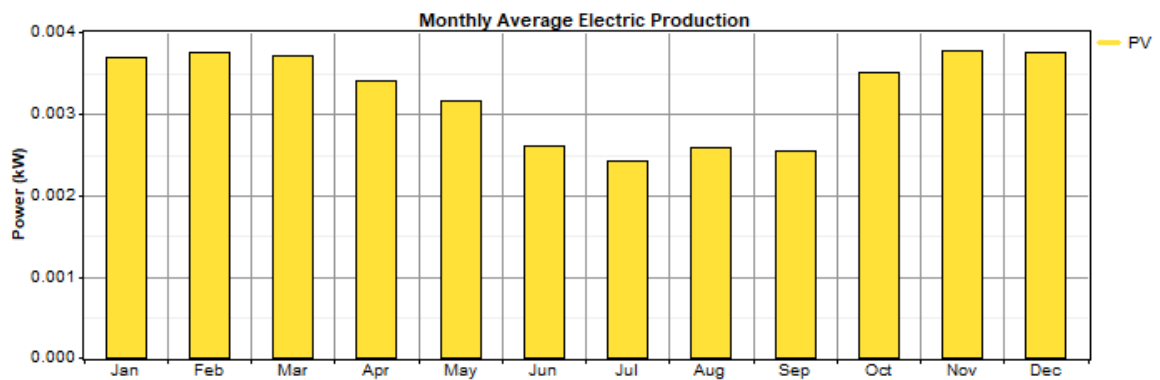
The average monthly global horizontal solar radiation for a year, starting from January to December is shown in figure 2-12, generated by HOMER software for the remote project area in Sylhet, Bangladesh. The annual average global solar radiation is 4.78 kWh/m<sup>2</sup>. The Photovoltaic panel generates electricity using this solar radiation information fetched by Homer software according to the longitude and latitude data of the remote area. The PV

panel output and peak load are shown in the figure 2-13. The average panel output is around 20 Wp and the peak load is 15 W for the simulated model 01.



**Figure 2- 13: Monthly PV Power Output and DC Load**

Figure 2-14, presents the average monthly electric power production by the 20 Wp pico-solar panel, simulated by the HOMER software. It is showing average values of different months of a year from January to December. From the HOMER optimization, the total net

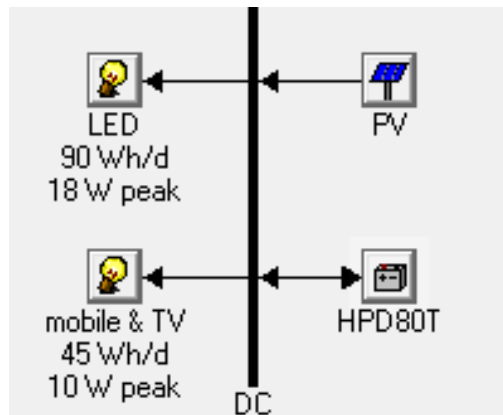


**Figure 2- 14: Monthly Average Electric Power Production.**

present cost (NPC) is CA \$810, levelized cost of energy is (COE) is CA \$4.430/kWh and the yearly operating cost is CA \$ 62. The price of the PV panel and battery is CA \$120 and \$79 respectively where the installation cost is included in the panel cost. However, according to HOMER software, the best-optimized panel for this load is 10 Wp with 30 Ah of the battery. The NPC and COE are CA \$600 and CA \$3.280/kWh.

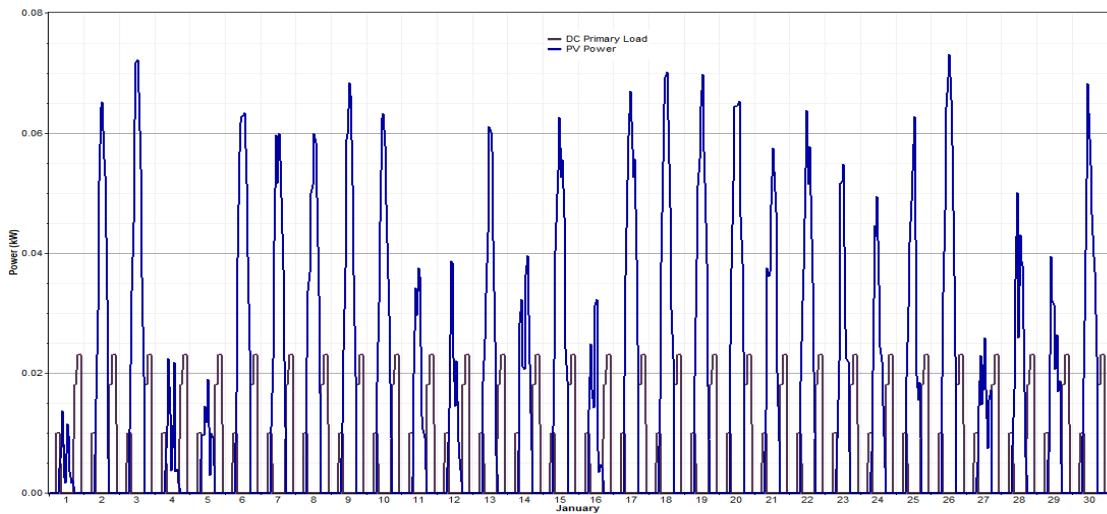
### 2.5.2 SHS Model # 2:

A 75 Wp SHS is presented in Figure 2-15, which consist of 75 Wp pico-solar panel with 80 Ah of battery and load of six LED tube light, one mobile phone charger and one black & white television (TV). LED tube lights are 3W each and these lights are running for 5 hours from 5 P.M. to 10 P.M. each day. A mobile charger of 5 W and 10 W black& white TV are also used to operate for 3 hours each day. So, the average load and peak load for LED light are 90 Wh/d and 18 W respectively. For mobile phone charger and TV, the average load is 45 Wh/d and peak load is 10 W.



**Figure 2- 15: System Modeling of 75 Wp SHS in HOMER**

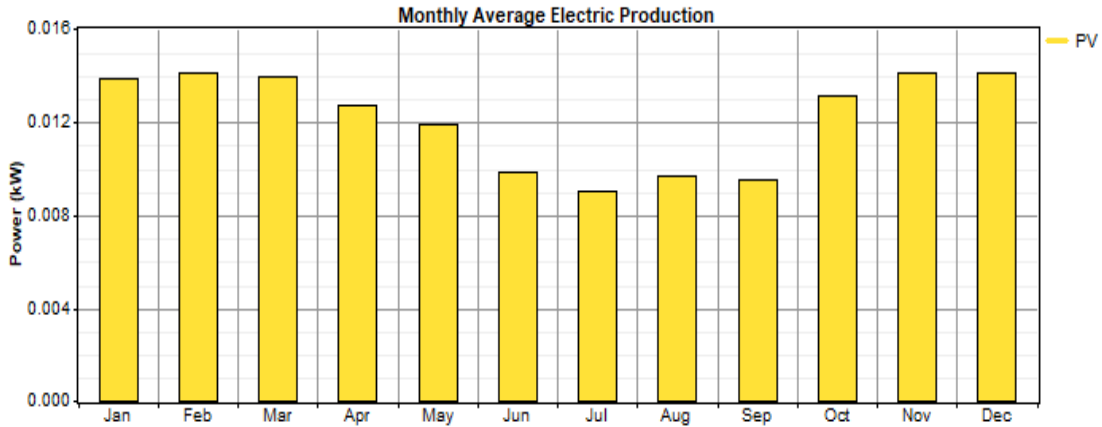
As mentioned earlier, the annual average global horizontal solar radiation is 4.78 kWh/m<sup>2</sup>, using this solar radiation information, Homer software generates PV output. The PV panel output and peak load are shown in the figure 2-16. The average panel output is around 75 Wp and the peak load is around 23 W for the simulated model 02.



**Figure 2- 16: Monthly PV Power Output and DC Loads**

Figure 2-17, presents the average monthly electric power production by the 75 Wp pico-solar panel, simulated by the HOMER software. It is showing average values of different months of a year from January to December. From the HOMER optimization, the total net present cost (NPC) is CA \$ 1642, levelized cost of energy is (COE) is CA \$3.393/kWh and the yearly operating cost is CA \$ 121. The price of the PV panel and battery is CA \$290

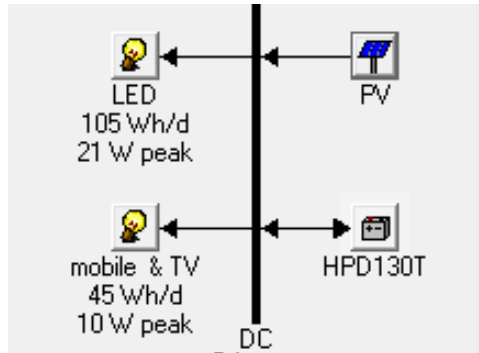




**Figure 2- 17: Monthly Average Electric Production for 75 Wp panel.**

and \$161 respectively where the installation cost is included in the panel cost. However, according to HOMER software, the best-optimized panel for this load is 40 Wp with 90 Ah of the battery. The NPC and COE are CA \$1201 and CA \$2.482/kWh.

2.5.3 SHS Model # 3:

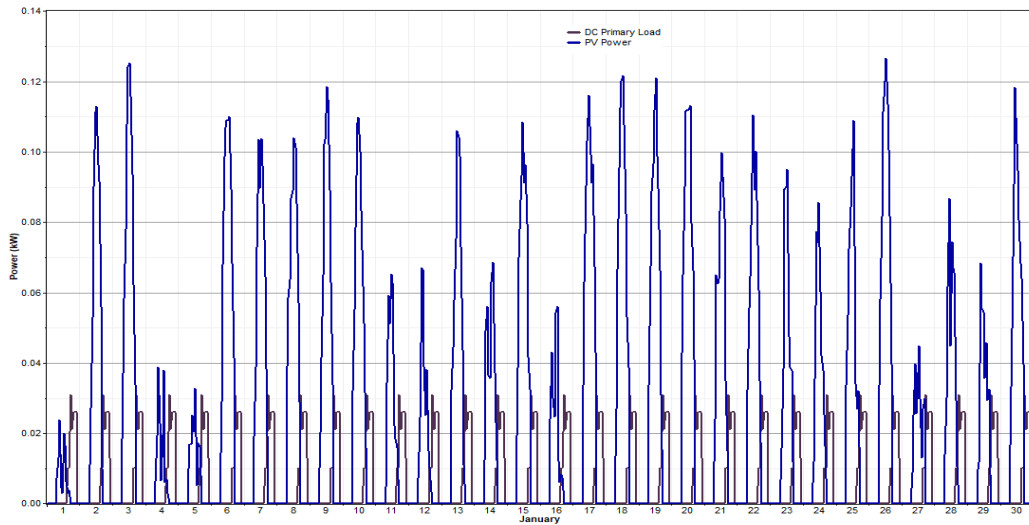


**Figure 2- 18: System Modeling of 130 Wp SHS in HOMER**

A 130 Wp SHS is presented in Figure 2-18, which consist of 130 Wp pico-solar panel with 130 Ah of battery and load of seven LED tube light, one mobile phone charger and one black & white television (TV). LED tube lights are 3W each and these lights are running

for 5 hours from 5 P.M. to 10 P.M. each day. A mobile charger of 5 W and 10 W black& white TV are also used to operate for 3 hours each day. So, the average load and peak load for LED light are 105 Wh/d and 21 W respectively. For mobile phone charger and TV, the average load is 45 Wh/d and peak load is 10 W.

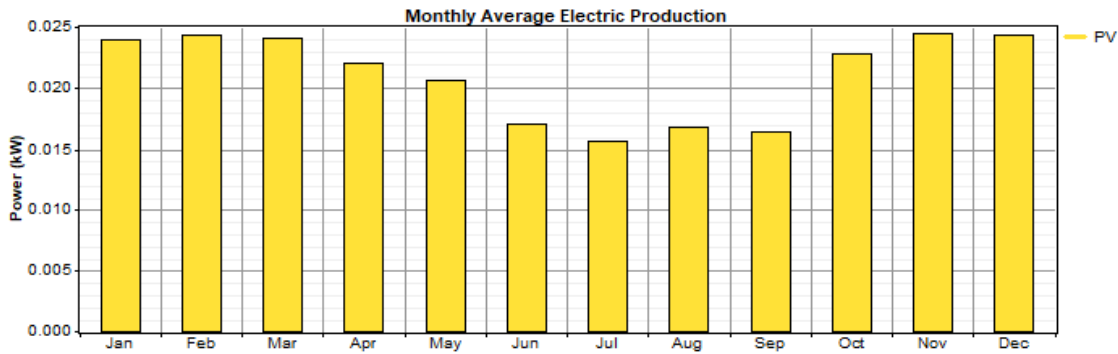
As mentioned earlier, the annual average global horizontal solar radiation is 4.78 kWh/m<sup>2</sup>, using this solar radiation information, Homer software generates PV output. The PV panel output and peak load are shown in the figure 2-19. The average panel output is around 130 Wp and the peak load is around 31 W for the simulated model 03.



**Figure 2- 19: Monthly PV Power Output and DC Loads**

Figure 2-20, presents the average monthly electric power production by the 130 Wp pico-solar panel, simulated by the HOMER software. It is showing average values of different months of a year from January to December. From the HOMER optimization, the total

net present cost (NPC) is CA \$ 2152, levelized cost of energy is (COE) is CA 4.001/kWh and the yearly operating cost is CA \$ 146. The price of the PV panel and battery is CA



**Figure 2- 20: Monthly Average Electric Production for 75 Wp Panel.**

\$460 and \$254 respectively where the installation cost is included in the panel cost. However, according to HOMER software, the best-optimized panel for this load is 100 Wp with 130 Ah of the battery. The NPC and COE are CA \$1842 and CA \$3.426/kWh.

## 2.6 Conclusion:

Solar Home System (SHS) has greatly enhanced the rural electrification program in the many developing countries where grid connection is not available for the remote locations. SHSs are not only lighting up homes but also contributing a lot to the economic development of the society. The size of the system depends on the load requirement of the house. Load estimation and system sizing are very important for designing a SHS. Three different capacities of SHS are designed according to their load requirements and the designs are also simulated in HOMER software for the best-optimized results and presented in this second chapter. In the next chapter system, instrumentation and data logging will be discussed.

## **Chapter 03: Design of Low Power Data Logger for Pico-Solar System**

### **3.1 Introduction:**

Monitoring and data logging is an essential part for the proper and efficient operation of any solar energy system. The monitoring system is used to protect the overall system especially PV panel and battery. Usually, almost all monitoring system for Solar PV system displays PV voltage, current, power on the system display monitor or LCD screen. For sophisticated monitoring system and control purposes along with those parameters, other environmental data like panel temperature, ambient temperature, solar radiation, wind speed, can also be data logged and analyzed those data later on for system maintenance and troubleshooting. Monitoring and controlling can be performed by various local and remote connection method, for example, an analog modem, GSM, USB, and RS232, are commonly used for data acquisition from the PV system. Recently wireless connection of Bluetooth and Wi-Fi is used for both local or remote control and monitoring system design.

Data logging of an energy system can be done by storing all monitoring parameters using a different type of analog or digital sensors. Data is stored in the datalogger device or in the external memory card. This memory can be increased or update depending on the user requirement. The complexity of the data logger depends on the required numbers of the sensor, data collecting device and the technology or method using for the acquisition of data.

PV monitoring and data logging systems require a huge number of input parameters and these types of system is very expensive [32]. There are some commercial monitoring systems for PV solar energy system with the option of on-grid or off the grid. However, this complex and expensive monitoring and data logging system is not suitable for small PV system. To overcome the technological and cost limitation, an Arduino, ESP32, and Wi-fi based datalogger have been designed to provide a low cost, reliable and user-friendly monitoring system for pico solar energy system, mainly for the rural electrification programs in developing countries in Asia and Africa.

### **3.2 Datalogger Description:**

To provide a low-cost low power data logger for pico PV monitoring for the rural electrification in the developing countries like Bangladesh, India, Nepal etc. an ESP32 microcontroller-based system is designed using Arduino IDE software. Three basic PV parameters and two meteorological information are logged by the monitoring system. It has a simple local web server which is configured using HTML language, and the monitored parameters are stored in a micro SD card. All the monitoring parameters are saved in a text file and can be download from the web page through an internet browser like Firefox Mozilla, Google Chrome or even Microsoft Edge by the end user.

2 ADC pins of ESP32 are used to get the analog values of the battery charging current and battery or load voltage of pico PV energy system. To measure the charging current,  $I_c$  a ACS712 Current Sensor IC of Allegro MicroSystems is used. For the load or battery

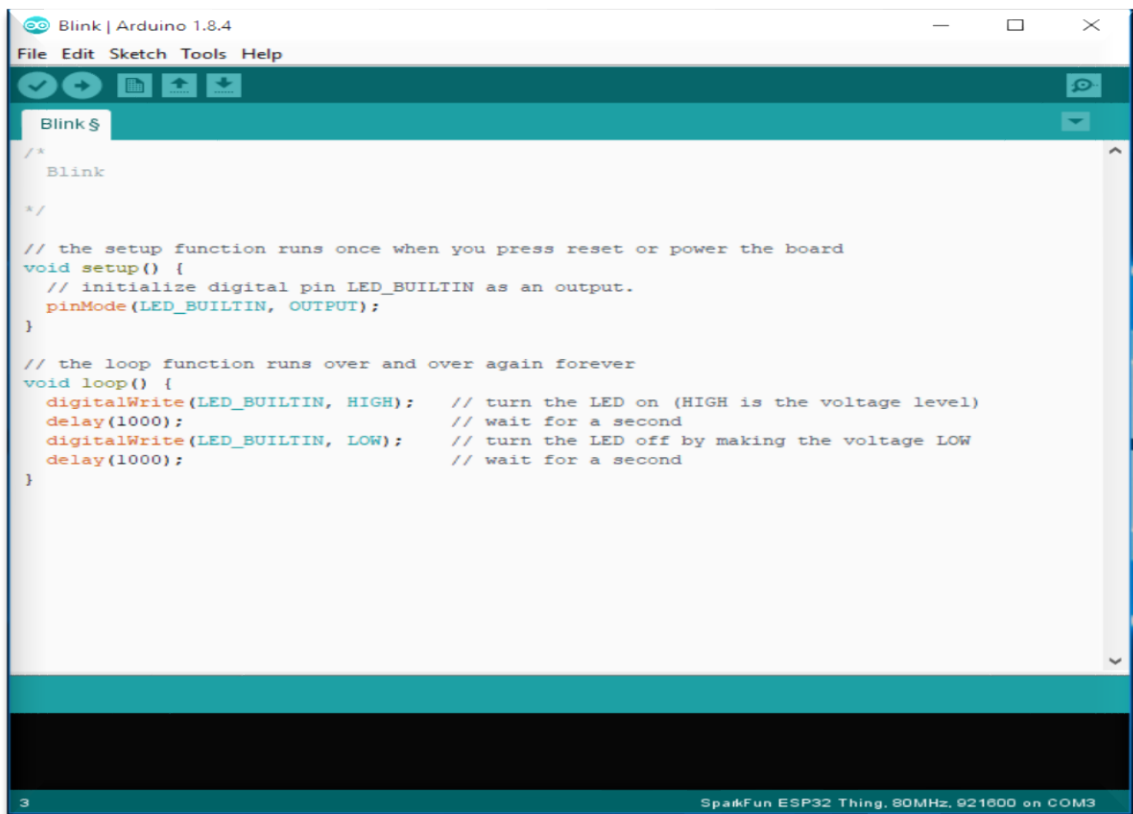
voltage measurement, a voltage sensor from MH Electronic is used which is a simple voltage divider circuit. The output power generated by the small PV is also displayed in the HTML web page. Other two ADC pins are used for the ambient temperature and presence of sunlight.

There is microswitch to control the data writing on the SD card, initially, it is normally open (NO). If the user wants to remove or replace the SD card, then the user needs to press the microswitch and there is also a LED which will lit up to show that it is safe to remove SD card.

The detailed hardware is design discussed throughout this chapter. An android app for displaying those monitoring parameters is also developed which is discussed in the next chapter.

### **3.2.1 Arduino IDE:**

Arduino integrated development environment (IDE) is a cross-platform application which is written for both Windows and Linux operating systems using Java programming language. Arduino IDE is developed by Arduino and it originated from the IDE for the languages Processing and Wiring. The IDE consists of a text editor for writing code, a compiler, and debugger to compile the code and checking errors in the code. It supports the languages C and C++ using special rules of code structuring. Figure 3-1 shows an Arduino IDE sketch.



```
Blink | Arduino 1.8.4
File Edit Sketch Tools Help
Blink$
/*
 * Blink
 */
// the setup function runs once when you press reset or power the board
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(LED_BUILTIN, OUTPUT);
}
// the loop function runs over and over again forever
void loop() {
  digitalWrite(LED_BUILTIN, HIGH); // turn the LED on (HIGH is the voltage level)
  delay(1000); // wait for a second
  digitalWrite(LED_BUILTIN, LOW); // turn the LED off by making the voltage LOW
  delay(1000); // wait for a second
}
3 SparkFun ESP32 Thing, 80MHz, 921600 on COM3
```

**Figure 3- 1: Arduino IDE [33]**

A software library from the Wiring project is supplied by Arduino IDE, which offers many common input and output procedures. In this IDE a code only requires two basic functions, one is set up which initializes all modes and setup of different pins. The other function is a loop which executes in the cyclic order of its commands. The Arduino IDE uses the *avrdude* program to convert the executable code into a text file in a hexadecimal encoding which is loaded into the microcontroller board by a loader program in the board's firmware [33].

### 3.2.2 ESP32:

ESP32 is a microcontroller from Espressif and the SparkFun ESP32 Thing is a WiFi-compatible comprehensive development platform. It has 28 GPIO pins, 802.11 B/G/N integrated WiFi transceiver. ESP32 is a **WiFi**-compatible microcontroller, but to that, it adds support for **Bluetooth low-energy**, and nearly 30 I/O pins. The ESP32's power and versatility will help make it the foundation of IoT and connected projects for many years to come. Figure 3-2 depicts a SparkFun ESP32 Thing. [34]



**Figure 3- 2: SparkFun ESP32 Thing [34]**

The operating range of SparkFun ESP32 is 2.2 to 3.6V and it is also a low power consumption device(less than 100mA). There are 18 analog-to-digital converter (ADC) and 2 digital-to-analog converters (DAC) channels and 3 SPI interfaces. Table 3-1 represents the brief hardware overview of SparkFun ESP32 Thing. [35]



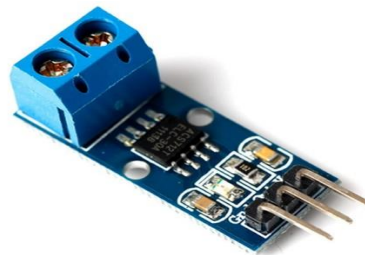
**Table 3- 1: Hardware Overview of SparkFun ESP32 Thing. [35]**

Item	Description
Processor	Dual-Core Tensilica Lx6
Clock Frequency	Up To 240 MHz
SRAM	520KB Internal
GPIO	28
Operating Range	2.2 to 3.6 V
Flash Memory	4MB
DAC	2
ADC	17
Features	Wi-Fi, Bluetooth, Touch, Encryption, Li-Ion Battery

### 3.2.3 Sensors:

#### 3.2.3.1 Current Sensor:

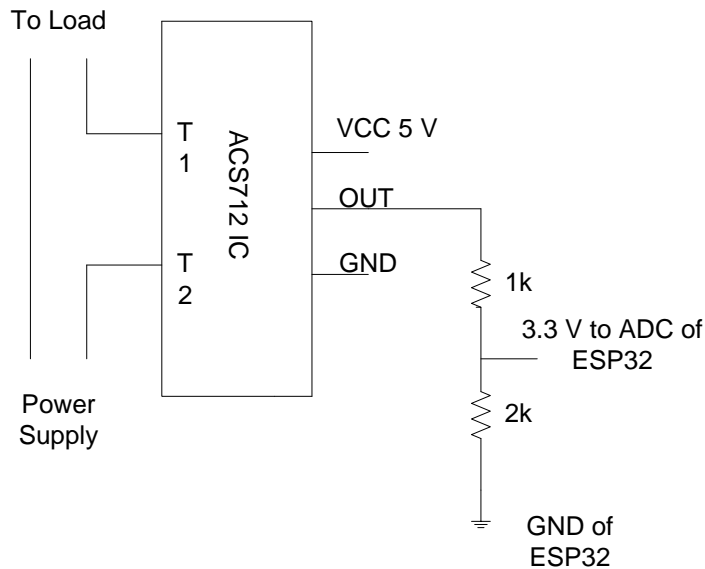
ACS712 Current Sensor IC of Allegro MicroSystems is used to measure the charging current,  $I_c$  of PV system at the maximum power point tracking (MPPT) controller, generated by the small PV panel. ACS712 provides economical and precise solutions for AC or DC current sensing in the



**Figure 3- 3: ACS712 Current Sensor [36]**

industrial, commercial, and communications systems. The device consists of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. The operating voltage is 5 V single supply and the output voltage is proportional to AC or DC currents. The ACS712 sensor has low- noise analog signal path and a sensitivity of 66 to 185 mV/A. It can measure up to 20 A of the input current of a load. Figure 3-3 shows a ACS712 Current Sensor.

As the maximum input voltage on the SparkFun ESP32 Thing is 3.3 V, so the output of the ACS712 current sensor requires pull-down resistors to adjust that output value from 5 V to 3.3 V for ESP32. Figure 3-4 shows the schematic diagram of this setup. A 0 (zero) ampere input current gives 2.5 V output at the ACS712 output pin and 1.66 V ( $2.5 \times \frac{2}{3}$  V) to the analog input pin of ESP 32, with a span of 2.5 V for a positive current increase above 2.5 V and negative current drops below 2.5 V.



**Figure 3- 4: ACS 712 pull-down resistor setup**

### 3.2.3.2 Voltage Sensor:

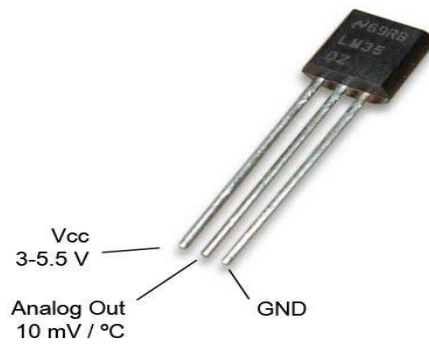
A voltage sensor from MH Electronic is used to measure the load or battery voltage of the PV system which is a is used which is a simple voltage divider circuit. It is basically a 5:1 voltage divider using a 30K and a 7.5K Ohm resistor. This voltage sensor can only measure up to 25 V of the input voltage and its operating voltage range is 3.3 V to 5 V. The Voltage detection range is 0.02445 to 25 V DC and voltage analog resolution is 0.000806 V for 12-bit ADC. Figure 3-5 represents a voltage sensor.



**Figure 3- 5: A Voltage Sensor [37].**

### 3.2.3.3 Temperature Sensor:

A LM35 is an ideal temperature sensor for measuring ambient temperature. It provides a linear output proportional to the temperature, with 0 V corresponding to 0 degrees C and an output voltage change of 10 mV for each degree C change. LM 35s are easier to use than thermistors and thermocouples because they are linear and require no signal conditioning. Figure 3-6 shows a temperature sensor. [38]



**Figure 3- 6: LM 35 Temperature Sensor. [38]**

The output of an LM35 can be connected directly to a ESP32 analog input. ESP32 analog-to-digital converter (ADC) has a resolution of 4096, and the reference voltage is 3.3 V, the equation used to calculate the temperature from the ADC value is:

$$\text{temp} = ((3.3 * \text{analogRead}(\text{TempPin})) / 4096) * 100.0 \quad [39]$$

#### **3.2.3.4 LDR:**

Light Dependent Resistors (LDR) or photoresistors are often used in circuits where it is necessary to detect the presence or the level of light. LDR is a special type of resistor that allows higher voltages to pass through it, that means low LDR resistance, whenever there is a high intensity of light and passes a low voltage, that means high LDR resistance, whenever it is dark [40]. Figure 3-7 shows an LDR which is used in this thesis work.



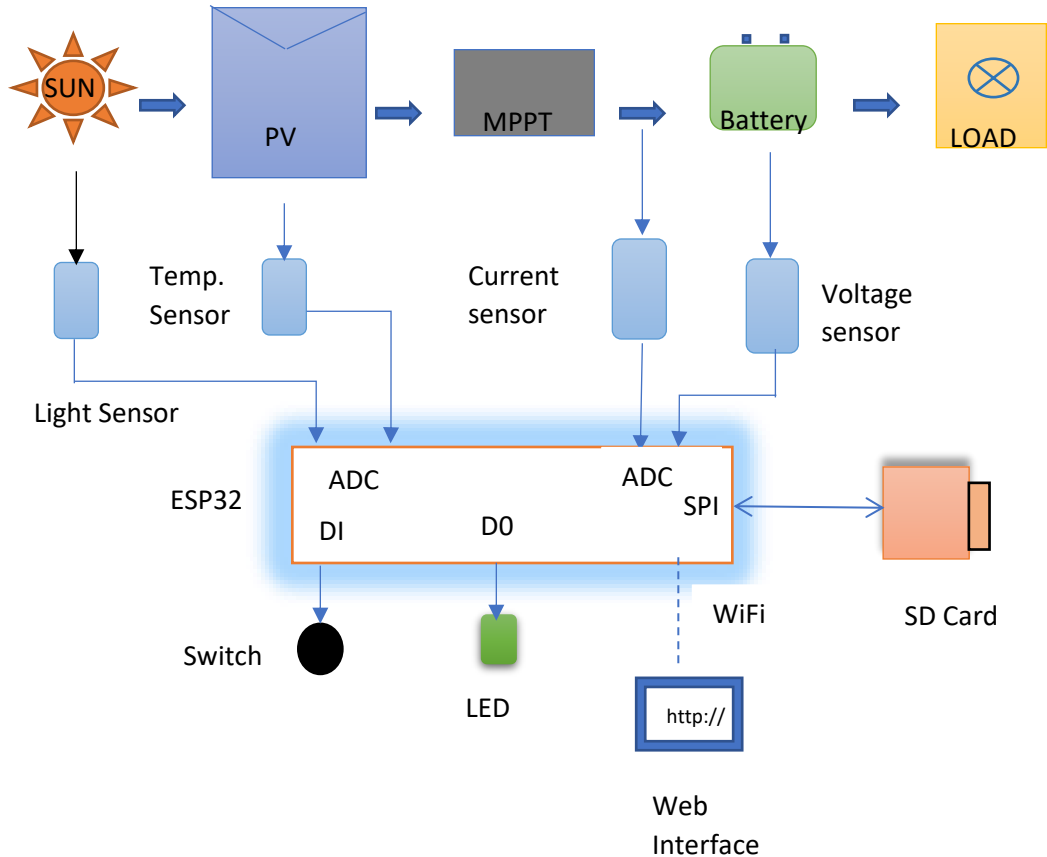
**Figure 3- 7: Light Dependent Resistors [41]**

The LDR gives out an analog voltage when connected to VCC (3.3V), which varies in magnitude in direct proportion to the input light intensity on it. That is, the greater the intensity of light, the greater the corresponding voltage from the LDR will be. Since the LDR gives out an analog voltage, it is connected to the analog input pin on the ESP 32. The ESP 32, with its built-in ADC (analog-to-digital converter), then converts the analog voltage (from 0-3.3V) into a digital value in the range of (0-4095). When there is sufficient light in its environment or on its surface, the converted digital values read from the LDR through the ESP 32 will be in the range of 3000-4095. [40]

### **3.3 System design:**

For the implementation of datalogger for a pico PV energy system, a blew depicted system was designed for this thesis work in figure 3-8.

### 3.3.1 System Block Diagram:



**Figure 3- 8: Block Diagram of Datalogger System**

### 3.3.2 Hardware Setup:

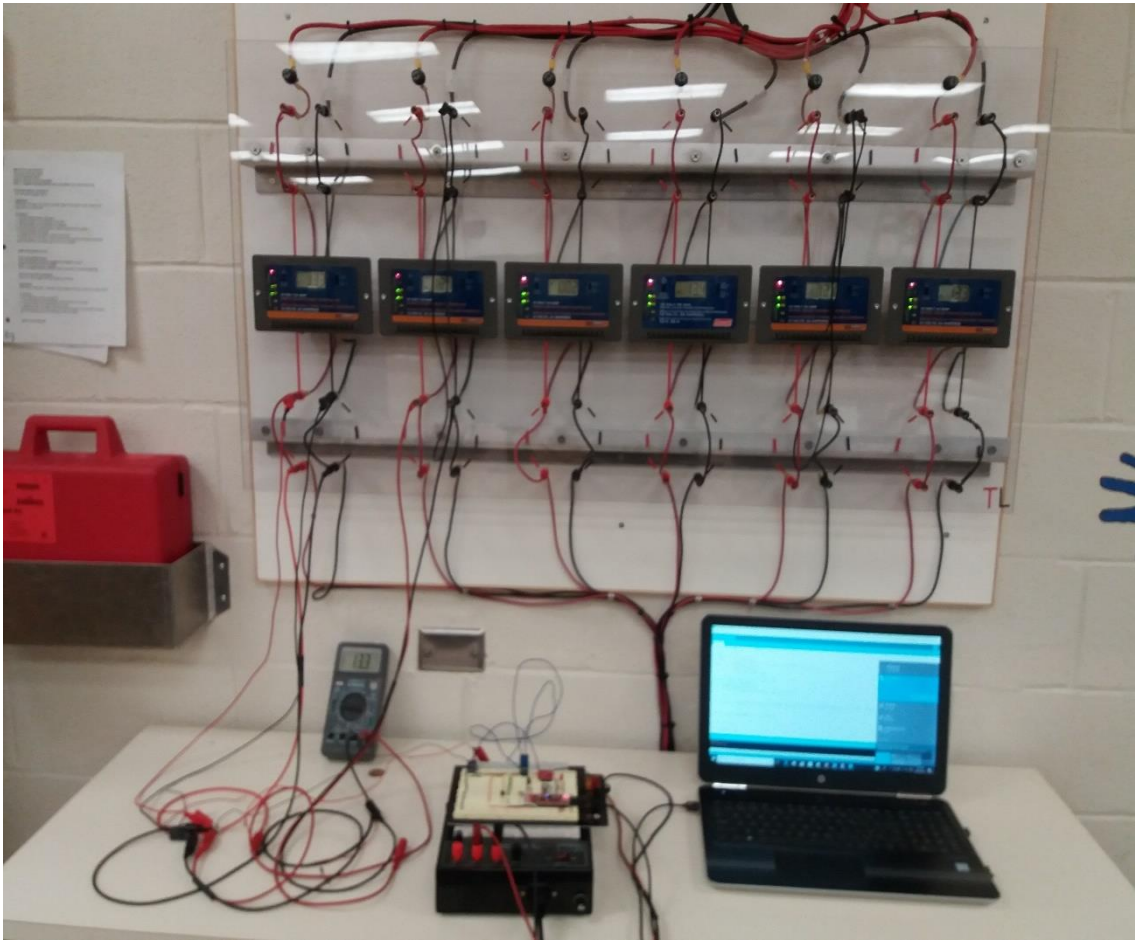
To develop a PV datalogger and monitoring system, a low-cost hardware has been implemented on a breadboard. ESP 32 development board, sensors, and SD card have been purchased from different sources. Figure 3-10 shows the hardware setup with the solar PV system.

To verify the functionality of the developed datalogger, it has been tested with an actual solar PV system setup which is installed in the laboratory at the Department of Electrical

and Computer Engineering, Memorial University, St. John's, Canada. It has 12 solar panels up to 130 watts and 7.6 amps each. Two modules are connected in parallel. So, it consists of 6 sets of 260 watts each. Figure 3-9 shows the installed solar PV panel. Only one set was used for this work.



**Figure 3- 9: Solar Panel Installed in Engineering Building**



**Figure 3- 10: Designed Datalogger Hardware Setup**



### 3.3.2.1 Schematic Diagram:

Figure 3-11 shows the schematic diagram of the designed datalogger hardware with all the analog to digital (ADC), digital to analog (DAC) input/outputs, serial peripheral interface(SPI) connection for SD card.

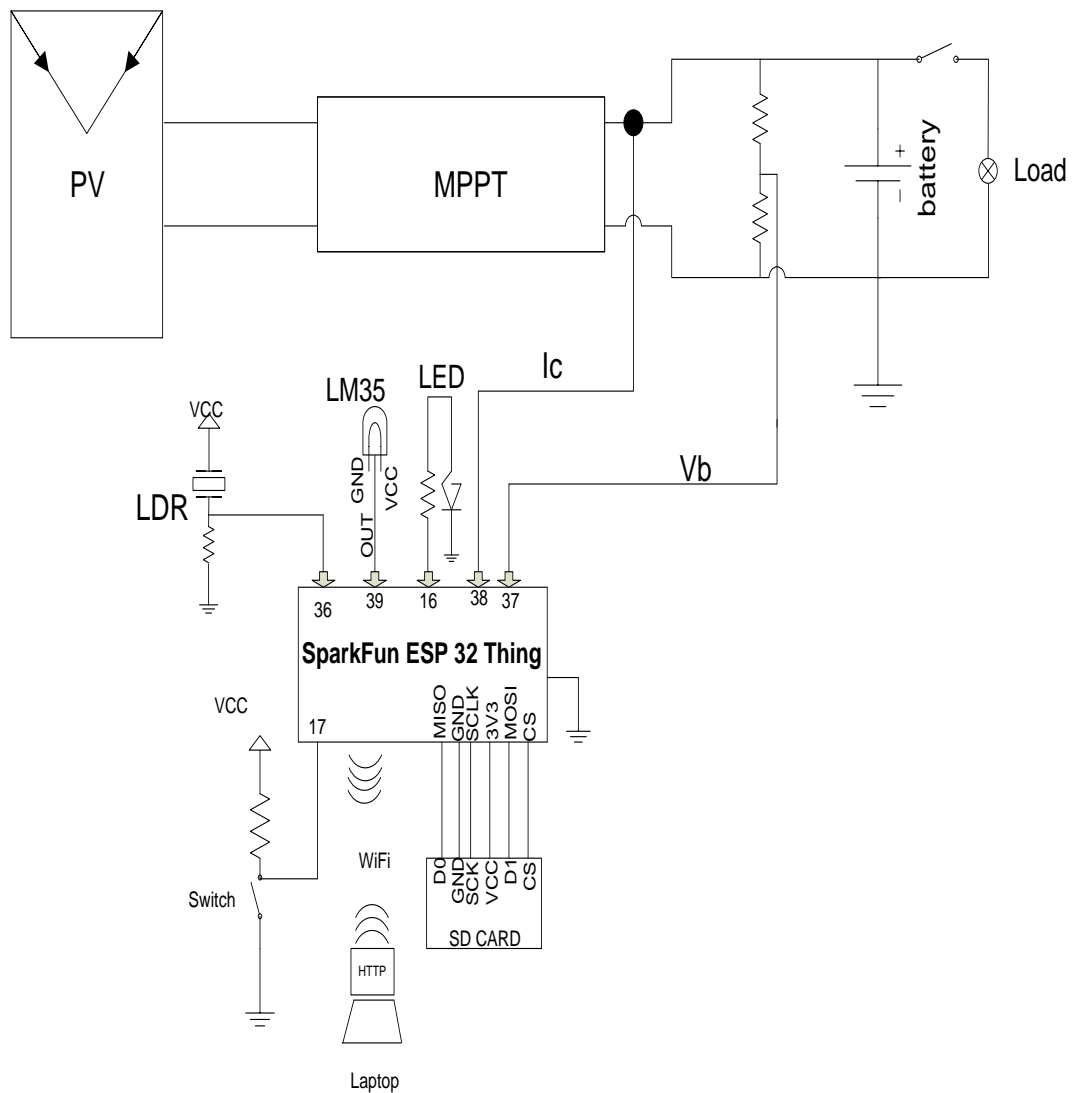
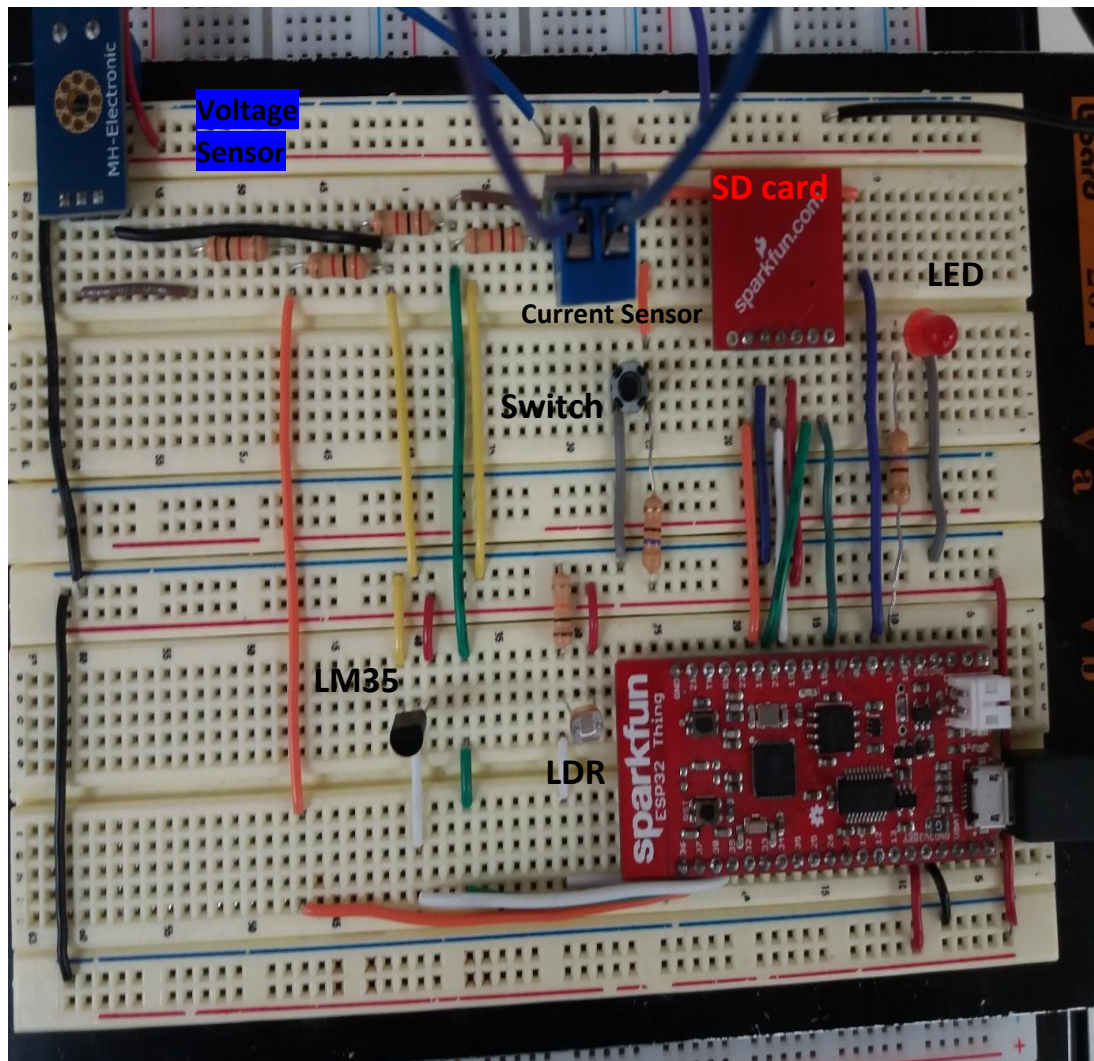


Figure 3- 11: Schematic Diagram of Datalogger System

### 3.3.2.2 Prototype Image:

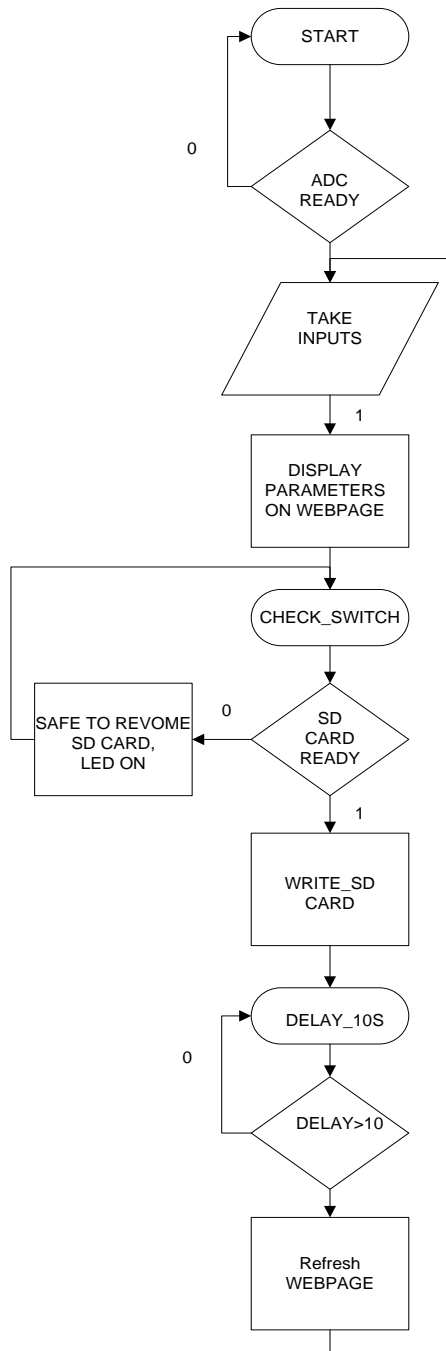
figure 3-12 depicts the prototype of the designed datalogger hardware.



**Figure 3- 12: Prototype of Datalogger System**

### 3.3.2.3 Software Flowchart:

Figure 3-13 represents the flow chart of designed datalogger using ESP32.



**Figure 3- 13: Datalogger Design Flow Chart.**

### 3.3.2.4 Programming of ESP32:

ESP32 is programmed using Arduino IDE software which is an open source software and the code is written in C language. The below code is for acquiring PV parameters from all analog sensor using SparkFun ESP32.

```
#include <WiFi.h>
#include <SPI.h>
#include <SD.h>

// WiFi Definitions //

const char *ssid = "ESP32";
const char *password = "123";

// Pin Definitions //

const int LED_PIN = 16;

const int chipSelect = 2;
int SwitchPin = 16;
int LedPin = 17;

int SwitchStatus;

int sensorPin = 36; // select the input pin for ldr
int sensorValue = 0; // variable to store the value coming from the sensor

WiFiServer server(80);

void setup()
{
  Serial.begin(115200);
  initHardware();
  setupWiFi();
  server.begin();
  intSDcard ();
```

```

// Open serial communications and wait for port to open:
//Serial.begin(9600);
while (!Serial)
{
  ; // wait for serial port to connect. Needed for native USB port only
}

}

void loop()
{
  // Check if a client has connected
  WiFiClient client = server.available();
  if (!client) {
    return;
  }

  // Read the first line of the request
  String req = client.readStringUntil('\r');
  Serial.println(req);
  client.flush();

  // The client will actually be disconnected
  // when the function returns and 'client' object is destroyed
  SwitchStatus = digitalRead(SwitchPin);
  Serial.println(SwitchStatus);

  // make a string for assembling the data to log:
  String dataString = "";

  // read three sensors and append to the string:
  String dataString = "";

  float sensor = (((analogRead(37)*3.3)/4095)*1.5)/0.2;
  float sensor2 = (((analogRead(38)*3.3)/4095)*1.5)-2.5)/0.1;

  dataString += String(sensor);
  dataString += ",";
  dataString += String(sensor2);

  delay(10000);
}
//open file in SD card

```

```

File dataFile = SD.open("/datalog.txt", FILE_APPEND);

// if the file is available, write to it:
if (dataFile) {
  dataFile.println(dataString);
  dataFile.close();
  // print to the serial port too:
  Serial.println(dataString);
}
// if the file isn't open, pop up an error:
else {
  Serial.println("error opening datalog.txt");
}
// read the value from the sensor:
sensorValue = analogRead(sensorPin);
Serial.println(sensorValue); //prints the values coming from the sensor on the screen
delay(1000);

Serial.println("Client disconnected");
}

void setupWiFi()
{
  WiFi.mode(WIFI_AP);
  WiFi.softAP(ssid, password);
  IPAddress myIP = WiFi.softAPIP();
  Serial.print("AP IP address: ");
  Serial.println(myIP);
}

void initHardware()
{
  Serial.begin(115200);
  pinMode(16, OUTPUT);
  pinMode(SwitchPin, INPUT);
  pinMode(LedPin, OUTPUT);
}

void intSDcard ()
{
  Serial.print("Initializing SD card...");

```

```
// see if the card is present and can be initialized:
if(SwitchStatus == LOW) {

  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");

    return;
  }
  Serial.println("card initialized.");
}
else {
  // turn LED ON:
  SD.end();
  digitalWrite(LedPin, HIGH);
  Serial.println("safe to remove card.");
}
}
```

### 3.3.3 Web Interfacing:

A local web server is developed using Hypertext Markup Language (HTML) to display all monitoring parameters of the PV system. This server is built within the ESP32 microcontroller. The SparkFun ESP32 development board is a WiFi compatible system which can act as an Access Point (AP) and a client, for example, a personal computer(PC), laptop or cell phone, can be connected to its WiFi. Whenever a client gets connected to its AP, then it can browse that local server data through a webpage.

### 3.3.3.1 Screen-shot of the Web page:

That local web server page (<http://192.168.4.1>) is shown in the figure 3-14.



**Figure 3- 14: Webpage to Display PV Parameters.**

### 3.3.3.2 HTML Code:

HTML code of the local webpage is presented below:

```
String s = "HTTP/1.1 200 OK\r\n";  
s += "Content-Type: text/html\r\n\r\n";  
s += "<!DOCTYPE HTML>\r\n<html>\r\n";  
s += "<html lang=fr-FR><head><meta http-equiv='refresh' content='10'/>";  
  
s += "<center>";  
s += "<style> body { background-color: #add8e6;text-align: justify;font-family:  
Arial, Helvetica, Sans-Serif; Color: #000000; }</style>";
```



```

s += "<h1>Solar Home System Web Server </h1><br/>\n";
if (sensorValue > 700)
{
  s += "Weather is ";
  s += (sensorValue)?"SUNNY":"CLOUDY";
  s += "<br>\n"; // Go to the next line.
}
s += "Temperature,Deg C = ";
s += String (analogRead(39)*(3.3 / 4095.0))*100.0;
s += "<br>\n"; // Go to the next line.
s += "Charging Current,Ic = ";
s += String (((analogRead(38)*3.3)/4095)*1.5)-2.5)/0.1;
s += "<br>"; // Go to the next line.
s += "Battery Voltage,Vb = ";
s += String (((analogRead(37)*3.3)/4095)*1.5)/0.2;
s += "<br>\n"; // Go to the next line.
s += "Output Power,W = ";
s += String((((analogRead(38)*3.3)/4095)*1.5)-2.5)/0.1)*
      (((analogRead(37)*3.3)/4095)*1.5)/0.2);
s += "<br><br><p><center><a href='/datalog.txt' download='datalog.txt' >Click
HERE to Download  Data</center></a></p>";
s += "</center>";
s += "</html>\n";

// Send the response to the client
client.print(s);

if (req.indexOf("/datalog.txt") != -1)
{
  File sensorFile = SD.open("/datalog.txt");
  if (sensorFile)
  {
    while (sensorFile.available())
    {
      client.write(sensorFile.read());
    }
    sensorFile.close();
  }
  else {
    client.println("FILE NOT FIND"); }
}

```

### 3.3.4 Data Logging on SD card:

Datalogger design algorithm is developed to store all the PV system parameters to a text file on an SD card. ESP32 programming code also includes this process of writing data to an SD card.

#### 3.3.4.1 Screen-Shot of Data Acquisition:

The serial monitor of Arduino IDE is used to display the data logging values for SD card, figure 3-15 shows the data logging process.

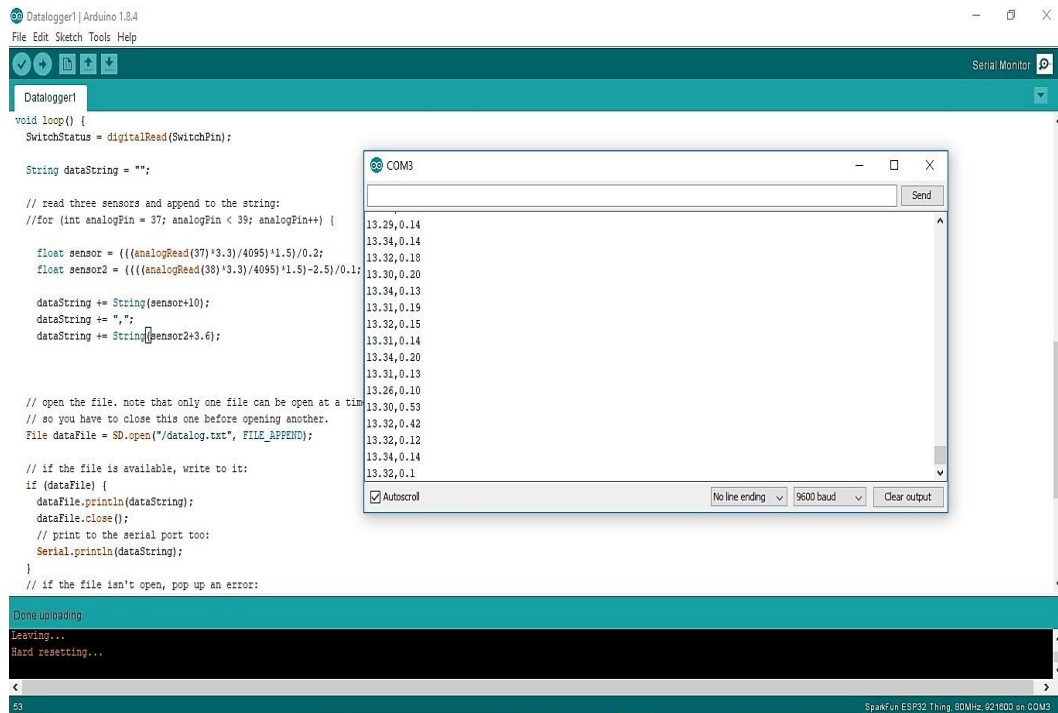
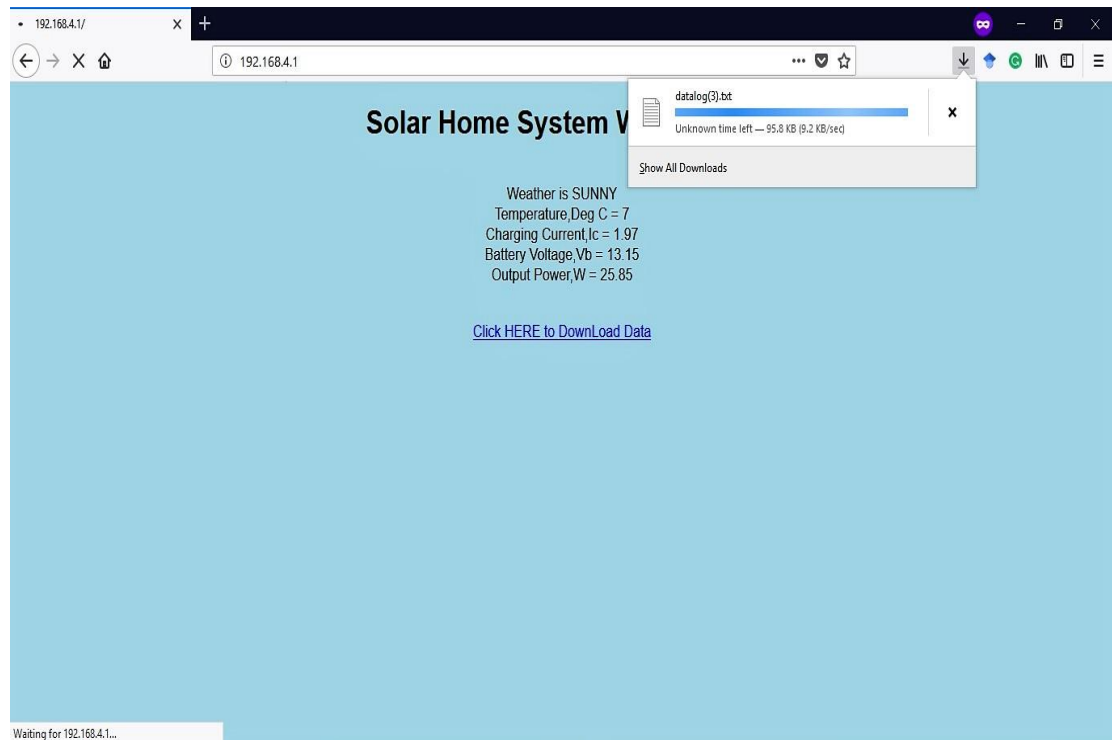


Figure 3- 15: Datalogging on SD card

The stored text file of PV system parameter on the SD card can be download to a laptop or cell phone using a web browser form the developed webpage by clicking on the download button link provided on the webpage. This text file contains all monitoring

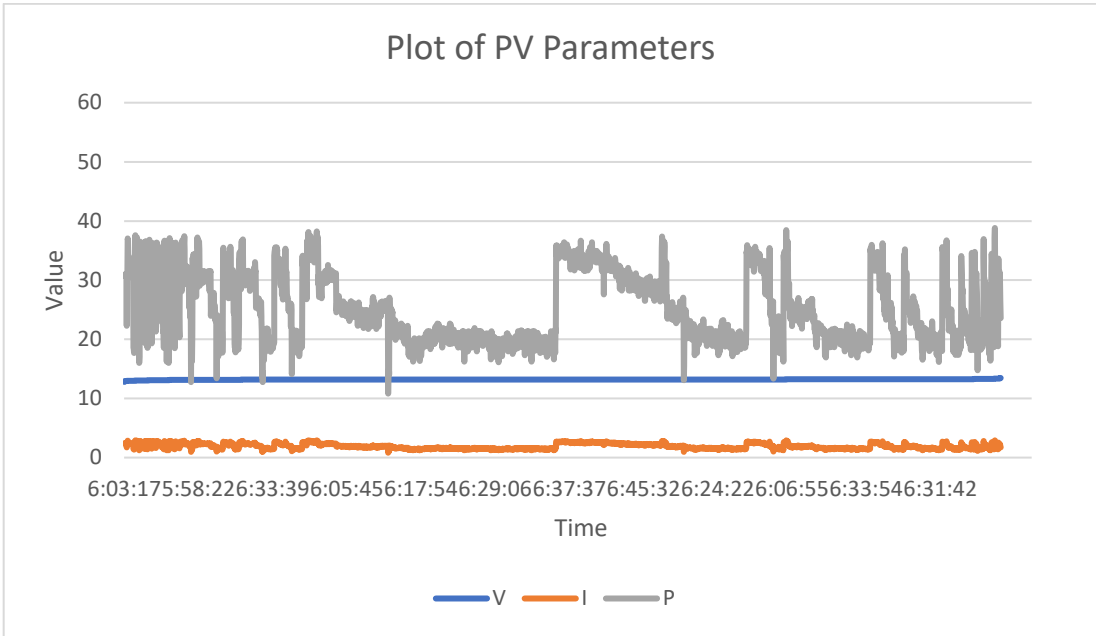
values which can be used for troubleshooting and monitoring of PV system. Figure 3-16 represent the graphical process of data downloading.



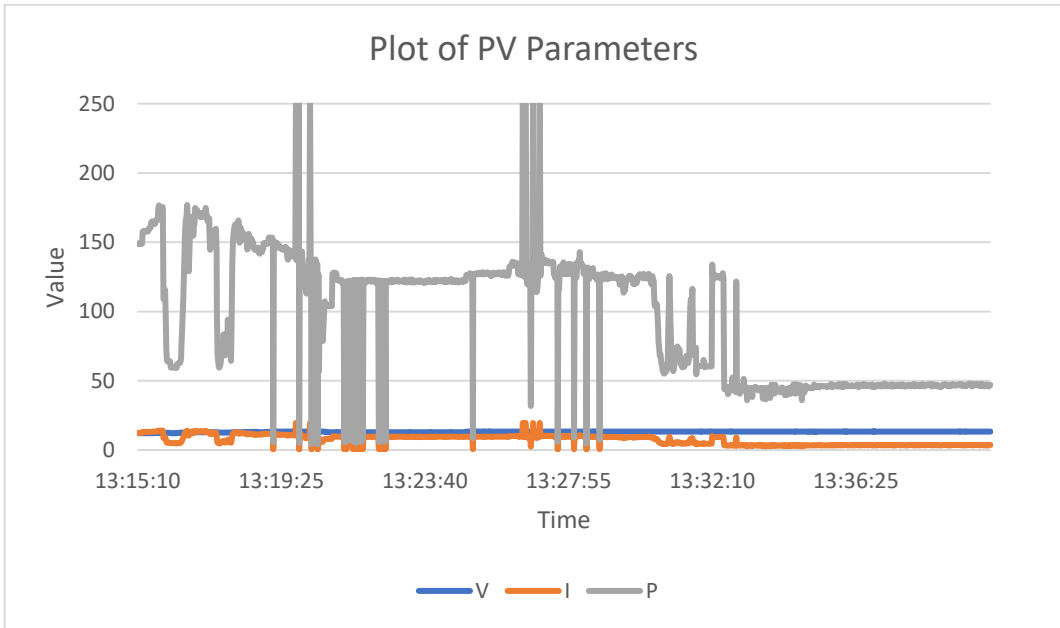
**Figure 3- 16: Data Downloading from Webpage**

### **3.3.4.2 Plot on Excel:**

Figure 3-17 and figure 3-18 shows the plot of two different days of charging current and battery voltage of the monitored solar PV system install in the Engineering building of the Memorial University of Newfoundland, St. John's, Canada using Microsoft Excel Software.



**Figure 3- 17: Plot of Charging Current and Battery Voltage (sample-1)**



**Figure 3- 18: Plot of Charging Current and Battery Voltage (sample-2)**

### **3.4 Conclusion:**

There are many complex commercial monitoring systems available in the market for large and medium PV system. However, it is hard to find any cost-effective data logger for a small PV system [41]. A simple low-cost user-friendly PV monitoring and data logging system design have been discussed for a small Pico Solar Energy System in this chapter. All the monitoring parameters are displayed on a webpage through a local web server which also provides remote data download from the storage device. This data logger can be accessed by a cellphone commonly used by people in developing countries like Bangladesh. An android app development is discussed in the next chapter for live data plot and displaying PV parameters on a cellphone.

## **Chapter 04: Design of A Cellphone App for PV System Monitoring**

### **4.1 Introduction:**

A monitoring system is crucial for the operation of photovoltaic plants (PV), which gives the user a huge privilege for performance analysis and optimize its proper operation and maintenance of any malfunctioning or troubleshooting. The greatest consequence of using monitoring system is the enhancement of the reliability of the PV plant.

Rapid advancement in technology flourishing new appliances like a smart cellphone, particularly Android operating system-based smartphone has become a growing concern in this new technological era. This Android smartphone is vividly used for different purposes due to its huge compatibility and mobility. This user-friendly and open sourced based device is contributing significantly to interfacing with other electronics system such as health monitoring, industrial security, and safety equipment, IoT (internet of thing) based home automation. As android applications are easy to develop and open source, so it has low cost in developing new applications [42].

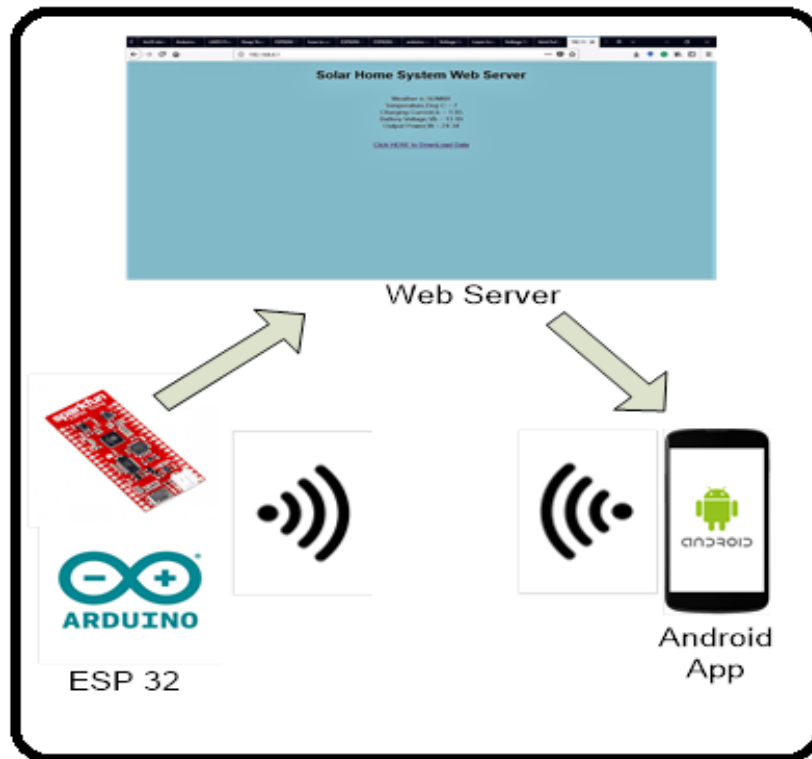
For developing an easy access and low-cost monitoring system, an Android-based smartphone plays a substantial role. Due to the simplicity and easy incorporation of other electronic appliances, such android application can be used for PV monitoring system development. As, almost all people have an android cell phone and available for daily personal use even in the rural areas of developing countries like Bangladesh, India, etc. In

this chapter, an android application is developed to monitor a Pico PV energy system which is commonly used for the solar home system.

#### **4.2 Monitoring App Description:**

An android application (App) is developed for monitoring the PV energy system which fetches information from a web server running in a SparkFun ESP 32 microcontroller development board. The detail datalogger design and web server development using Arduino IDE have been discussed in Chapter 03. Figure 4-1 shows the development principles of an android app.

This developed PV monitoring App displays all monitoring parameters of the PV system in an android cellphone. This app displays a real-time plot of battery voltage, charging current and output power along with temperature and sunlight availability. This plot depicts the last five consecutive values of the battery voltage. This app sends a text message to the maintenance personnel if the battery voltage drops beyond the threshold value for a period of 30 minutes.



**Figure 4- 1: Android App Development Architecture**

### **4.3 Monitoring App Development:**

Android application development is a process of creating a new app for Android devices using the Android software development kit (SDK). Apps can be written using Java, C++, kotlin languages. There are other third-party tools, development environment, and language support to build an android app [43].

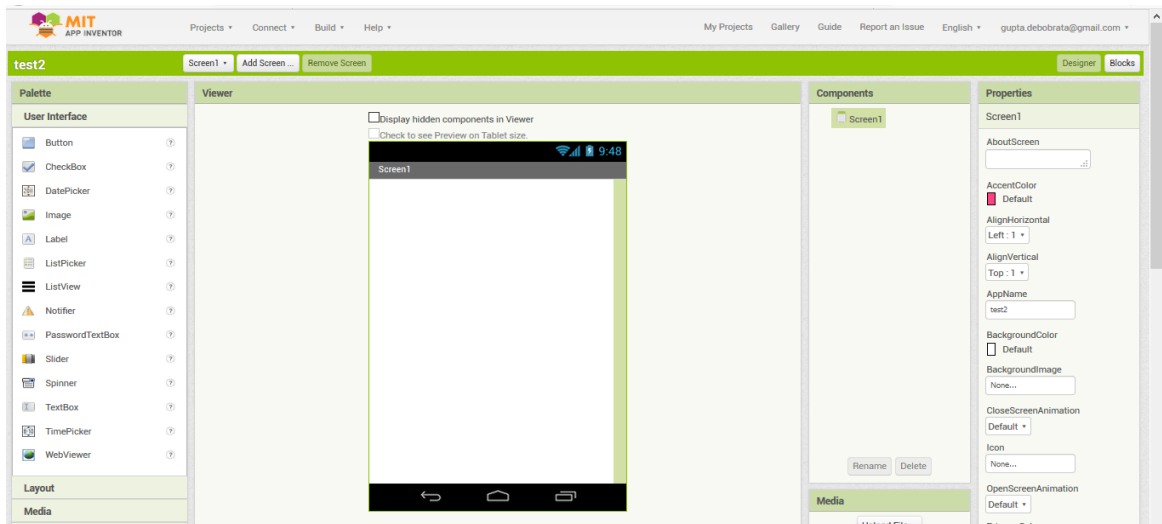
Among various Android app development software, Android Studio, MIT App Inventor, Android Processing IDE has become popular. To develop an android app for this thesis work, MIT App Inventor is used solely.



### 4.3.1 MIT App Inventor:

MIT app inventor is an open source web-based integrated development environment (IDE), which is developed by Google and now it is maintained by the Massachusetts Institute of Technology (MIT). It allows the user to create and build Android applications for an Android operating system like a smart cellphone, tablet computers. It has a graphical interface, similar to Scratch and StarLogo TNG user interface, which allows users to drag and drop visual objects to create an android application that can be run on any android devices [44].

MIT app inventor is a simple and interactive software development tool to build Android applications without having knowledge of Java Language. Java works behind that visual drag and drops object after compiling the scratch code to make a .apk file. After building a .apk file, it can be shared and installed on any android device. Figure 4-2 shows the MIT App Inventor IDE [45]. Figure 4-2 shows the front page of the MIT App Inventor software.



**Figure 4- 2: MIT App Inventor IDE.**

### 4.3.2 System Schematic Diagram:

Figure 4-3 represents the schematic diagram of the monitoring system app development. The developed app is always connected to the web server and android cell phone is connected to the WiFi access point of the SparkFun ESP 32. Detail working principle of this hardware system is discussed in chapter 03.

This developed app displays all monitoring parameters from the local web server every 10 seconds and plots all parameters in a graph view in real time.

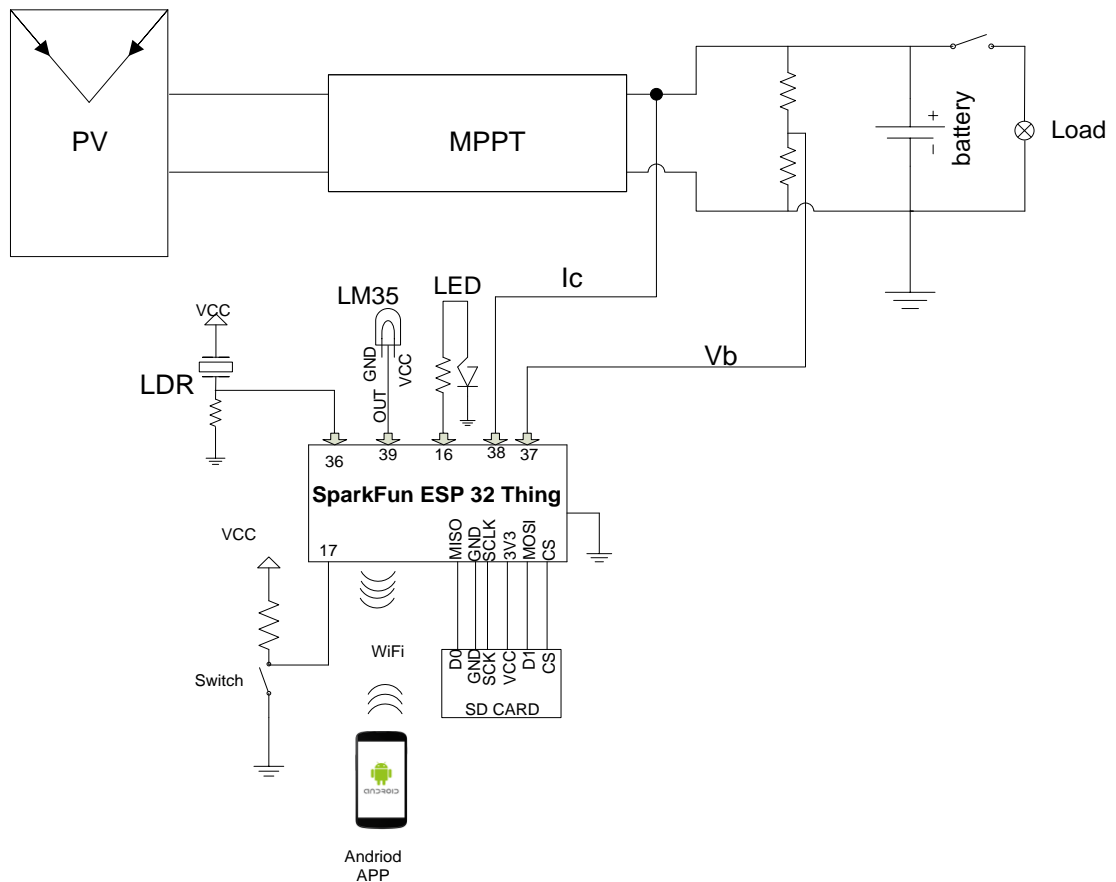
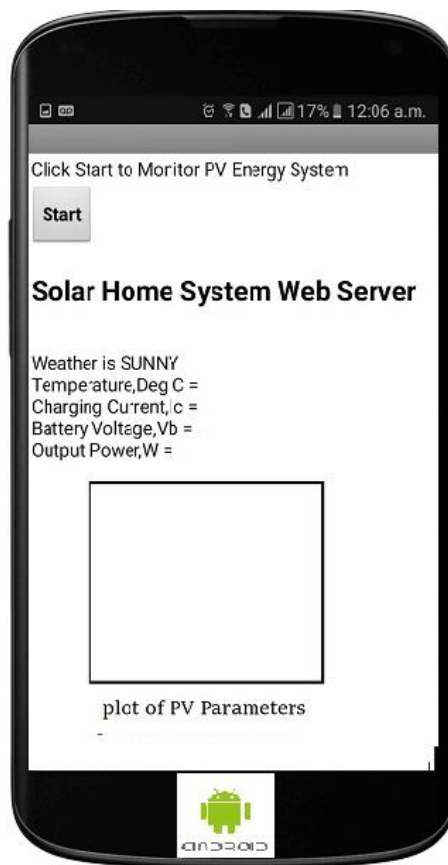


Figure 4- 3: Schematic Diagram of Monitoring System App Development

### 4.3.3 Initial Design Plan:

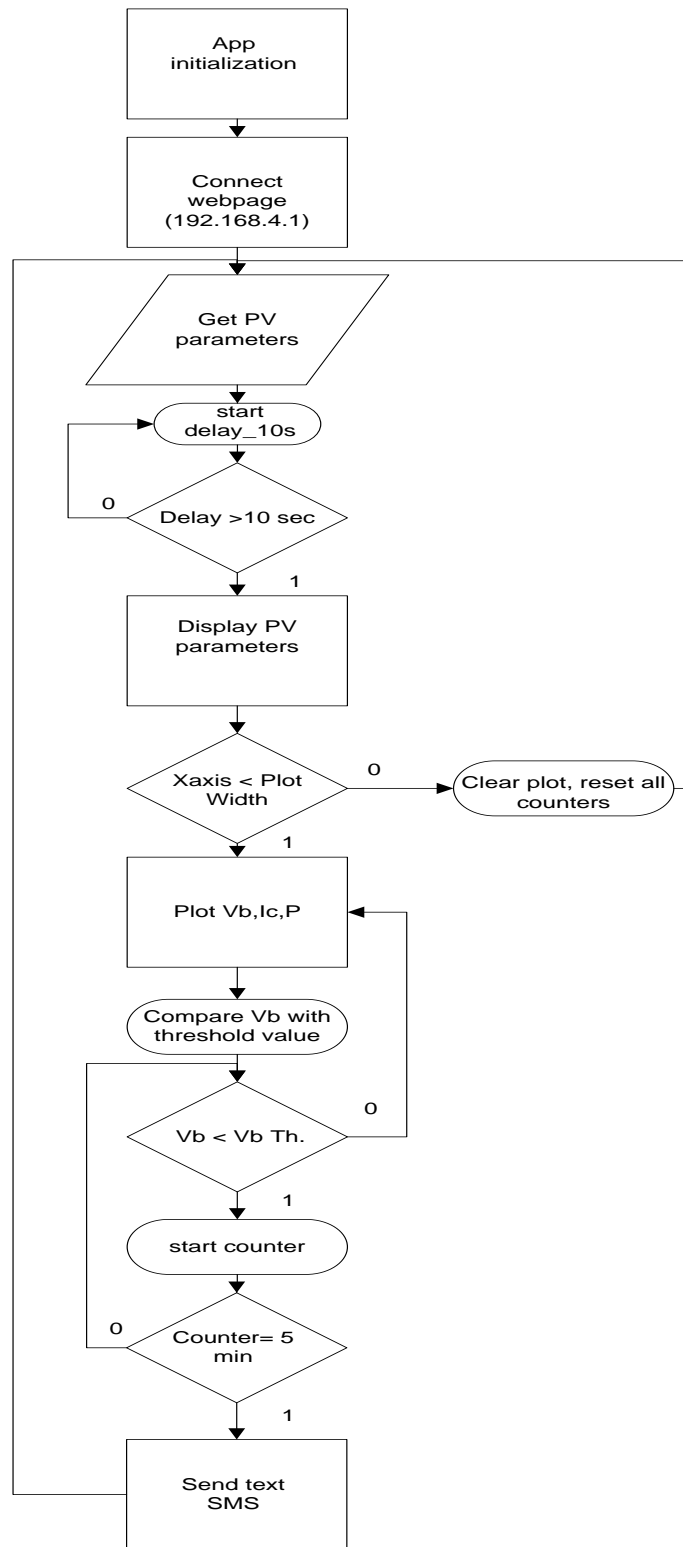
The initial plan to design a PV monitoring plan was that the Android application will connect to the local web server IP (192.168.4.1) and display all the monitoring values from the web server. Along with the PV parameters- charging current, battery voltage, output power, it will display whether sunlight is available or not and ambient temperature. Moreover, it will plot all PV parameters on a real-time graph. Figure 4-4 shows the layout of the initial design plan.



**Figure 4- 4: Initial App Design Layout.**

#### **4.3.4 App Design Flow Chart:**

Figure 4-4 represents the flow chart of the PV monitoring App designed using MIT app inventor. This flow chart a 10 seconds delay start after every data acquisition from the web server when the delay is over it displays monitoring parameters. It monitors the battery voltage with its threshold value and if the battery voltage remains under the threshold level then a counter of 5 minutes starts and after 5 minutes it sends a text message to the maintenance personnel. Figure 4-5 represents the flow chart for app development.



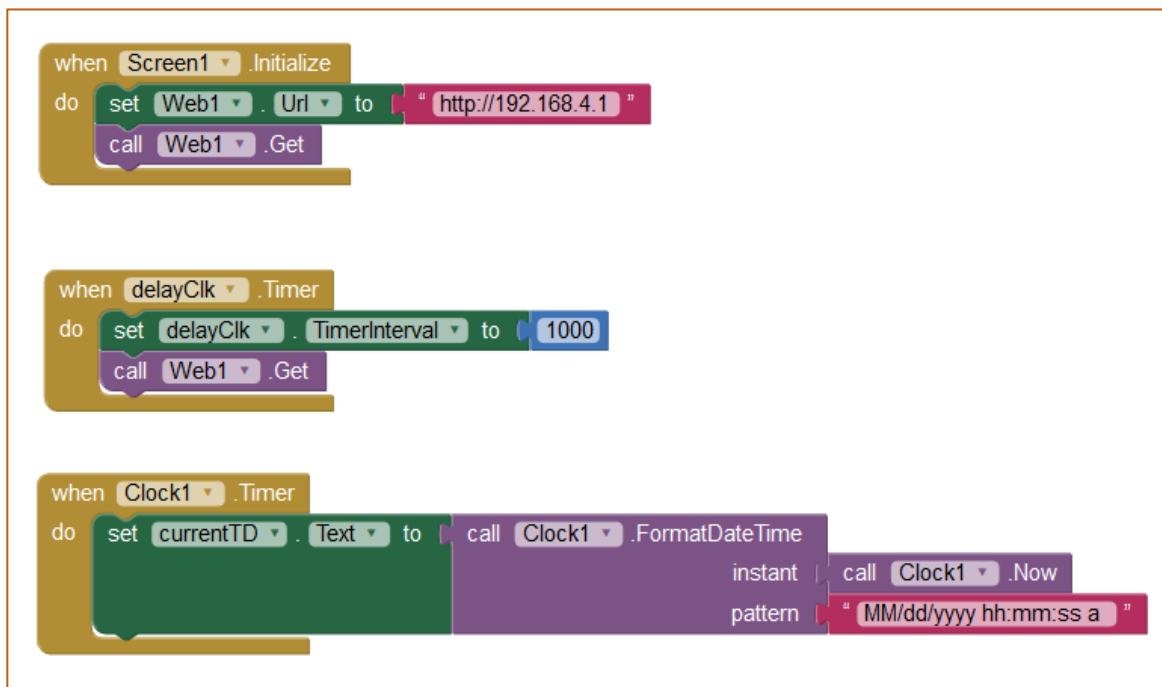
**Figure 4- 5: App Design Flow Chart**

### 4.3.5 Scratch Code:

#### 4.3.5.1 Initial Screen:

This developed android app first connects with the web-server IP (192.168.4.1) and call web service by Web1.Get. A 10-second delay is initialized by delayClk module. A real-time clock is displaying the current time by Clock1.Timer module. The clock gets the system time form the android device and the time display mode is MM/dd/yy hh:mm: ss a.

Figure 4-6 shows the scratch code.



**Figure 4- 6: Screen Initialization for Android App.**

#### 4.3.5.2 Get Web Service:

First, the developed app fetches the information about whether sunlight is available or not in every refresh cycle. As an LDR is connected with the ADC pin of ESP32, it updates the availability of sunlight for every 10 second time interval.

```

when Web1 GotText
  url responseCode responseType responseContent
do
  set weatherlbl . Text to segment text get responseContent
  start starts at text get responseContent
  piece " Weather is "
  length " 16 "

  set templbl . Text to segment text get responseContent
  start starts at text get responseContent
  piece " Temperature, Deg C "
  length " 21 "

  set global volt to replace all text segment text get responseContent
  start starts at text get responseContent
  piece " Battery Voltage, Vb = "
  length " 26 "
  segment " Battery Voltage, Vb = "
  replacement ""

  set voltlbl . Text to get global volt

  set global current to replace all text segment text get responseContent
  start starts at text get responseContent
  piece " Charging Current, Ic = "
  length " 26 "
  segment " Charging Current, Ic = "
  replacement ""

  set currentlbl . Text to get global current

  set global power to get global volt × get global current

  set powerlbl . Text to get global power

  if get global time ≥ Canvas1 . Width
  then
    call Canvas1 . Clear
    call resetVariables
  else
    if get global time < Canvas1 . Width
    then
      call drawVolt
      call drawCurrent
      call drawPower

  set global prntText to get global time / get global counter

  if get global prntText = 50
  then
    set Canvas1 . PaintColor to
    call displayBVolt
    call drawYaxis
    call drawXaxis
    set global counter to get global counter + 1
    set global counter2 to get global counter2 + 1

  call displayTextVb
  call checkVbth
  call sendTextSMS
  set global time to get global time + 1

```

Figure 4- 7: Get Web-Server Response

Ambient temperature is also displaying in the app by using a LM35 sensor. The sensor value is displaying on the webpage by the web server running in ESP32. Figure 4-7 represents the web service fetching scratch code.

The current value of battery voltage, charging current and power are displayed in the text field by segmenting from the webpage text. This segmenting only the numeric value deleting other text.

As all the monitoring PV parameters are fetched by call this webpage server by the app, so plotting of those parameters are also occurred by web1.GotText loop which refreshes every 10 seconds.

Plotting of PV parameters is done by using the canvas module of MIT App Inventor software. In this plot, real-time data of battery voltage, charging current and power output is drawn by canvas module. It displays real-time values of PV parameters for a time span of 6 minutes. After every 6 minutes, it refreshes the plot by call Canvas1.Clear command and start again.

In this web1.GotText loop, it calls other procedures like drawVolt, drawCurrent, drawPower, drawXaxis, drawYaxis, displayBvolt are called. The details are discussed in the following subsections.

A procedure of checking battery voltage beyond the threshold level and sending a text message to a specific cell phone number is also called here by checkVbTH and SendTextSMS procedures.



#### **4.3.5.3 Draw Line on Canvas:**

Curves of battery voltage, charging current and output power are plotting using `Canvas1.DrawLine`. Canvas is a two- dimensional touch-sensitive rectangular panel on which drawing can be done by using the continuous line. Any location on the canvas can be specified as a pair of (x, y) coordinates and the two coordinates are (x1, y1.x2, y2). The line draws based on this two coordinates values, in this case, one is time and other is the parameter value at that specific time. In the developed app there, lines are drawing continuously in the real-time to display battery voltage, charging current and output power. Figure 4-8 represents canvas drawing scratch code.

```

to drawVolt
do
  set Canvas1 . PaintColor to [black]
  call Canvas1 . DrawLine
    x1 get global time2
    y1 Canvas1 . Height - get global volt2 * 5
    x2 get global time
    y2 Canvas1 . Height - get global volt * 5
  set global volt2 to get global volt
  set global time2 to get global time
end

to drawCurrent
do
  set Canvas1 . PaintColor to [red]
  call Canvas1 . DrawLine
    x1 get global time2
    y1 Canvas1 . Height - get global current2 * 5
    x2 get global time
    y2 Canvas1 . Height - get global current * 5
  set global current2 to get global current
  set global time2 to get global time
end

to drawPower
do
  set Canvas1 . PaintColor to [blue]
  call Canvas1 . DrawLine
    x1 get global time2
    y1 Canvas1 . Height - get global power2 * 4
    x2 get global time
    y2 Canvas1 . Height - get global power * 4
  set global power2 to get global power
  set global time2 to get global time
end

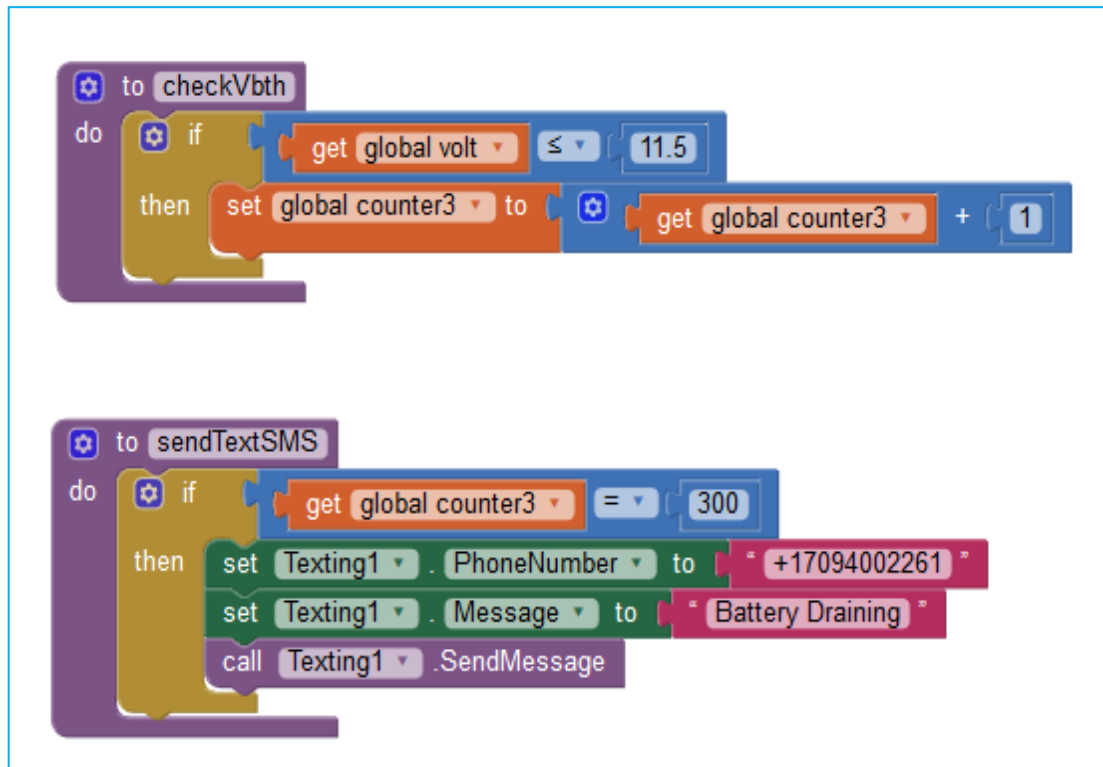
```

**Figure 4- 8: Line Drawing on Canvas.**

#### 4.3.5.4 Sending Text Message:

For sending a text message to a specific number `Texting1.PhoneNumber`, `Texting1.Message`, `Texting1.SendMessage` modules of MIT App Inventor are used. Figure 4-9 shows the scratch code of this operation.

This part the developed App continuously monitors battery voltage  $V_b$ , if the battery voltage drops beyond 11.5 V in case of a 12 V battery system for a time period of 5 minutes, then it sends a text message to +17094002261 cellphone number that “Battery is Draining” using the GSM service of the user cell phone.

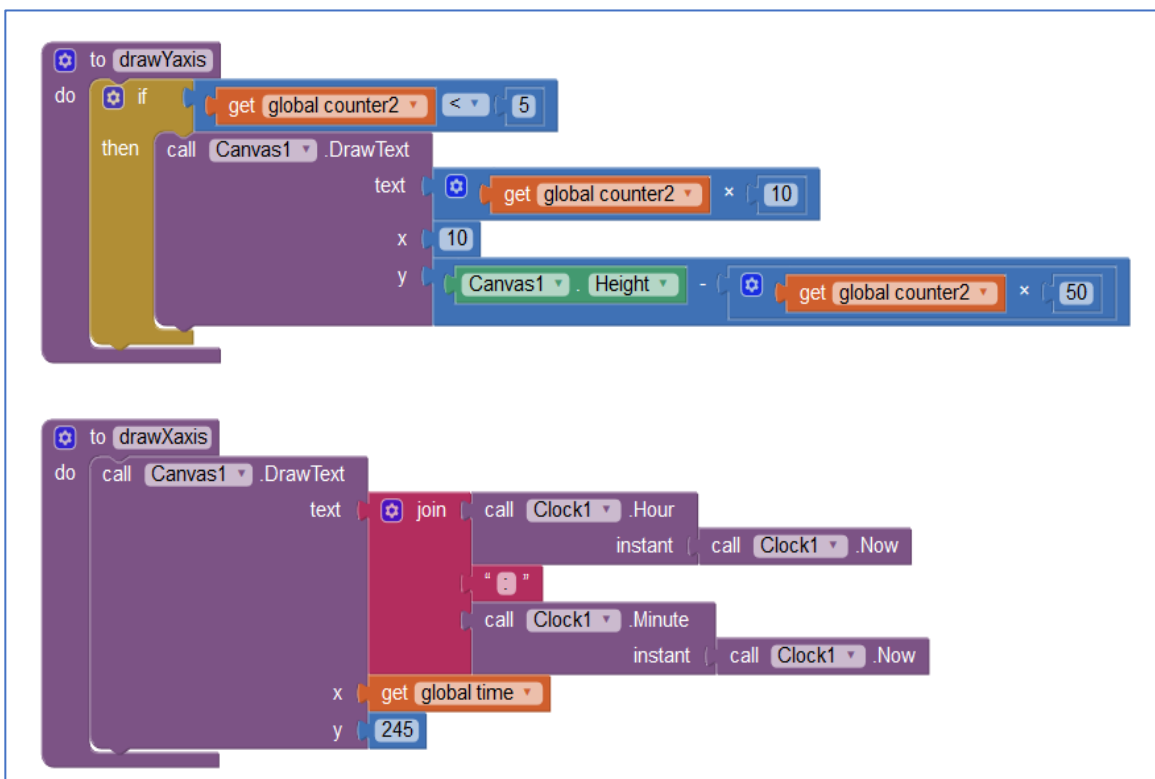


**Figure 4- 9: Sending Text Message.**

#### 4.3.5.5 Draw Axis:

Two-axis X and Y are shown in the developed Android App by Canvas1.DrawText module. The X-axis of the plot shows the real time from the system clock which the clock of the android device. It shows hour and minute of the clock after each minute in the plot. Figure 4-10 shows the scratch code for drawing axis.

Y-axis shows the scale of PV parameters value and the scale starts from 0 to 60 in the plot. The scale interval is 20 that means it shows scale value after every 20 division.



**Figure 4- 10: Drawing Axis on Canvas.**

#### 4.3.5.6 Display Battery Voltage Value as Text:

Battery voltage after every minute is displaying as text by using Canvas1.DrawText module in MIT App Inventor. Draw text uses only one (x, y) coordinate to locate the text position on the canvas. The current value of battery voltage is displayed on the top of the canvas starting with the “Vb=” text. Figure 4-11 shows the scratch code for drawing text.

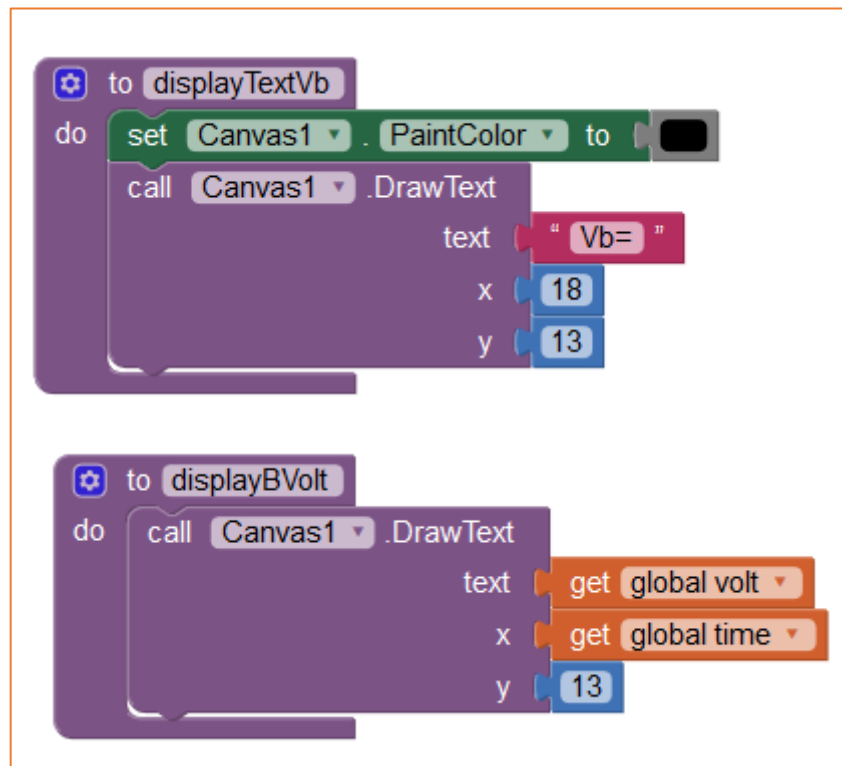


Figure 4- 11: Drawing Text on Canvas.

#### 4.3.5.7 Variable Declaration:

All variables are initialized as a global variable for time, voltage, current and power. Three counters are also used for different counting purposes. These variables are resets to it initial values when the canvas refresh after every 6 minutes. Figure 4-12 shows a set of variables which are used in this app development.

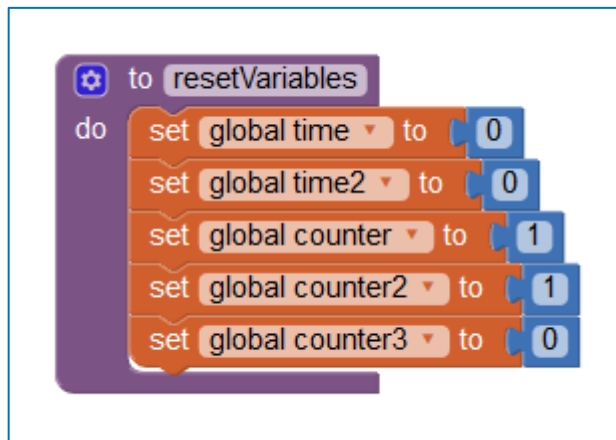
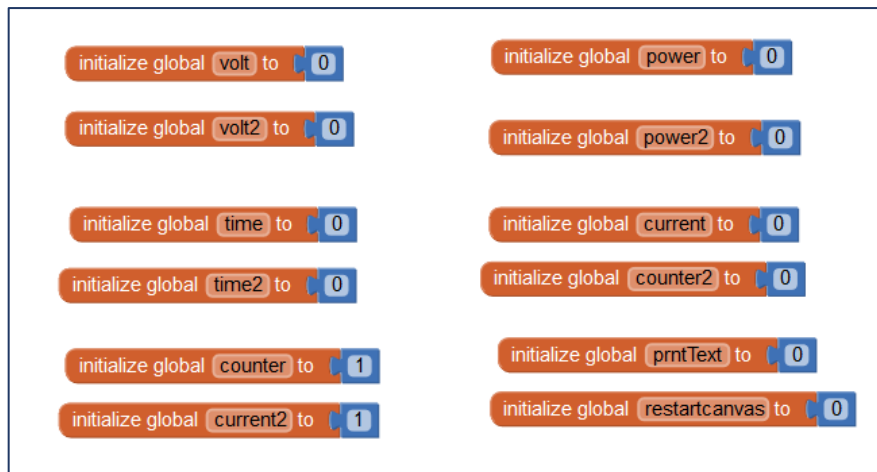
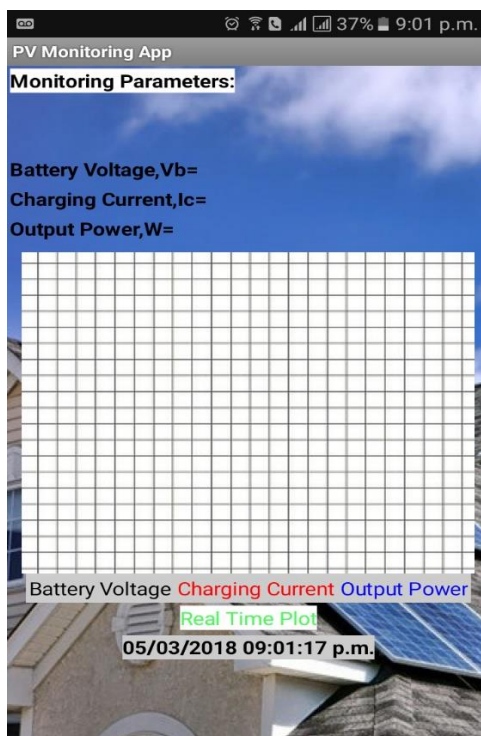


Figure 4- 12: Variable Declaration and Resetting.

#### 4.3.6 Final Design:

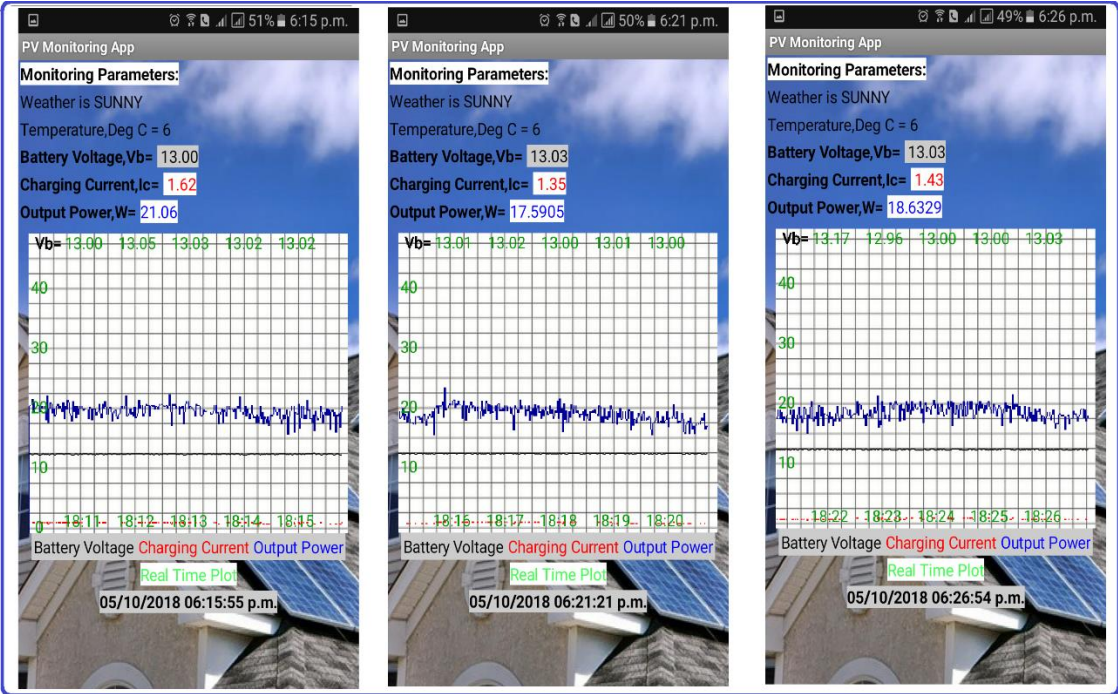
The final version of the designed app is represented in figure 4-13, it shows availability of sunlight, current temperature, all PV parameters and plots PV parameters in a graph in real time. It also displays the current date and time.



**Figure 4- 13: Final Layout of Developed App**

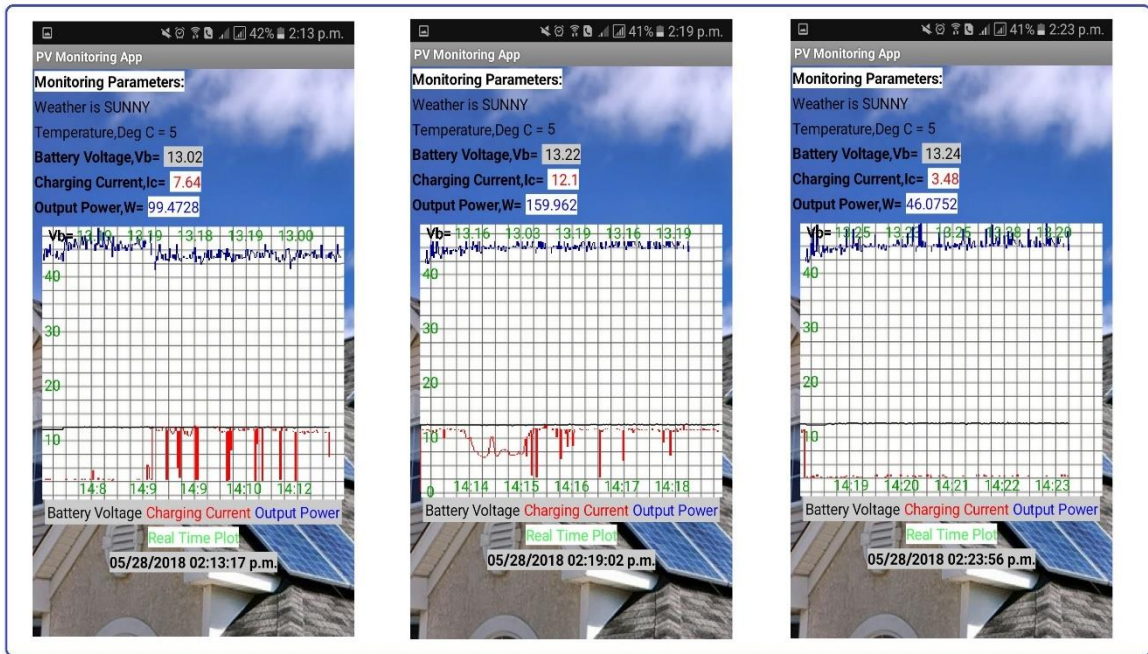
The plot shows real-time values of battery voltage, charging current and output power for an interval of 6 minutes and then the plot refresh. Figure 4-14 and figure 4-5 shows three consecutive plots of total 18 min duration as an example of two different days. As, for one of the objectives of this thesis to protect the battery from every abnormal

condition and run the overall system smoothly, so, the battery voltage is displaying at the top of the plot of a one-minute interval. This developed app displays the axis values, the X-axis shows time and the Y-axis displays the PV parameters scale from zero to its peak value. In this case (sample-1), the scale is 0 to 60. In sample-2, the power output curve is displayed on a smaller scale after the range of 60, which is not on the same scale as battery voltage and charging current.



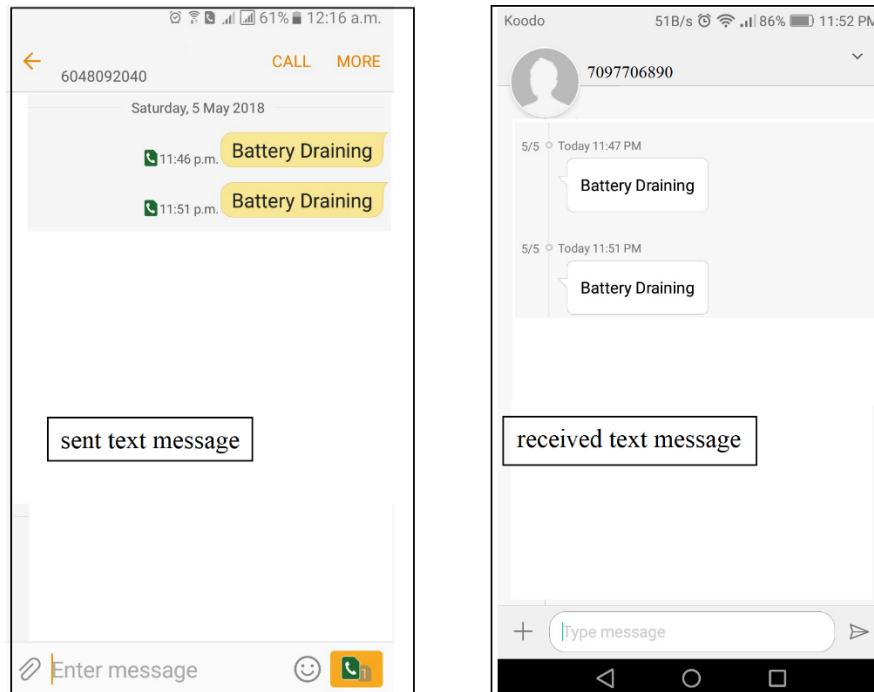
**Figure 4- 14: Three Consecutive Plot of PV Parameters (sample-1).**





**Figure 4- 15: Three Consecutive Plot of PV Parameters (sample-2).**

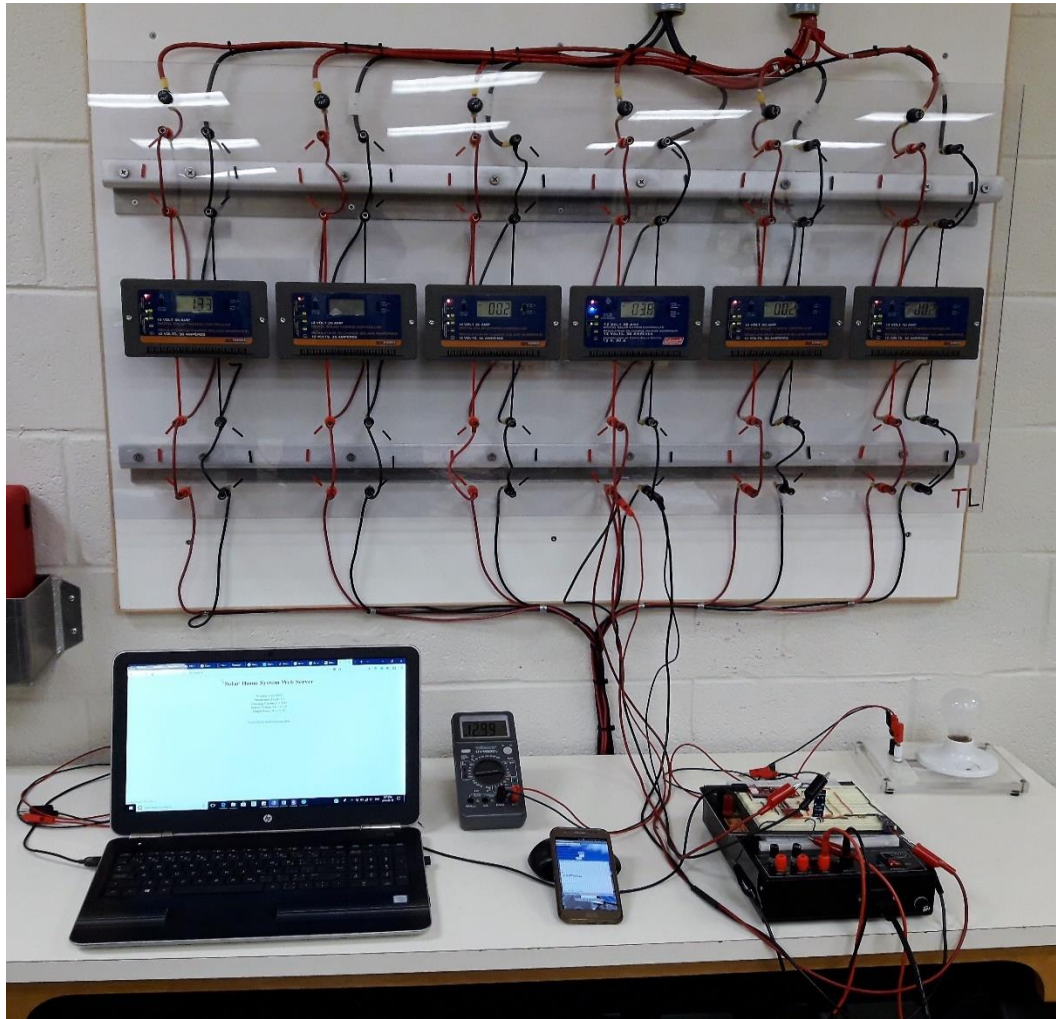
Another feature of the developed App is that it can send an alert message if the battery voltage drops below the threshold values to the maintenance personnel. This App continuously monitors the battery voltage and if it remains below the threshold value for 5 minutes then it sends a text message to a specific number using the cellphone GSM service. In a 12 V battery, if the battery voltage remains below 11.5 V for 5 minutes, then it sends a text message. Figure 4-16 shows a test case of text message sending by the App.



**Figure 4- 16: App Sends Text Message**

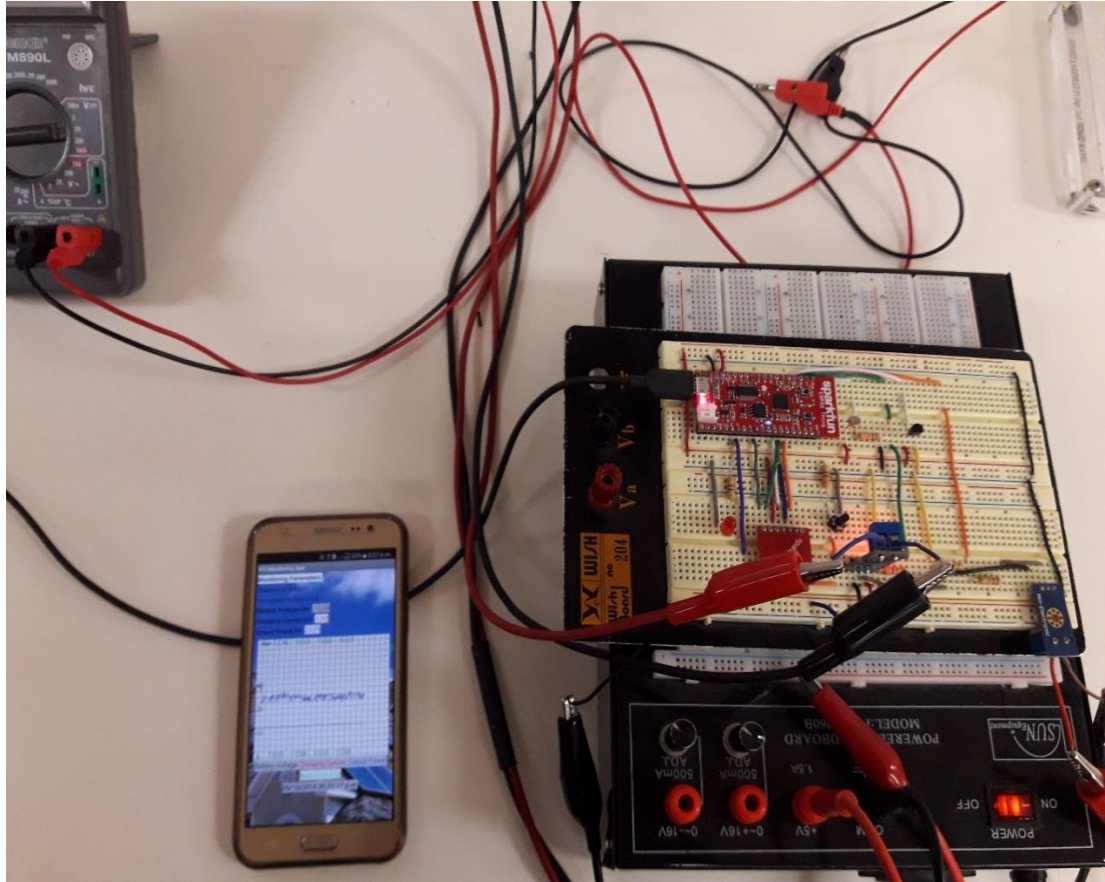
#### **4.3.7 System Testing:**

The developed App is verified in a practical setup of solar PV system which is installed in the laboratory at the Department of Electrical and Computer Engineering, Memorial University, St. John's, Canada. Figure 4-17 show the full hardware and software setup with the developed android cellphone App.

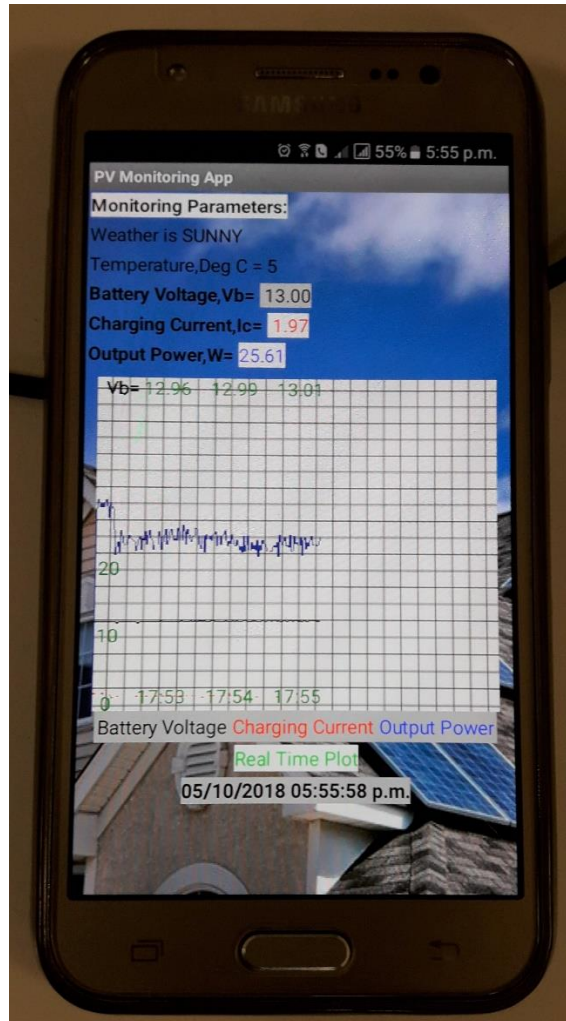


**Figure 4- 17: Hardware Setup for App Testing.**

Figure 4-18 and 4-19 are showing two closer views of the developed app working scenario.



**Figure 4- 18: Developed Android App in Operation**



**Figure 4- 19: Closer View of Developed App.**

#### **4.4 Conclusion:**

To provide a low-cost, user-friendly and easy access non-commercial monitoring system, an Android application is developed for pico solar energy system monitoring for rural electrification program in developing countries like Bangladesh. This App is developed using an open source-based software call MIT App Inventor which is basically a drag and drop software development tool. This developed Android App shows all PV parameters in a plot in the real-time form. It has a special feature to send a text message to maintenance personnel if the battery voltage goes beyond a threshold value.

## **Chapter 05: Conclusion and Future Work**

### **5.1 Conclusion:**

For a smooth, efficient and robust operation of PV solar energy system, a data logger, and monitoring system is very foremost. Datalogger and monitoring system enables the proper operation and contributes to identifying system malfunctioning before any major failure. By having a data logger, it becomes very easy to trace any particular data on a specific time period which leads to an easily traceable scenario to find any anomalies in operation. Moreover, deploying the monitoring system in the PV solar energy system increase system reliability and ensure smooth operation. An efficient monitoring system can assist the user of this energy system to run the system trouble-free for many years.

To design a Solar Home System (SHS) using pico-solar PV panel, a remote area in Bangladesh is visited and real-life data has been collected. According to the acquired data of load requirement, a pico-solar panel, charge controller and battery are selected to meet all energy requirement of a rural house of developing country like Bangladesh. After designing the overall system, it has been simulated in Homer Pro software for an optimal sizing and energy analysis.

In this thesis, a low-cost, user-friendly, reliable datalogger and monitoring system has been developed for pico solar energy system, mainly for the small solar home system in a rural area or remote area of a developing country. This datalogger store all monitoring parameter

in a micro SD card and displays that on a local webpage in HTML format. Data can be downloaded directly from the webpage to analyze and verify the system operation. For an efficient monitoring, an Android App is also developed for a cell phone to display all parameters in real time basis. This App is able to send a text message to maintenance personnel for any issues in battery charging. Cell phones are commonly used in developing countries and people are familiar with their use and application.

This data logger is developed using ESP 32 microcontroller with the help of open sourced software called Arduino. The developed datalogger hardware prototype is very simple and uses only three sensors for temperature, voltage, and current sensing. The overall cost of this prototype is only around C\$ 50 (Canadian Dollar). Moreover, the easily accessible android app is also developed for monitoring PV parameters with an open source software to make it cost effective. The cost and error calculations are discussed below in this chapter.

## **5.2 Cost Calculation:**

Table 5-1 represent the overall cost of the entire datalogger and monitoring system. The initial cost of the developed system is around C\$ 63 (Canadian Dollar) but the per unit cost considering only one item per unit is around C\$ 50 in Canadian Dollar [46], [47].



**Table 5- 1: Overall System Cost Calculation:**

<b>NO</b>	<b>Item</b>	<b>Quantity</b>	<b>Price</b>	<b>Per Unit Price</b>
<b>1</b>	Voltage Sensor	1	11.64	11.64
<b>2</b>	Current Sensor	1	2.76	2.76
<b>3</b>	Resistors	300	4.56	0.106
<b>4</b>	ESP32	1	19.95	19.95
<b>5</b>	Software Arduino IDE	---	Free	----
<b>6</b>	Software AI2 For Android App (IDE)	---	Free	----
<b>7</b>	LM35	1	0.9	
<b>8</b>	LDR	50	1.49	0.029
<b>9</b>	LED	500	4.68	0.009
<b>10</b>	Micro Switch	10	0.94	0.094
<b>11</b>	SD Card Socket	1	3.95	3.95
<b>12</b>	SD Card with Adapter (16GB)	1	9.98	9.98
<b>13</b>	Micro USB	1	1.93	1.93
<b>Total Cost C\$</b>			<b>62.78</b> (Initial Cost)	<b>50.45</b> (Per Unit Cost)

### **5.3 Power Consumption:**

Table 5-2 shows the overall power consumption of the developed datalogger and monitoring system. The power consumption is 758.6 mW for the entire system considering the data transmission over WiFi connection [48]-[52].

**Table 5- 2: Power Consumption of Developed System**

<b>Device</b>	<b>Voltage Source</b>	<b>Current Drawn</b>	<b>Power</b>
<b>ESP32</b>	3.3V	150mA	500 mW
<b>Current Sensor</b>	5V	12.5mA	62.5 mW
<b>LM35</b>	3.3	40mA	130.6
<b>Voltage Sensor</b>	5V	13mA	65 mW
<b>SD-Card</b>	3.3V	0.15mA	0.5 mW
<b>Total Power Consumption</b>			758.6 mW

#### **5.4 Comparison of Measured Value:**

The error calculation of the measured values by the developed datalogger is represented in table 5-3. The values are samples every 10 seconds and picked a random one for error calculation. It is found that battery voltage and charging current has an error of 1.07% and 4.6% respectively. The actual value is measured by a calibrated multimeter during functional testing of developed hardware using the PV system installed in the laboratory at Memorial University, Newfoundland, Canada.

**Table 5- 3: Error Calculation:**

<b>Sample</b>	<b>Parameter Name</b>	<b>Measured Value</b>	<b>Actual Value</b>	<b>Error (%)</b>
<b>1.</b>	Battery Voltage	13.22 V	13.06 V	+1.07%
<b>2.</b>	Charging Current	2.06 A	2.16 A	-4.6%

## **5.5 Thesis Contributions:**

The main objective of this thesis was to design a pico solar system for developing countries and develop a low-cost data logger and monitoring system to prevent the battery or PV panel damage or irregular use of a pico solar energy system. The thesis contributions are described below:

- Pico solar system data collection
- Design and analysis of a pico solar system for Bangladesh
- Design Low cost, reliable datalogger hardware for pico solar system.
- Develop local webpage to display data logging without requiring any internet connection.
- Integrate direct data downloading from the datalogger
- Develop an easy, user-friendly monitoring android application for a cellphone.
- Test the designed system in a lab and plot all PV parameters in a graph in real time.
- Add an alert feature in the app for maintenance personnel if battery voltage drops below the threshold value and send a text message in cellphone using cellphone GSM service.

## **5.6 Future Work:**

A data logger and monitoring are developed for PV solar energy system for the solar home system user in a rural area with limited access to technology and resource. There was also a time constraint for this thesis work of the Master's Program. The following work can be done to enhance the developed system.

❖ **Graphics on the Web Page:**

the developed local webpage is very simple and less striking in graphics from the user perspective. For a future work, the graphical interface can be developed with a background image and other advanced HTML features.

❖ **File Removal Process for SD Card:**

Currently, the data logger file can be downloaded locally via any internet browser for analysis or record checking. A 16 GB SD card can be used for almost 400 years but a file deleting command from the webpage can be added to delete data for example after every 30 days when a smaller SD card is used.

❖ **Database Option in the Monitoring App:**

In the developed App, all parameters are displayed in real time and plots values with a time span of 6 minutes before the refresh. It is possible to develop a local database for storing value and display in the app in hourly, monthly or yearly basis.

❖ **Customization for other Location:**

The proposed datalogger hardware and developed monitoring cell phone app can be easily reconfigured or customize to use for designing and analyzing a pico solar system in any other location of the world.

## Reference:

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