Palestine Polytechnic University

College Of Engineering

Energizing and Monitoring Cellular Base Stations using Photovoltaic Systems

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Project:

Monitoring of Photovoltaic systems that Energize Cellular Base Stations

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By the guidance of our supervisor, and by the acceptance of all members in the testing committee, this project is delivered to the Electrical Engineering Department in the College of Engineering, to be as a fulfillment of the requirement of the department for the degree of Bachelor's.

Supervisor signature

The head of department signature

Acknowledgment

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Abstract

The increasing number of cellular users in remote areas coupled with the difficulty of placing cellular base stations in these regions due to the absence of electricity network has triggered engineers to think of using alternative energy sources like PV cells systems to energize base stations. Monitoring of PV cells and base stations has been an issue to be resolved.

This project aims at designing and implementing a system for energizing and monitoring PV cells and base stations deployed in remote areas. The system will help Mobile phone service providers to easily cover remote areas with base stations. At the same time they will keep the performance of the system running well by monitoring these cells frequently using GSM technology.

The implemented system has been tested in a real environment and the initial results were promising.

Further, it is aimed to empirically compare three methods proposed for estimating energy produced by PV systems. In this research part, we have found the best model.

الملخص

زيادة أعداد مستخدمي الهواتف الخلوية بشكل كبير و خصوصا في المناطق النائية , عدم القدرة على توزيع أبراج الاتصالات لتغطية المناطق النائية بسبب بعدها عن شبكة الكهرباء المغذية للأبراج , كل هذه التحديات أدت إلى التوجه نحو استخدام مصادر الطاقة البديلة مثل خلايا الطاقة الشمسية التي تقوم بتغذية الأبراج في المناطق النائية كما و أدى ذلك أيضا إلى التوجه نحو استخدام نظام مراقبة خاص بهذه الخلايا الشمسية المغذية للأبراج للحصول على الكفاءة المرجوّة في كلا النظامين و هما الخلايا الشمسية و أبراج الاتصالات في المناطق النائية .

تم تنفيذ المشروع حتى نتمكن من إيجاد نظام متكامل لتغذية أبراج الاتصالات و مراقبتها , هذا النظام المتكامل سوف يعمل على مساعدة الشركات المزودة بخدمة الاتصالات الخلوية المتنقلة في تغطية المناطق النائية و تزويدها بالخدمات اللازمة بكفاءة عالية و في ذات الوقت سيتم الحفاظ على جودة الخدمة و التغطية من خلال مراقبة الخلايا الشمسية المزودة للأبراج بالطاقة اللازمة لعلمها بشكل متواصل , كل هذا سيتم عن طريق استخدام النظام العالمي للاتصالات المتنقلة و باستخدام المتحكم الدقيق لفحص أداء النظام بشكل متواصل و اتخاذ القرار المنا سب بإرسال رسالة نصية عند الحاجة في حال وقوع أي عطل تتضمن المعلومات اللازمة لإصلاح العطل أو اتخاذ القرار بعدم إرسال أي إنذارات بالأعطال , و كل هذه التطبيقات ستتم من خلال برمجة المتحكم بشكل مناسب و القيام ببعض العمليات الحسابية الخاصة بالنظام.

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List of Abbreviations

PV	Photo voltaic
SMS	Short Message Service
DC	Direct current
AC	Alternating current
PWM	Pulse-width-modulation
MPPT	Maximum power point tracking
TMP36	Temperature Sensor
I_s	cell saturation of dark current
V_T	thermal voltage
T_c	cell's working temperature
q	electron charge
n	ideality factor
I_d	diode current
G	solar insolation W/m^2
I_{sc}	solar cell short-circuit current
T_{ref}	cell's reference temperature
G_{ref}	reference solar insolation in W/m^2
K_I	cell's short-circuit current temperature coefficient
I_{RS}	cell's reverse saturation current
E_g	band-gap energy of the Si solar cell
V_{oc}	Open circuit voltage
I_{sc}	Short circuit current
FF	reduction in Fill Factor
FF_{idea}	Ideal Fill Factor
STC	Standard Test Condition
VA	Volt ampere
Wh	Watt hour
Wp	Watt Peak

CHAPTER ONE

INTRODUCTION

1.1 Overview.

1.2 Project Importance

1.3 Project Objectives

1.4 Related Work.

1.5 Economical Study.

1.6 Project Schedule.

1.7 Project Content.

1.1 Overview:

In the last years there has been a rapid growth in using PV cells to energize cellular base stations in the far away areas. This is because of the huge growth in the number of mobile phones users in recent time in all regions. This has been causing a demand for covering all far away areas that do not have coverage at all. PV cells were the perfect solution to extend the cellular coverage in these areas.

This project mainly consists of two parts, the PV system and the cellular base station. The PV system will provide the desired power to make the base stations able to work efficiently with good coverage for all subscribers. The base station is the heart of the cellular system, its main function is to cover the subscribers in the cell and provide them with the best services without any problems. So, we will energize these base stations using the PV system. To achieve a good quality of service and assure sustainability of service, we developed methods for controlling and monitoring the PV system.

1.2 Project Importance:

The importance of powering and monitoring cellular systems lies in the following features and characteristics:

1. The project is related to a system that will make the cellular services available in faraway areas.
2. It provides coverage easily at a satisfactory level.
3. The system provides means for monitoring PV and cellular systems.
4. The innovative and secured protocol is an important part of the system which allows it to operate according to users' needs.

1.3 Project Objectives

The project objectives can be summarized in the followings:

1. Energize base stations with desirable power in faraway areas using PV system.
2. Design powering and monitoring system for cellular base stations in order to cover the far away areas.
3. Compare different power estimation methods so as to choose the best one.

4. Design special protocol to monitor the PV system.
5. Send SMS message with information to the cell phone using (GSM) and microcontroller.

1.4 Related Work:

Since the use of the cellular system spread over the whole world including the far away areas from the electrical network, many researches and studies were performed in this stream for improving the cellular system in these areas generally by using renewable energy systems. The PV solar system was the perfect choice to energize the base stations as been proposed in many studies.

- A research paper with a title "Analysis Of Telecom Base Stations Powered By Solar Energy" done by Dike U. Ike, Anthony U. Adoghe, Ademola Abdulkareem in the " INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 3, ISSUE 4, APRIL 2014" (1). In this paper researchers aimed to improve the quality of service and cost reduction in the telecommunication industry by using PV solar energy as a renewable energy source. Also, they use simulation software PVSYST6.0.7 to obtain an estimate of the cost of generation of solar power for cellular base stations. Simulation was carried out for the Grid-Connected and the Stand-Alone solar power systems by using Benin City, Nigeria as a case study. The PVSYST6.0.7 simulation results shows that the power generation costs for the grid connected solar powered system is less when compared to stand alone solar powered system in Benin City, Nigeria.

- Another related research is "Nobel approach of power feeding for cellular mobile telephony base station site: Hybrid energy system ", done by Electrical Engineering Department, Lakshmi Narain, College of Technology, Indore, Madh yapradesh and published in "International Journal of Energy and Power Engineering , November 06, 2014 " (2) . In this paper the researcher discussed the problem of providing energy to remotely located systems and telecom industry, specially powering the mobile telephony towers in rural areas, which lacks quality grid power supply. The paper presents and explores the possibility of putting hybrid energy system for powering cellular mobile base station sites. Looking at Indian weather conditions, the most feasible configuration is the stand alone PV/Wind Hybrid Energy System with diesel generator as a backup for cellular mobile telephony base station site. This system will be more cost effective and environmental friendly over the conventional diesel generator based systems in near future.

The relation between the previous researches and our research is the use of the Off-Grid PV cells system to energize base stations in faraway areas from electrical network. However, our system includes a monitoring and controlling system using the GSM technology and mobile SMS in order to have an efficient complete system. This part of the project doesn't exist in any previous work. Some researchers have proposed methods to monitor the PV cells in general by using methods for data analysis, fault detection and classification the automatic identification of faults. Avery relevant publication is:

- "Monitoring Of Photovoltaic System: Good Practices and Systematic Analysis" done by group of researchers and presented at the 28th European PV solar energy conference and exhibition, 30 September – 4 October, 2013, Paris, France (3). The paper starts with a historical review of the performance of the PV system. It documents the current state of the art and good practices in PV system monitoring. Finally, it presents periodic linear regression as a simple though systematic approach for the visual and mathematical analysis of monitoring data.

  The authors use methods of data analysis and fault detection without alarming the user when there are any faults or problems. In our planned system, we will use mathematical approaches and modules and we will alarm the user if there's anything wrong by sending SMS message directly. This is a major improvement in our project.
  Another application was used by some people to monitor PV system; it's simply a wireless web-connected PV system monitor to measure generation, and grid import/export, called Open Energy Monitor system (4). It comprises wireless sensor nodes that periodically send data to a web-connected base-station. The wireless sensor node used to monitor the PV system is the multipurpose board called ***emonTx***. Connected to the emonTx are two clip-on CT sensors and an AC-AC plug-in voltage adapter, used to sense the PV system generation, and consumption. It is possible to monitor the LED pulses from a pulse output utility meter to measure the energy flow. However, CT sensors yield a more accurate measurement of instantaneous power. When monitoring power using the pulse

counting method, the accuracy is determined by the meter's pulse rate. When minimal power is flowing, the duration between pulses can be extremely long.

Also this method is different from our method, as it is intended to follow different design approach in terms of techniques, electronics and the technology.

1.5 Economical Study

This section lists the overall cost of the system components that will be used in the implementation phase. The hardware components are listed in Table [1.1].

Table[1.1] Project Hardware Cost

Category	Number of pieces needed	Price per Piece (JD)	Pieces we got from previous projects
Programming components	2	100	-
Materials , Samples	1	100	-
Equipment's	5	400	-
Wires and connections	1	100	-
Electronic components	1	200	-
	-	900	-

1.6 Project Schedule:

This section lists the phases and time schedule for the project for the first semester. Table [1.2] provides the system development phases, while Table [1.3] details the distribution of the phases among the working weeks.

- **Stage1 : Select the idea**

  Determine the idea of the project, and the main objectives we intend to achieve.

- **Stage2 : Preparing for the project and collecting data**

  In this stage, more and deeper determination of the tasks and steps we want to perform is done, and more information about the project is prepared.

- **Stage 3 :project analysis**

  In this step, a study of all possible design options to determine the project specifically.

- **Stage 4 : determine the project requirement**

  After determine the design approach, we specify all needed requirements for the user and the system, software and hardware. We try to bring them to be ready for the implementation stage.

- **Stage 5:studying the principles**

  This stage of the project is necessary to study arduino and connection sensor with adruino , then design protocol, and study design PV system, finally send SMS using GSM SIM 900a mini.

- **Stage 6:Documintation writing**

  Documenting the project will begin from the first stage to the last stage.

- **Stage 7 :make the hardware available**

  In this stage, the needed connection of hardware devices of the project will be brought for the next steps.

- **Stage 8:build up the software available**

In this stage, we will program sensors with arduino ,make sure the needed to connect all the parts of the system together, then develop the monitoring protocol .

- **Stage 9: testing the system**
- **Stage 10: writing documentation**

  The documentation will continue from the first stage to the last one.

- **Stage 11: preparing for the final presentation**

  The presentation will be prepared to show the project and its parts.

Table[1.2]Task Time Schedule

Task Number	Task	Time (Weeks)
T1	Discussion Ideas	2
T2	Collecting Data about the System	3
T3	Design the system	13
T4	Analysis	11
T5	Documentation of the System	6
T6	Building the system design	15
T7	Implementation	15
T8	Collecting data and results	9
T9	Editing for the introduction of project	6
T10	Preparing the final report	4

Table[1.3] Distribution of tasks Schedule (first semester)

First semester																
Week / Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1																
T2																
T3																
T4																
T5																

Table[1.4] Distribution of tasks Schedule (second semester)

Second semester																
Week / Work	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
T6																
T7																
T8																
T9																
T10																

1.7 Project Content:

The documentation of this project is divided into seven chapters; the followings explain briefly, the contents of each chapter:

Chapter 2: Background

This chapter discusses the basic components of the system and all related theoretical aspects, including hardware.

Chapter 3: Mathematical Models Estimation

In this chapter, we provide the Photovoltaic Mathematical Models for energy estimation, the comparison between them, and choosing the best one of them.

Chapter 4: System Design and Block Diagram

This chapter provides the system design including both hardware and software and the block diagram of the project

Chapter 5: Detailed System Design

This chapter provides the specific details about the hardware and software design of this project

Chapter 6: Implementation

This chapter provides the implementation of the project, the codes.

Chapter 7: Results

This chapter includes the results achieved after implementation and testing of the system, conclusion of the work and other future work that can be done to improve the system and make it better.

Chapter 8: Conclusion and Recommendations

This chapter includes the conclusion and recommendations for future work.

CHAPTER TWO

BACK GROUND

2.1 Introduction.

2.2 Working Technology.

2.2.1 Basic Concept.

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2.3.1 Off-grid systems.

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2.4.6 PV inverter.

2.4.7 PV Batteries.

2.4.8 Sensors.

2.5 Application.

2.1 Introduction

This chapter describes the system components including hardware technologies to be used in the project. We intend to use R22 Band Selective Repeater instead of a real base station in the system due to technical limitations. However, this will not touch the core concepts and approach.

2.2 Working Technology

2.2.1 Basic concept:

The monitoring system that we design is based on the GSM (Global System for Mobile communication) (5). A SIM shield and Arduino microcontroller will be used to send a message from the shield to the cell phone of the person responsible for the service area. GSM is an open, digital cellular technology used for transmitting mobile voice and data services. GSM supports voice calls and data transfer speeds of up to 9.6 kbps, together with the transmission of SMS (Short Message Service). GSM operates in the 900MHz and 1.8GHz bands in Europe and the 1.9GHz and 850MHz bands in the US. GSM services are also transmitted via 850MHz spectrum in Australia, Canada and many Latin American countries. The use of harmonized spectrum across most of the globe, combined with GSM's international roaming capability, allows travelers to access the same mobile services at home and abroad. GSM enables individuals to be reached via the same mobile number in up to 219 countries.

Terrestrial GSM networks now cover more than 90% of the world's population. GSM satellite roaming has also extended service access to areas where terrestrial coverage is not available.

2.3 PV cells system connections:

Photovoltaic's offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of:

- Photovoltaic cells.

- Devices that convert light energy directly into electricity, because the source of light is usually the sun, they are often called solar cells.

The word photovoltaic comes from “photo” meaning light and “voltaic” which refers to producing electricity. Photovoltaic are often referred to as PV. PV is made of at least two layers of semiconductor material. One layer has a positive charge, the other has a negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current.

There are two major types connection of the system if it's connected to the main grid or it stands alone without any connection, these types are:

• Off-grid systems.

• Grid-tied systems.

2.3.1 Off-grid systems:

They are also called stand common in remote locations without utility grid service, off electric systems can work anywhere. These systems operate independently from the grid to provide loads this system.the system is shown in figure [2.1].

An off-grid solar system (off-the-grid, standalone) is the obvious alternative to one that is grid-tied. For homeowners that have access to the grid, off-grid solar systems are usually out of question. Here`s why:

To ensure access to electricity at all times, off-grid solar systems require battery storage and a backup generator (if you live off-the-grid). On top of this, a battery bank typically needs to be replaced after 10 years. Batteries are complicated, expensive and decrease overall system efficiency.

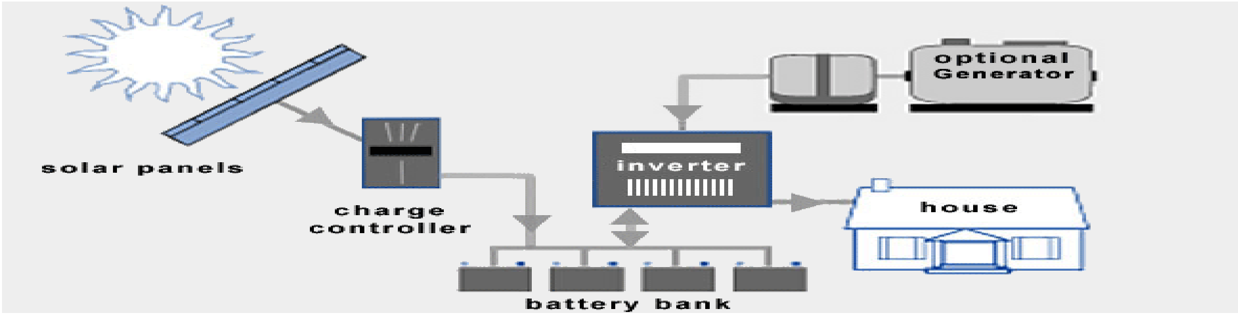


Figure 2.1 off-grid systems

Types of Off-Grid System:

1. DC system without storage.
2. AC system without storage.
3. Off-Grid system with DC output and battery.
4. Off-Grid system with battery and DC and AC output.
5. Off-Grid system with battery and without DC output.
6. Off-grid system with engine generator as back-up (hybrid system)

Advantages of Off-Grid Solar Systems:

1. No access to the utility grid

Off-grid solar systems can be cheaper than extending power lines in certain remote areas.

2. Become energy self-sufficient

Living off the grid and being self-sufficient feels good. For some people, this feeling feeling is worth more than saving money. Energy self-sufficiency is also a form of security. Power failures on the utility grid do not affect off-grid solar systems.

On the flip side, batteries can only store a certain amount of energy, and during cloudy times, being connected to the grid is actually where the security is. You should install a backup generator to be prepared for these kinds of situations.

Equipment for Off-Grid Solar System:

Typical off-grid solar systems require the following extra components:

- **Solar Charge Controller**

Solar charge controllers are also known as charge regulators or just battery regulators. The last term is probably the best to describe what this device actually does: Solar battery chargers limit the rate of current being delivered to the battery bank and protect the batteries from overcharging. Good charge controllers are crucial for keeping the batteries healthy, which ensures the lifetime of a battery bank is maximized. If you have a battery-based inverter, chances are that the charge controller is integrated.

- **Battery Bank**

Without a battery bank (or a generator) it'll be lights out by sunset. A battery bank is essentially a group of batteries wired together.

- **DC Disconnect Switch**

AC and DC safety disconnects are required for all solar systems. For off-grid solar systems, one additional DC disconnect is installed between the battery bank and the off-grid inverter. It is used to switch off the current flowing between these components. This is important for maintenance, troubleshooting and protection against electrical fires.

- **Off-Grid Inverter**

There`s no need for an inverter if you`re only setting up solar panels for your boat, your RV, or something else that runs on DC current. You will need an inverter to convert DC to AC for all other electrical appliances.

Off-grid inverters do not have to match phase with the utility sine wave as opposed to grid-tie inverters. Electrical current flows from the solar panels through the solar charge controller and the bank battery bank before it is finally converted into AC by the off-grid-inverter.

2.3.2 On-grid systems (Grid-Tied Systems) :

They are also called on-grid or utility interactive .grid-tied systems are designed to operate in parallel with and interconnected with the electric utility grid.

1. Grid-tied system with no battery for storing charges.
2. Grid-tied system with batteries for storing charges.
3. Grid-tied system with utility connected to charge battery

2.4 Hardware Description:

2.4.1 R22 Band Selective Repeater:

This system repeats and amplifies Multi-channel signals within the specified frequency band of GSM900/GSM1800 cellular system, improving the signal coverage and rejects the competitor's signals. The technical specifications are shown in Table [2.1].

Table [2.1] Technical Specifications of the RS22 Repeater

Item	Uplink	Downlink
Frequency Range	890 MHz ~ 915 MHz	935MHz ~ 960 MHz
	1710 MHz ~1785 MHz	1805MHz ~ 1880 MHz
-3dB Bandwidth	6.2MHz	
Maximum Gain	≧80dB	
Gain Flatness	≦±2dB	
Manual Gain Control	31dB@1dB/step	
Auto Gain Control	≧20dB	
Total Output Power	≧23dBm@1ch ≧20dBm@2ch	≧30dBm@1ch ≧27dBm@2ch

Max. Input Power Without Damage	≧0dBm
Noise Figure	≦ 5dB
V.S.W.R	<1.5
Group Delay	≦ 4.5μs
Band Isolation	≧110dB
Power Supply	AC90~264VAC, 50/ 60Hz
RF Connector	N-female
Dimensions	428mm*286mm*173mm
Power Consumption	≦75W
Operating Temperature	-25℃ ~ +55℃
Weight	≦15kg
MTBF	>50,000 hours
Environment Condition	IP55
Remote Control/ Monitoring	Via RS232 port at local site Via GSM modem at remote site

2.4.2 Arduino microcontroller:

There are a lot of different Arduino boards out there, Table [2.2] show different type; we decided to use Arduino Uno because it’s suitable for the SIM900 GSM shield that will be used to send SMS for the mobile.

Arduino Uno is a microcontroller board shown in Figure [2.2] based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; the technical specifications of the device are listed in Table [2.2].

Table [2.2]Technical specifications of Arduino Uno.

Item	System Voltage	Clock Speed	Digital I/O	Analog Inputs	PWM	UART	Programming Interface	Cost
 Arduino Uno - R3	5V	16MHz	14	6	6	1	USB via ATMega16U2	$17.99
 Arduino Mega 2560 R3	5V	16MHz	54	16	14	4	USB via ATMega16U2	$27.24

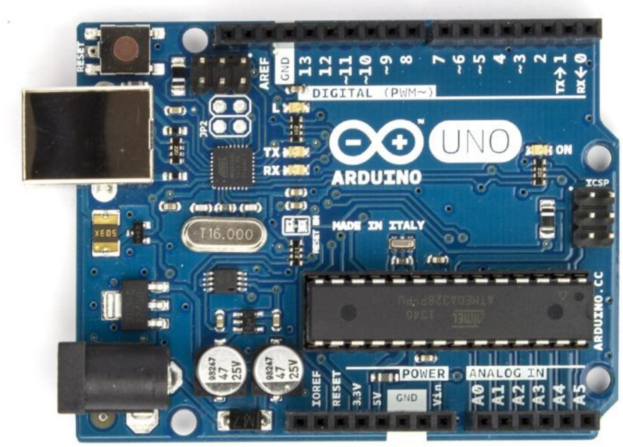


Figure 2.2 Arduino Uno

2.4.3 SIM900 GPRS/GSM Shield:

The SIM900 GSM/GPRS Shield shown in Figure [2.3] provides a way to use the GSM cell phone network to receive data from a remote location. The shield allows achieving this via any of the three methods:

- Short Message Service
- Audio
- GPRS Service

Features:

- Power supply by 5V, can be powered by USB, for long term use it is better to still use 1A current power source. XH2.54-2P connector.
- TTL 5V and 3V3 interface (yellow pins marked on board), compatible with arduino, STM32, raspberry pi, etc.
- On board RS232 interface, easy for debugging. On the left, white pins.
- On board ring signal LED, on the left-top corner of SIM900A IC.
- On Board reset and restart pins, on the bottom of the SIM900A IC.
- Reserved IPX mini connector, but not yet soldered.
- Standard SMA antenna connector.
- Serial port is protected by TVS and beads circuit, to prevent any surging current or HV.
- SIM circuit has SMF05C electrostatics releasing IC.
- Package includes antenna and DC jack.

Figure 2.3 SIM900 GPRS/GSM Shield

2.4.4 Solar Cell (PV cells):

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels as shown in Figure [2.4].

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

Figure 2.4 PV cells

Types of Photovoltaic (PV) Cells:

All photovoltaic (PV) cells consist of two or more thin layers of semi-conducting material, most commonly silicon. When the semiconductor is exposed to light, electrical charges are generated and this can be conducted away by metal contacts as direct current (DC). The electrical output from a single cell is small, so multiple cells are connected together to form a 'string', which produces a direct current.

In many roof-integrated applications, strings are encapsulated (usually behind glass) to form a module (commonly referred to as a 'panel'). The PV panel is the principal building block of a PV system and any number of panels can be connected together to give the desired electrical output. However, two types of PV are best deposited as a thin film, and usually sold encapsulated in a polymer bonded to a substrate that can be used as part of the roofing material.

Types of PV cell or film, any of which might be found in a module or film used on an active solar roof. We do not consider:

- Gallium Arsenide (GaAr) cells. Due to their toxicity and potential carcinogenic properties, these are only used in rare applications such as satellites or demonstration solar-powered cars.
- Organic-based PV solutions that are still under research.

2.4.4.1 The main industrialized PV technologies:

- **Mono crystalline silicon PV panels**

These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

- **Polycrystalline silicon PV panels**

Also sometimes known as multicrystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallised silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.

- **Thick-film silicon PV panels**

This is a variant on multi crystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, it is normally encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal framed module.

- **Amorphous silicon PV panels**

Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, but it tends to be easier and cheaper to produce. If roof space is not restricted, an amorphous product can be a good option. However, if the maximum output per square metre is required, specifiers should choose a crystalline technology**.**

- **Other thin film PV panels**

A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. Most offer a slightly lower efficiency: CIS is typically 10-13% efficient and CdTe around 8 or 9%. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal; although a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA-sized NiCad battery.

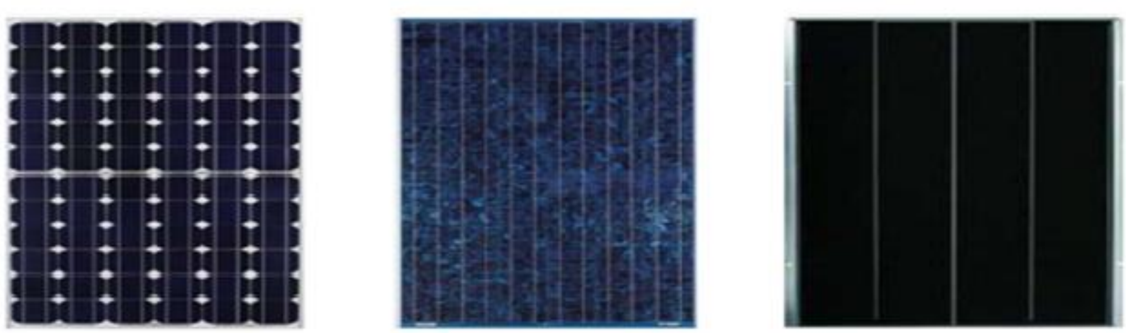


Figure 2.5 some types of PV

2.4.5 PV charge controller:

A charge controller's main function is to keep the battery from being overcharged and potentially damaged as shown in Figure[2.6] . The two common styles of charge controllers used with these systems attain this goal differently. Either type can be used in battery backup grid-interactive systems .

Figure 2.6 charge controller

Features:

1. LCD display, battery power display
2. Light control &delay time, lightening protection, automatic cooling function for over heating, 24V Battery active program.
3. Adopt microcomputer process to control and realize the SOC control of intelligent optimization.
4. With a protection for over-charging, over-discharging, back-flow prevention, overheating, etc. All these can ensure the reliability of the system and safer use.
5. One-button operation to finish all settings

Specification:

1. Output: USB 5V(USB DC 5V Recharge the phone), DC 5V*1(1A)
2.System voltage output: 12V/24V auto work
3.Current rating: 30A
5.EER: 92%（ PWM2.0）
6.Control mode: PWM pulse debug mode
7.Over release voltage returns: 12.2V/12V, 12.2V*2/24V
8.Over release voltage: 10.8V/12V, 10.8V*2/24V
9.Overloading voltage protection: 15V/12V, 15V*2/24V

Pulse-width-modulation (PWM)

Charge controllers regulate charging by adjusting the width and frequency of the full current pulses sent to the battery. The closer a battery is to full, the farther the pulses are apart, effectively lowering the charging current.

Maximum power point tracking (MPPT)

Charge controllers have several advantages. Their software algorithms can operate a PV array at its MPP over a wide range of operating conditions and at a voltage much higher than the battery voltage. This improvement increases power harvest by up to 30% (with greatest gains attained with cooler site temperatures) and allows longer distances or smaller wire sizes between the PV array and charge controller (6).

A charge controller should be sized to pass all the arrays current to the battery. A 60 A controller charging a 12 V battery can only pass 750 watts but if configured to charge a 48 V battery, it can pass nearly 3,000 W. Over sizing the controller slightly can be beneficial since the controller will not have to work at the upper limits of its capabilities all the time and it can harvest any unexpected wattage that could come from extra irradiance or environmental conditions.

If the PV array is capable of producing more power than one charge controller can handle, consider upgrading to a larger-amperage controller, installing multiple controllers, or increasing the battery bank voltage to get more wattage out of each controller.

2.4.6 PV inverter:

The inverter as shown in Figure [2.7] in a grid-tied battery-based system must be sized to do two things: power all of the backed-up loads simultaneously and pass the energy from the renewable sources (PV array, wind generator, etc.) to the grid . To calculate the inverter power rating, sum the total backup loads. If surge loads (pumps, compressors, induction motors) are anticipated, the inverter should be sized to also handle the maximum combined surge loads. Most inverters can handle a surge twice their rated output for a few seconds. If more power is needed than a single inverter can supply, the outputs of multiple inverters can be stacked to increase the total connected power and surge capabilities, or multiple inverters can separately feed separate loads.

The voltage and frequency of the inverter must also match the loads. Inverters for the United States are available in 120 and 240 VAC output at 60 Hz. If 120 V loads are needed to be backup, then a 120 V inverter will be the most economical choice as shown in Table [2.3] . However, purchasing a split-phase, 120/240 V inverter (or stacking two 120 V inverters for 120/240 V output) gives the flexibility to power both 120 and 240 V loads.

The second inverter selection factor is the ability to send renewable-made energy to the grid. If a PV array rated at 4,000 W, the inverter needs to be able to process the full amount. While it is true that the PV array will produce less power under normal operating conditions (due to module heating, dust/dirt, wiring inefficiencies, etc.), there are conditions (cold temperatures and clear skies) when the array can produce full power. Select an inverter that will handle the larger of the two factors: Array output and maximum combined backup loads (7).

Basic specification:

Table [2.3] basic specification of inverter

Rated Power	85%
Frequency	50Hz
Output Voltage	220V
Input Voltage	12V
Waveform	Pure Sine Wave
Type	Single
Power	1 - 200Kw
Type	DC/AC Inverters

Figure 2.7 inverter

2.4.7 PV batteries:

A battery is a device that converts chemical energy contained in its active materials directly into electrical energy by means of an electrochemical reaction. Batteries used in **photovoltaic (PV)** lighting systems must be rechargeable. Lead-acid batteries are the most common type of batteries used in PV systems, due to their wide availability in many sizes, their low cost, and their well understood performance characteristics. Lead-acid batteries are also commonly recycled. The most common ty;2pes of lead-acid batteries used in PV systems are lead-antimony batteries, lead-calcium batteries, lead-antimony/lead-calcium hybrid batteries, and captive electrolyte lead-acid batteries, which include gelled batteries and absorbed glass mat (AGM) batteries. Nickel-cadmium cells are used in some applications, but their high initial cost limits their use.

When selecting or specifying a PV lighting system, it is important to check that the battery capacity is sufficient to provide the energy needed to power the lighting system for the required amount of time. A battery's capacity is a measure of the amount of energy that a battery can store. This capacity is measured in ampere hours and indicates the amount of energy that can be drawn from the battery before it is completely discharged. A battery rated at 100 ampere hours, for example, should ideally provide a current of one ampere for 100 hours, or two amperes for 50 hours (or any combination of amperes and hours that give a product of 100) (8).

2.4.8 Sensors:

- LM35 Temperature Sensor

The LM35 as shown in Figure [2.8] is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature (in $^\circ$C).It can measure temperature more accurately than a using a thermostat. The sensor circuitry is sealed and not subject to oxidation. The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified. The LM35 has an output voltage that is proportional to the Celsius temperature. The scale factor is .01V/$^\circ$C.

The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4° C at room temperature and +/-0.8° C over a range of 0° C to +100° C.Another important characteristic of the LM35 is that it draws only 60 micro amps from its supply and possesses a low self-heating capability. (9).

Figure 2.8 Temperature sensor

- Temperature range : -55 to +150°

Solar Radiation sensor :

The Solar Radiation Sensor, or solar pyrometer, measures global radiation, the sum at the point of measurement both the direct and diffuse components of solar irradiance. In this project we use the LDR sensor as shown in figure [2.9]instead of using a real radiation sensor, so we create an equation to convert between them by using number of readings and Excel programme .

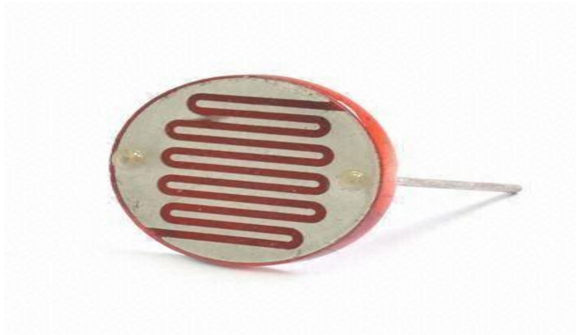


Figure 2.9 LDR sensor

- **Readings for both sensors:**

We take readings from a real radiation sensor from the laboratory and LDR sensor

Table [2.4] readings for LDR and radiation sensor

Radiation sensor (W/m2)	LDR(Ω)
1000	415
700	358
480	342
380	300
280	266
180	233
100	200
90	154

Voltage sensor:

We use two resistances to design our own voltage sensor (voltage divider) as shown in Figure [2.10].

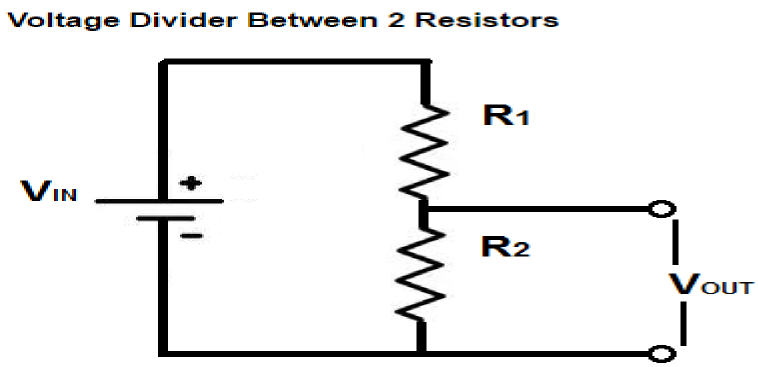


Figure 2.10 voltage sensor (voltage divider)

$$V_{OUT} = V_{IN} \frac{R_2}{(R_1 + R_2)}$$

R_1 = 100KΩ

R_2 = 10KΩ

$V_{IN} = V_{PV\ cell}$

V_{OUT} = analog read to Arduino.

- **Current sensor :**

ACS712 is a Hall Effect-Based Linear Current Sensor it can measure both DC (Direct Current) and AC (Alternating Current) (10), shown in Figure [2.11].

- Features and Benefits
- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 µs output rise time in response to step input current
- 80 kHz bandwidth

- Total output error 1.5% at TA = 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kV RMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratio metric output from supply voltage

Figure 2.11 Current sensor

2.5 Application

In this project we will use a SIM card (Subscriber Identity Module) that have a specific number with the SIM900 shield and connect them with the Arduino mega microcontroller. The protocol will send the data from this shield through the GSM and give an alarm about anything we will choose it in our protocol design. This technique will protect the PV cells from any harmful damages which protect our base station from being off and lose the coverage.

CHAPTER THREE

Energy Estimation Mathematical Models

3.1 Introduction

3.2 Energy Estimated Models

3.3 Comparison between the PV Cell Estimated Model

3.4 Comparison between PV Energy and Estimated Energy

3.1 Introduction:

In this chapter, we will show the differences between three different energy estimation models, we will compare between them and as a result, we will choose the best model that suitable for the system and use it as a reference for all our energy comparisons in the monitoring system.

3.2 Energy Estimated Models:

The PV module is the interface which converts light into electricity. Modeling this device, necessary requires taking weather data (irradiance and temperature) as input variables. The output can be current, voltage, power or other. However, trace the characteristics I(V) or P(V) needs of these three variables. Any change in the entries immediately implies changes in outputs. That is why, it is important to use an accurate model for the PV module.

The characteristic I(V) is a non-linear equation with multiple parameters classified as follows: those provided by constructors, those known as constants and the ones which must be computed. Sometimes, searchers develop simplified methods where, some unknown parameters cannot be calculated. They are thus assumed constant.

The number of unknown parameters increases when the equivalent circuit of the chosen model becomes more convenient and far from being the ideal form. But, most of the manufacturers' data sheets do not give enough information about the parameters which depend on weather conditions (irradiance and temperature). So, some assumptions with respect to the physical nature of the cell behavior are necessary to establish a mathematical model of the PV cell and the PV module

Now we will describe the Mathematical Models of PV Cells:

Algorithm 1: Ideal Photovoltaic Models

An ideal Photovoltaic cell consists of a single diode as shown in Figure [3.1], A diode is connected in anti-parallel with the light generated current source. The output current I is obtained by Kirchhoff law:

$$[I = I_{ph} - I_d]. \quad (1)$$

$$I_d = Io \left[\exp \left(\frac{V}{A .Ns .VT}\right) - 1 \right]. \quad (2)$$

$$a = \frac{Ns .A .K.Tc}{q} = Ns. A. VT \quad (3)$$

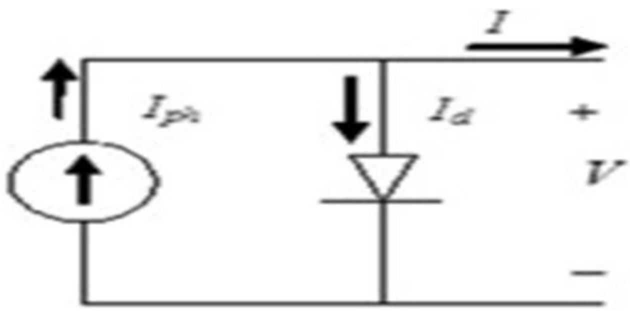


Figure 3.1 ideal single diode model

Where:

I_s = cell saturation of dark current.

I_{ph} =photocurrent.

I_d =diode current .

Io = the reverse saturation or leakage current of the diode

V_T = thermal voltage = kT_c/q= 26mV

V = voltage imposed on the diode.

K = Boltzmann's constant = $1.38 \cdot 10^{-23}$ J/K,.

T_c = cell's working temperature.

Q = electron charge ($1.6 \cdot 10^{-19}$ C).

n = ideality factor equal to 1.1.

Ns= the number of PV cells connected in series.

a =constant which depends on PV cell technology.

A = Identity factor

Non-Ideal Photovoltaic Models

In reality, it is impossible to neglect the series resistance Rs and the parallel resistance Rp because of their impact on the efficiency of the PV cell and the PV module.

Algorithm 2 : Photovoltaic Model with Series Resistance:

The photovoltaic model with series resistance (R_s-model) depicted in Figure [3.2] is achieved with inclusion of series resistance R_s, hence, the output current can be derived as:

$$I_d = Io \ \exp\left(\frac{V+I\ .Rs}{a} - 1\right) \qquad (4).$$

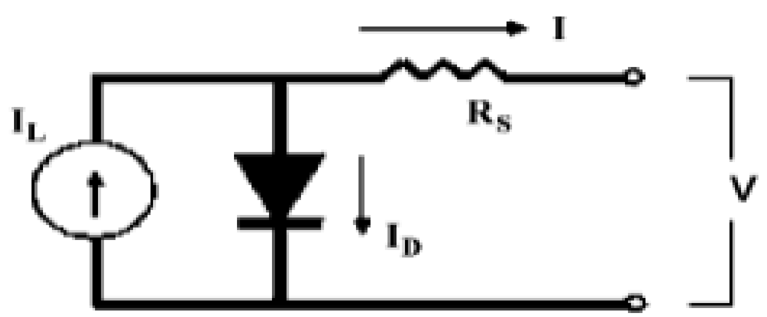


Figure 3.2 Photovoltaic Model with Series Resistance.

Where:

Rs =series resistance

.

Algorithm 3 : Photovoltaic Model with Series and Parallel Resistances:

Equation (4) does not adequately represent the behavior of the cell when subjected to environmental variations, especially at low voltages. A more practical model can be seen in Figure [3.3] , where series R_s, and parallel resistances R_p**,** are introduced .Series resistance is very small, which arises from the ohmic contact between metal and semiconductor internal resistance. But shunt resistance is very large and represents the surface quality along the periphery, noting that in ideal case R_s is 0 and R_p is ∞ .Applying Kirchhoff's law to the node where I_{ph}, diode, R_p and R_s meet, and one get :

$$I = I_{ph} - I_d - I_p . \qquad (5).$$

the output current of a module containing Ns cells in series will be:

$$I = I_{ph} - Io \left[\exp\left(\frac{V+I.Rs}{a} - 1\right)\right] - \left(\frac{V+Rs.I}{Rp}\right) \qquad (6)$$

It is not easy to determine the parameters of this transcendental equation. But this model offers the best match with experimental values.

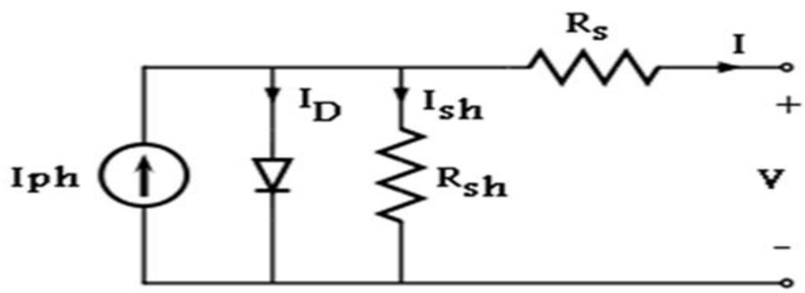


Figure 3.3 Photovoltaic Model with Series and Parallel Resistances

This model yields more accurate results than the R_s model, but at the expense of longer computational time. A modification of this model was proposed by several authors by adding an extra diode. This additional diode represents the recombination effects of the charge carriers. In general, the two diode model is more accurate but the computational time is much longer .For simplicity, the single diode model was used throughout the present work

The number of unknown parameters increases when the equivalent circuit of the chosen model becomes more convenient and far from being the ideal form. But most of the manufacturers' data sheets do not give enough information about the parameters which depend on weather conditions (irradiance and temperature). So, some assumptions with respect to the physical nature of the cell behavior are necessary to establish a mathematical model of the PV cell and the PV module.

Determination of the parameters:

The number of parameters varies depending on the chosen model and on the assumptions adopted by the searchers. It is considered that I_{ph}, Io, Rs, Rp and the factor ideality are five parameters that depend on the incident solar radiation and the cell temperature. the unknown parameters are I_{ph} , Io, Rs and γ. Where

$$\gamma = A \cdot Ns \quad (7)$$

In this work the four parameters that have to be evaluated are also I_{ph}, Io, Rs, Rp .The photocurrent mainly depends on the solar insulation and cell's working temperature, which is described as :

$$I_{ph} = [Isc + ki\ (Tc - T_{ref})]\frac{G}{Gref} \quad (8\ )$$

where: I_{sc} = solar cell short-circuit current.

G_{ref} = reference solar insolation in W/m^2 .

G = solar insolation in W/m^2.

T_{ref} = cell's reference temperature(25C).

K_I = cell's short-circuit current temperature coefficient.

- **Determination of I_{ph}:**

The output current at the standard test conditions (STC) is:

$$I = I_{ph,ref} - Io\ [\ \exp\ (\frac{V}{aref}) - 1\ ] \quad (9)$$

This equation allows quantifying Iph,ref which cannot be determined otherwise. When the PV cell is short-circuited:

$$Isc = I\ I_{ph,ref} - Io,ref\ [\ \exp\ (\frac{0}{a\ ref}\ ) - 1] = I_{ph,ref} \quad (10).$$

But this equation is valid only in ideal case. So, the equality is not correct. And then, equation (10) has to be written as:

$$I_{ph,ref} \approx I_{psc,ref} \quad . \quad (11).$$

The photocurrent depends on both irradiance and temperature:

$$I_s = I_{RS} \left(\frac{T_c}{T_{ref}}\right)^3 \exp\left(\frac{qE_g}{nk}\left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)\right) \tag{12}$$

where :

I_{RS} = cell's reverse saturation current at a reference temperature and a solar radiation.

E_g = band-gap energy of the Si solar cell, = 1.10 Ev.

n = is dependent on PV technology.

The reverse saturation current at reference temperature can be approximately obtained as:

$$I_{RS} = (\text{Isc})/\exp\left[\left(q.\frac{Voc}{nkTc}\right) - 1\right] \tag{13}$$

The V_{oc} parameter is obtained by assuming the output current is zero .

The photocurrent depends on both irradiance and temperature:

$$I_{ph} = \frac{G}{G_{ref}} \left(I_{ph,ref} + \mu_{SC} * \Delta T \right) \tag{14}$$

G= Irradiance (W/m2).

G_{ref} = rradiance at STC = 1000 W/m2.

ΔT = $T_c - T_{c,ref}$ (Kelvin).

$T_{c,ref}$ = Cell temperature at STC = 25 + 273 = 298 K.

μ_{SC} = Coefficient temperature of short circuit current (A/K).

$I_{ph,ref}$ =Photocurrent (A) at STC.

Determination of *I*o

The shunt resistance Rp is generally regarded as great, so the last term of the relationship (9) should be eliminated for the next approximation. By applying equation (9) at the three most remarkable points at standard test condition: the voltage at open circuit (I = 0, V = $V_{oc,ref}$), the current at short circuit (V = 0, I =$I_{sc,ref}$), and the voltage ($V_{mp,ref}$) and current ($I_{mp,ref}$) at maximum power, the following equations can be written:

$$I_{sc,ref} = I_{ph,ref} - I_{0,ref}\,[\exp\,(\frac{I_{sc,ref} * R_s}{a_{ref}})\text{ -1}] \quad (15)$$

$$0 = I_{ph,ref} - I_{0,ref}\,[\exp\,(\frac{V_{oc}}{a_{ref}}) - 1] \quad (16)$$

$$I_{pm,ref} = I_{ph,ref} - I_{0,ref}\,[\exp(\frac{V_{pm,ref} + I_{pm,ref}}{a_{ref}} R_s)\text{ -1}] \quad (17)$$

The (−1) term has to be neglected because it is very smaller than the exponential term.

$$0 \approx I_{sc,ref} - I_{0,ref}\,\exp(\frac{V_{oc,ref}}{a_{ref}}) \quad (18)$$

So :

$$I_{0,ref} = I_{sc,ref}\,\exp(\frac{-V_{oc,ref}}{a}) \quad (19)$$

The reverse saturation current is defined by:

$$I_0 = DT_c^3\,\exp\,(\frac{-q\varepsilon_G}{A.k}) \quad (20)$$

εG= Material band gap energy (eV), (1.12 eV for Si)

D = diode diffusion factor.

To eliminate the diode diffusion factor, at T_c and at $T_{c,ref}$. Then, the ratio of the two equations is written as :

$$I_0 = I_{0,ref}\,(\frac{T_c}{T_{c,ref}})^3 \exp\,[(\frac{q\varepsilon_G}{A.K})\,(\frac{1}{T_{c,ref}} - \frac{1}{T_c})] \quad (21)$$

$$I_0 = I_{sc,ref} \exp\left(\frac{-V_{oc,ref}}{a}\right) \left(\frac{T_c}{T_{c,ref}}\right)^3 \exp\left[\left(\frac{q\varepsilon_G}{A.K}\right)\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \quad (22)$$

Determination of Rp and Rs:

In order to make the proposed model more credible, Rp and Rs are chosen so that the computed max power P_{mp} is equal to the experimental one $P_{mp,ex}$ at STC conditions. So it is possible to write the next equation:

$$I_{mp,ref} = \frac{P_{mp,ref}}{V_{mp,ref}}$$

$$= \frac{P_{mp,ex}}{V_{mp,ref}}$$

$$= I_{ph,ref} - I_{0,ref}\left[\exp\left(\frac{V_{mp,ref} + I_{mp,ref}.R_S}{a}\right) - 1\right] - \frac{V_{mp,ref} + R_s.I_{mp,ref}}{R_p} \quad (23)$$

Therefore:

$$R_p = \frac{V_{mp,ref} + I_{mp,ref}.R_s}{I_{sc,ref} - I_{sc,ref}\left[\exp\left(\frac{V_{mp,ref} + R_S.I_{mp,ref} - V_{oc,ref}}{a}\right)\right] + I_{sc,ref}\left[\exp\left(\frac{-V_{oc,ref}}{a}\right)\right] - \left(\frac{P_{max,ex}}{V_{mp,ref}}\right)} \quad (24)$$

The iteration starts at Rs = 0 which must increase in order to move the modeled Maximum Power Point until it matches with the experimental Maximum Power Point. The corresponding Rp is then computed. There is only one pair (Rp, Rs) that satisfies this condition.

An important characteristic of solar panels is its Fill Factor (FF). The factor which represents how square the voltage/current characteristic of a panel is. In general, PV panels usually have an FF somewhere between 0.4 and 0.8; ideal PV panels have a Fill Factor of 1.0. The Fill Factor (FF) is the ratio of the maximum power point divided by V_{oc} and I_{sc} .

$$FF = \frac{P_{max}}{V_{oc}\, I_{sc}} \tag{25}$$

The reduction in Fill Factor (FF) corresponding to the total series resistance is given by:

$$\Delta FF = \frac{-I_{sc}}{V_{oc}}\ R_s . FF_{ideal} \tag{26}$$

Where, FF_{ideal} = ideal Fill Factor equal to 0.824

3.3 Comparison between the PV Cell Estimated Model:

To achieve the monitoring of PV cells , PV parameters and estimated parameters from best estimated models need to be compared with each other , the best estimated model will be obtained by making this comparison and choose the best of them using Arduino program.

3.4 Comparison between PV Energy and Estimated Energy:

After choosing the best estimated model ,a comparison between the parameters that out from it and the parameters that out from PV cells will be done , if there are a significantly difference between them ,that mean there are a problem in the PV cell then the Arduino will send SMS message to the user when this is happened through SIM900 shied that connected with the Arduino .

CHAPTER FOUR

System design and block diagram

4.1 Introduction

4.2 System Block Diagram

4.3 Hardware Design

4.3.1 PV cell design

4.3.2 Arduino board

4.4 Software Design

4.1 Introduction:

This chapter presents the system design, hardware and software design. It explains the monitoring part of the PV cells that energize the base station.

4.2 System Block Diagram :

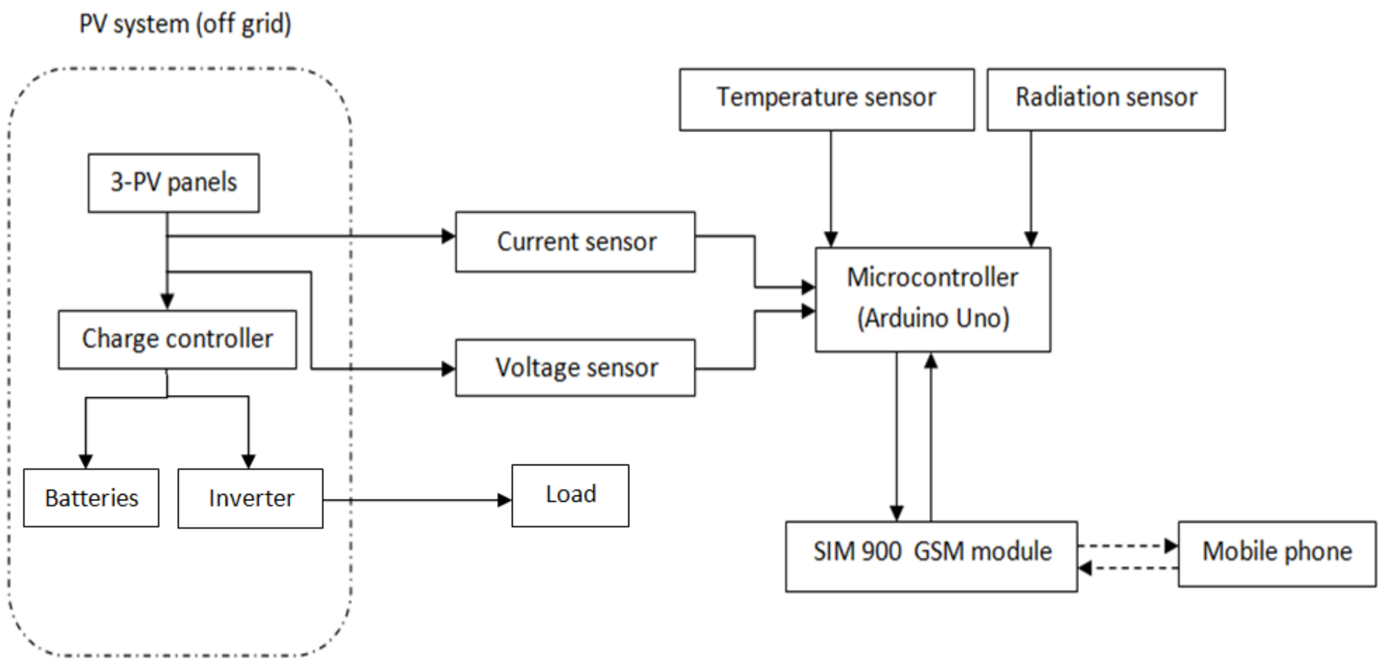


Figure 4.1 block diagram of the system

4.3 Hardware Design:

4.3.1 PV cell design:

We will design a PV cell to energize base station . The type of PV cell is off-grid because off-grid solar energy systems include storage solutions such as batteries or flywheel energy storage, which allow excess electricity to be saved for future use. The main components of off-grid systems include solar panels, inverter, charge controller and batteries.

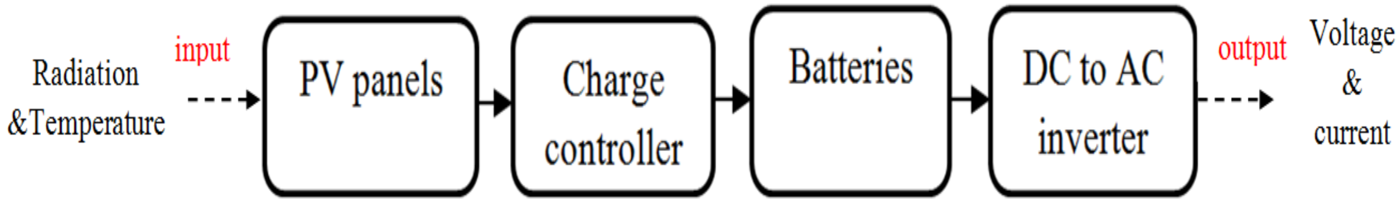


Figure 4.2 off-grid PV system

Figure 4.2 shows the off-grid system components to be designed. Also, the figure shows the input (radiation & temperature) and output (voltage &current) of the PV system.

4.3.2 Arduino board:

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino board is able to read inputs and turn it into an output.

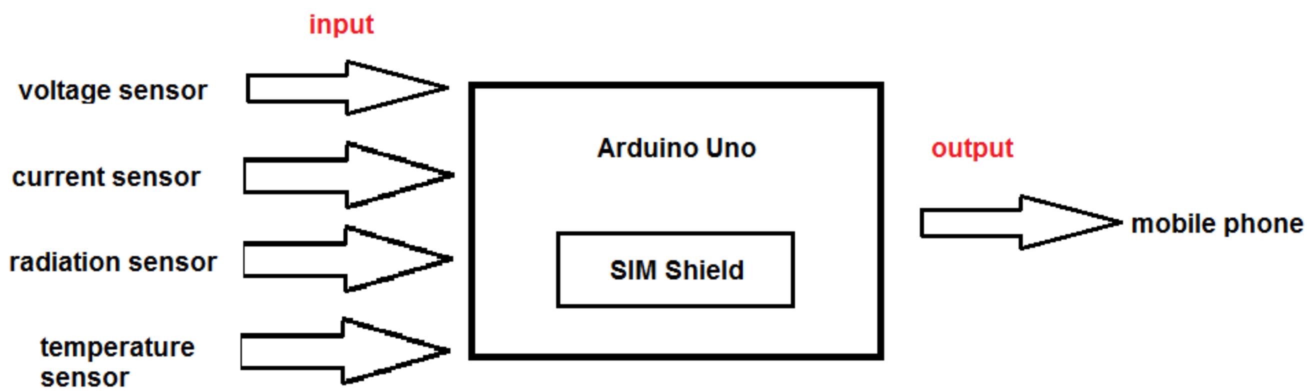


Figure 4.3 arduino board that require to monitor of PV cell

Figure [4.3] shows the Arduino board that will be used it in the system to monitor the PV cell. The input of the board is voltage &current sensors that read V & I from the PV cell. Also, there are radiation and temperature sensors that take readings from the sun, we will connect the Arduino with SIM shield to send message to the user when PV disrupted.

4.4 Software Design

In this part, we provide the different software modules necessary for system operation.

1. Data delivering to mobile phone :

   This Module will be Responsible for Sending, Monitored and Measured Parameters from both PV and Telecommunication Systems components like (power, voltage, current, etc….) to Mobile Device.

2. Mobile module:

   This is an android application responsible for receiving and displaying parameters for both PV system and telecommunication systems using SIM of mobile to receive the SMS, the Mobile services based on GSM technology.

3. Global System for Mobile Communication (GSM):

   Digital mobile telephony system that is widely used in the world. GSM uses a variation of time division multiple access (TDMA) and is the most widely used of the three digital wireless telephony technologies (TDMA, and CDMA). GSM digitizes and compresses data, then sends it down a channel with two other streams of user data, each in its own time slot. It operates at either the 900 MHz or 1800 MHz frequency band.

4. Energy Estimation Module :

   In this Part, we intend to examine and analyze three different Algorithms. The objective is to compare them then choose the best one.

CHAPTER FIVE

Detailed System Design

5.1 Introduction

5.2 Hardware and software detailed design

5.2.1 Arduino Uno

5.2.2 Sensors

5.3 PV design and calculation

5.4 Load (base station)

5.5 Mobile phone.

5.1 Introduction:

In this chapter, detailed system design is presented, including hardware and software. Also, show datasheets for sensors and the PV cells detailed design.

5.2 Hardware and software detailed design:

This part shows the hardware component that required for implementing the system such as: sensors, photovoltaic cells, load, mobile phone, SIM900shield and Arduino Uno.

5.2.1 Arduino Uno:

The system implementation depends on the Arduino Uno that shown in Figure [5. 1] that will be used to connect four different analog sensors with four analog inputs. Two sensors will measure the voltage and the current that will produce from the solar panels of the PV system which converts the sunlight into electricity. The other two sensors will measure the temperature and radiation direct from the surrounding environment. All sensors will deliver results to the Arduino to perform specific calculations and comparisons that will be useful and compatible with the special goals to choose the best energy estimation model and to monitor the PV cell system and send alarming SMS when there is any problem in the system.

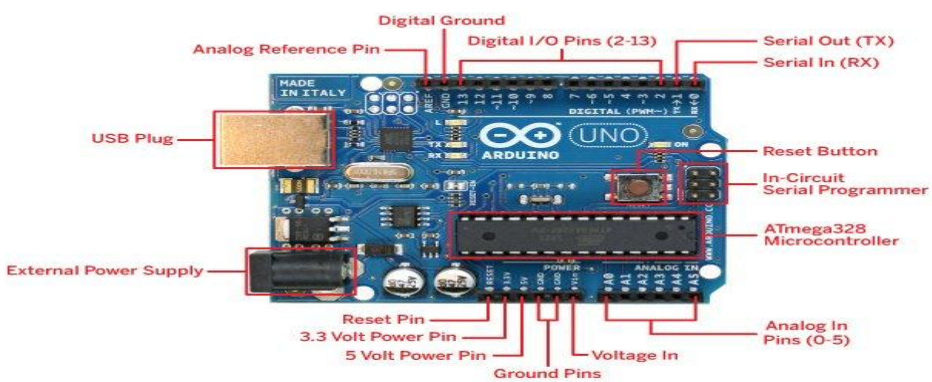


Figure 5.1 Arduino Uno.

5.2.2 Sensors:

1. Radiation sensor:

A light dependent resistor is a component that is sensitive to light. When light falls upon it then the resistance changes. Values of the resistance of the LDR may change over many orders of magnitude the value of the resistance falling as the level of light increases. It will be connected to the Arduino with analog pin, and the readings of it will be used in the equations of the three PV models. See Figure [5.2]

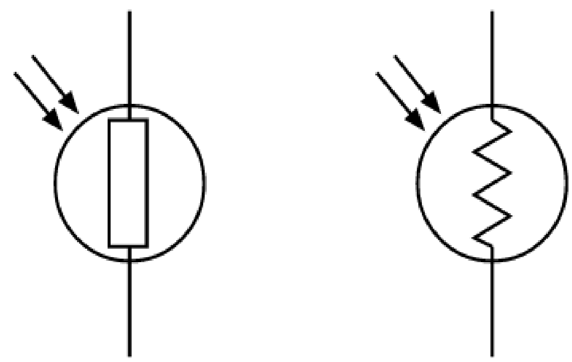

Circuit symbols used for the light dependent resistor / photoresistor

Figure 5.2 LDR sensor

2. Temperature sensor:

This sensor takes the reading of the temperature from sun. It will be connected to the Arduino with analog pin and take these reading to use it in the equations of the three PV models (11), the connection of this sensor shown in Figure [5.3].

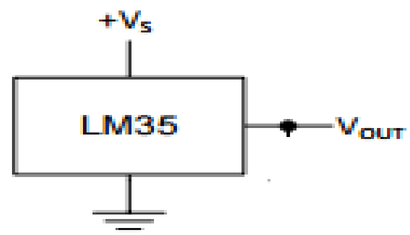


Figure 5.3 connection of temperature sensor.

3. Voltage sensor:

This sensor takes the reading of the voltage out from the PV cell. It will be connected to the Arduino with analog pin and take these reading to make comparison between the energy of the photovoltaic cell and estimated energy (12), the connection of this sensor shown in Figure [5.4].

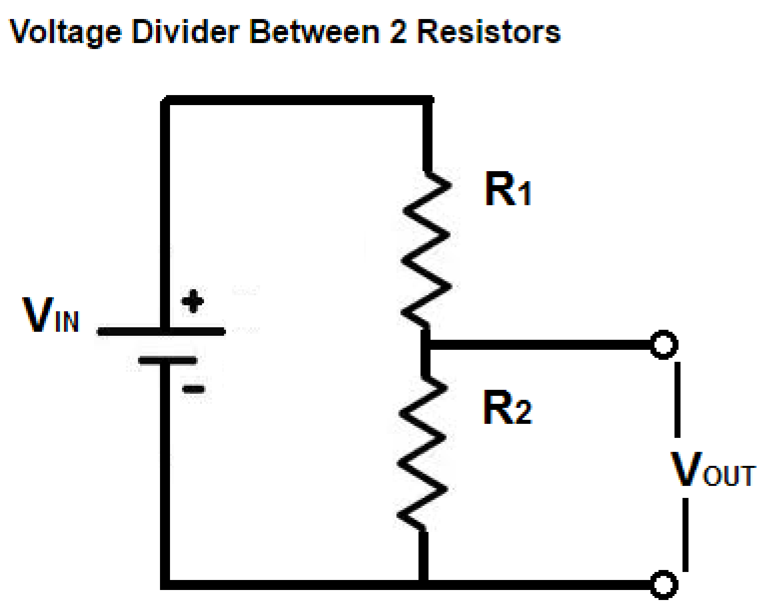


Figure 5.4 voltage sensor

4. Current sensor:

This sensor takes the reading of the current out from PV cell. It will be connected to the Arduino with analog pin as shown in Figure[5.5] and take these reading to make comparison between energy of the photovoltaic cell and estimated energy from estimated models (13).

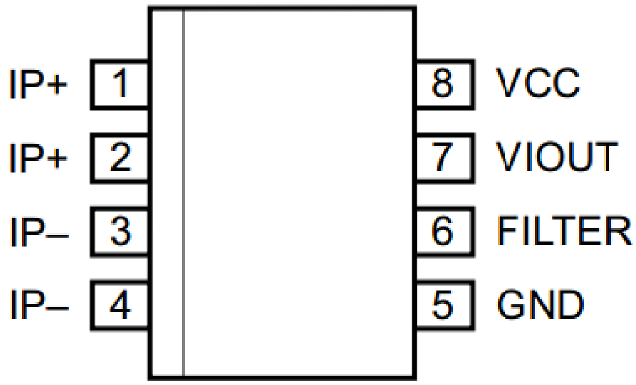


Figure 5.5 the connection of current sensor.

5.3 PV Design and Calculations

To design a PV system, we must follow these steps in calculations:

Table [5.1] load specification

Application	Power(w)	Quantity	Time	Energy(Wh/day)
Repeater	75	1	20	1500

1. PV energy $= \frac{enargy\ \ consumption\ \ \ per\ \ day}{\tau inverter\ \ *\tau charge\ \ controller}$

$$= \frac{1.5KW}{0.9*0.92} = 1.8 \text{ KWh.}$$

2. Power peak (wp) = $\frac{pv\ enargy\ \ per\ day * safty\ \ fact\,or}{peak\ \ sun\ \ houers}$

$$= \frac{1800*1.15}{5.4} = 333 \text{ W}$$

3. Number of module= $\frac{power\ \ peak}{power\ \ of\ one\ module}$

$$= \frac{333}{115} \approx 3module..$$

2.Battery:

The Ampere hour capacity (C*Ah*) of the block battery, necessary to cover the load demands for a period of 2 days autonomy is obtained as:

Where DOD is the depth of discharge=0.75.

$$C_{Ah} = \frac{2*1500}{12*0.75*0.85*0.9} = 436Ah$$

And the Watt hour capacity (C_{Wh}) is obtained as:

$$C_{Wh} = 436*12 = 5.232KWh$$

DC load = $\frac{AC\ load}{\eta inverter}$

= $\frac{1500}{0.9}$ = 1667Wh/day.

With 12v system voltage = $\frac{1667}{12}$ = 140 Ah/day at 12 volt.

For two day without sun 140/2 = 70 Ah (select battery provide 80Ah)

To install this capacity, need 4 block batteries in series (each Battery rated at 80 Ah).

5.4 Load (base station)

The load in our system is the R22 Band Selective Repeater, this repeater input connected with the PV cells to energize it and the output of it is the power that used to cover a certain area effectively, the repeater shown in Figure [5.6].

Figure 5.6 R22 band selective repeater

5.5 Mobile phone

The mobile phone or cell phone used to receive the SMS that sent when there are faults in the PV system that energize the base station, so the input of this device is the SMS that contains information from the Arduino sent by SIM900 shield, and the output is its screen that display the alarming message, this device shown in Figure [5.7].

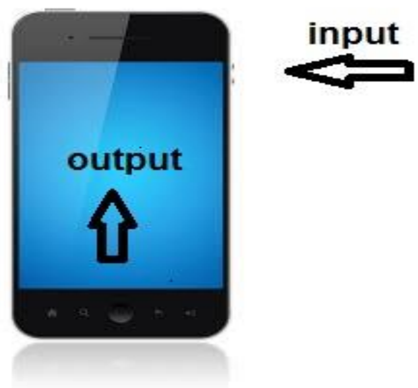


Figure 5.7 mobile phone

CHAPTER SIX

Implementation

6.1 Introduction.

6.2 Photovoltaic System.

6.3 Monitoring System.

6.4 Monitoring Protocol.

6.1 Introduction:

In this chapter, we will provide all the steps of the system implementation including the Arduino codes of the sensors and the protocol and some pictures to show the hardware connections and implementation.

6.2 Photovoltaic system:

In the following Figure [6.1], the design of the photovoltaic system is shown in details with basic components and connection.

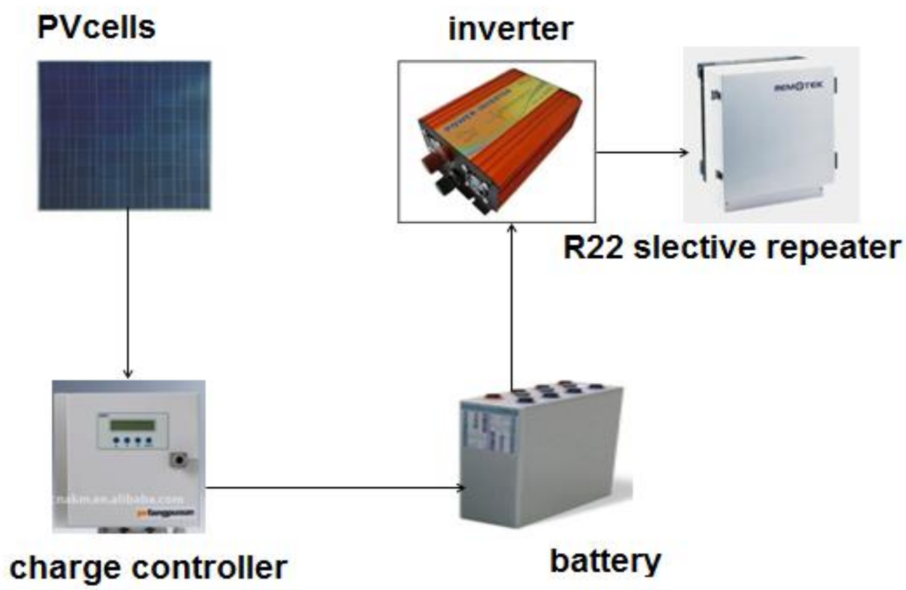


Figure 6.1 Design of PV Cells System

- The sunlight fall on the PV cells , then pv convert the light into electrons as in Figure [6.1](a)

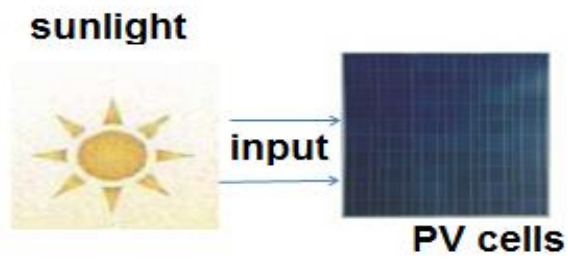


Figure 6.1 (a)

- The output of the PV cells is the input of the charge controller as shown in Figure[6.1] (b).

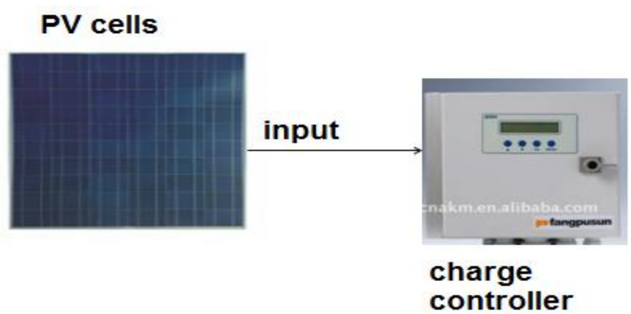


Figure 6.1 (b).

- The output of the charge controller is the input of the battery, and the output of the battery is the input of the inverter as shown in Figure[6.1] (c) .

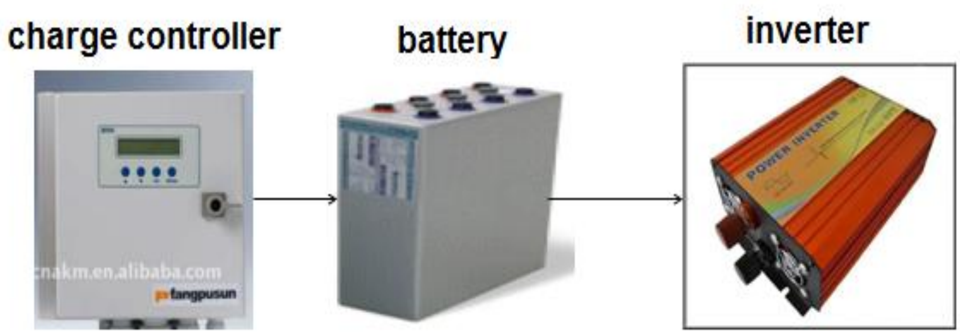


Figure 6.1 (c) .

- The inverter converts DC power from the PV module into AC power to run the load (R22repeater) as shown in Figure[6.1](d).

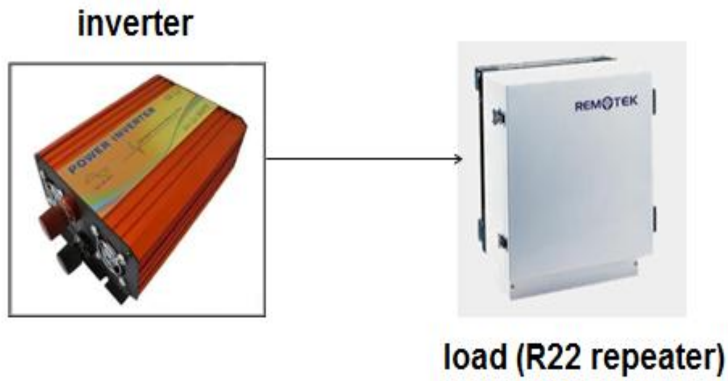


Figure 6.1 (d).

6.3 monitoring system:

In the following Figure [6.2], the design of the monitoring system will be shown in details with basic components and connection.

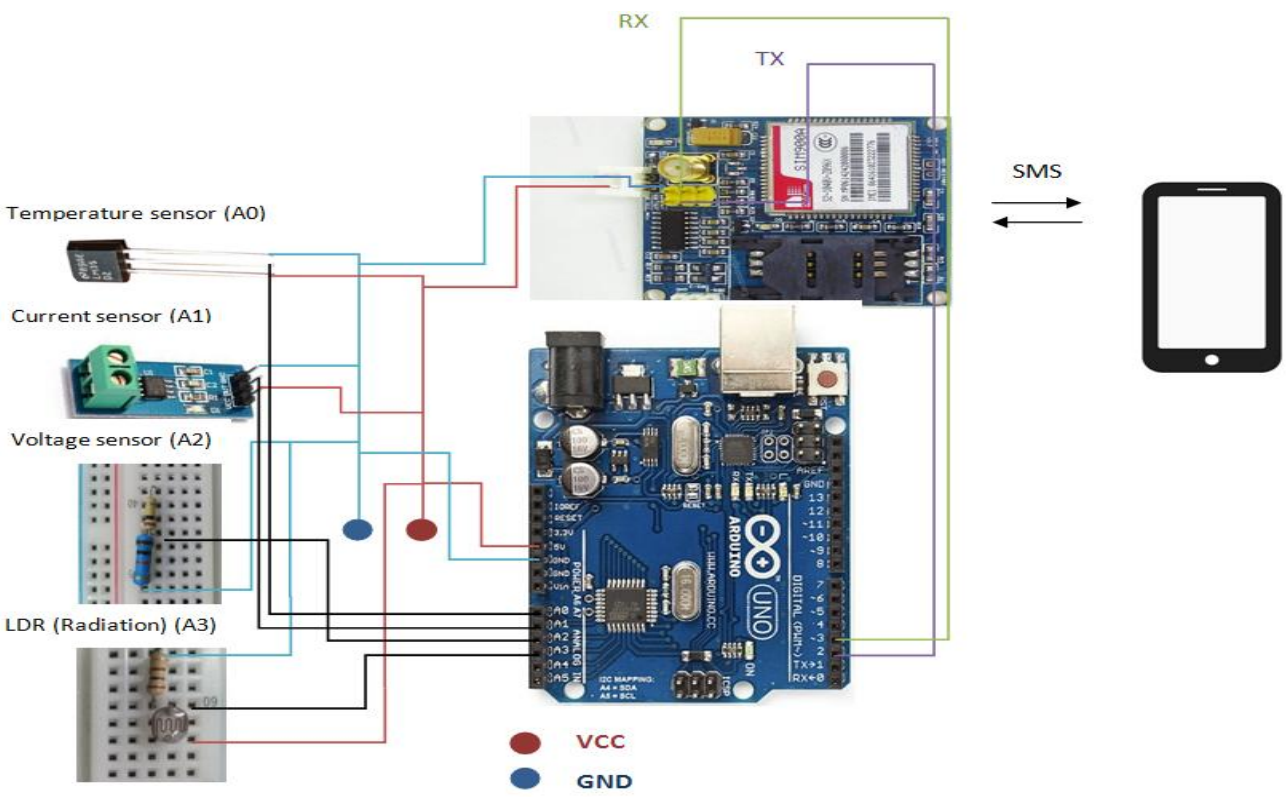


Figure 6.2 monitoring system design

Temperature sensor:

Temperature sensor in Figure [6.2] (a) connected with analog pin 0 on microcontroller and programmed with Arduino code A[1] to measure the Temperature.

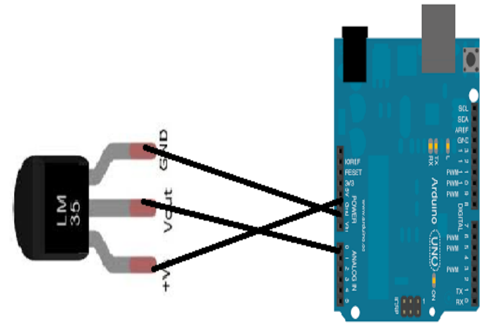


Figure 6.2 (a) temperature sensor connection

Current sensor:

Current sensor in Figure [6.2] (b) connected with analog pin 1 on microcontroller and programmed with arduino code A[2] to measure the current from the PV system .

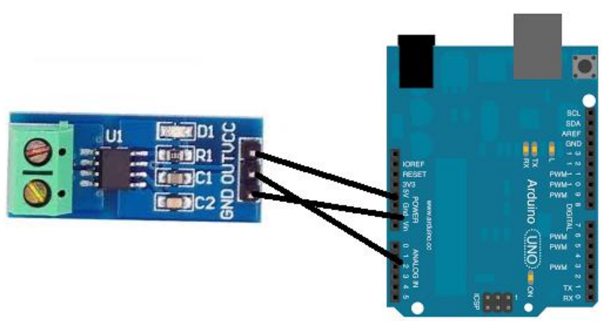


Figure 6.2 (b) current sensor connection

Radiation Sensor (LDR):

As we mentioned before, we use the LDR instead of a real radiation sensor, we make a mapping between parameters from the two sensors and use the Excel programme to create an equation for this purpose shown in Figure [6.3].

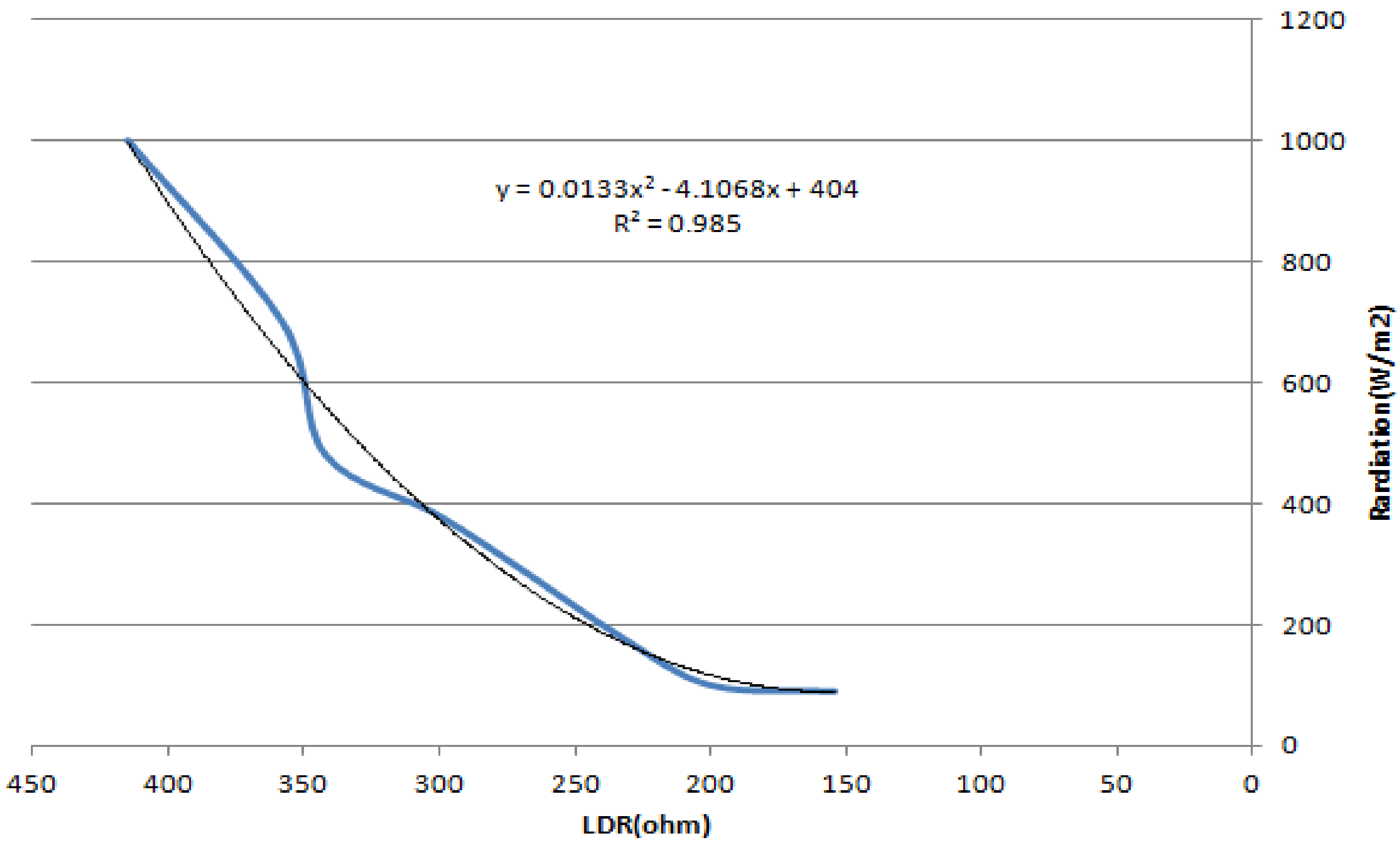


Figure 6.3 radiation vs ldr

We use the equation in the figure 6.3 in arduino programming and it give close values to the real radiation sensor values because the correlation between LDR and the radiation sensor is 0.985 , LDR sensor as shown in Figure [6.2] (c) connected with analog pin 3 on microcontroller and programmed with arduino code A[3] to measure the radiation .

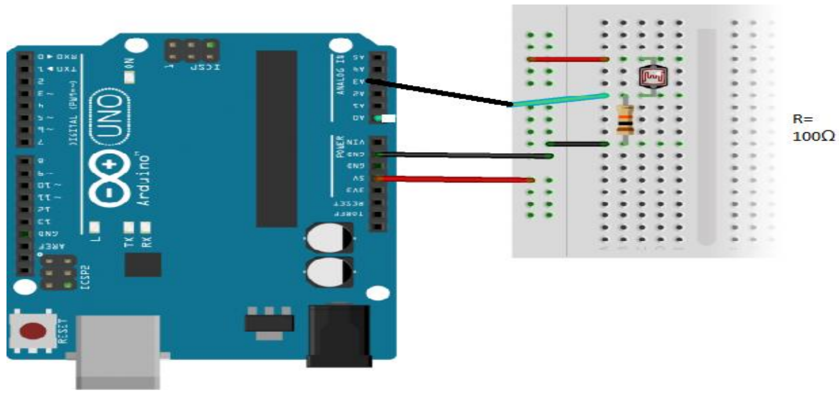


Figure 6.2 (c) LDR connection

Voltage sensor:

Voltage sensor as shown [6.2] (d) connected with analog pin 2 on microcontroller and programmed with Arduino code A[4] to measure the voltage .

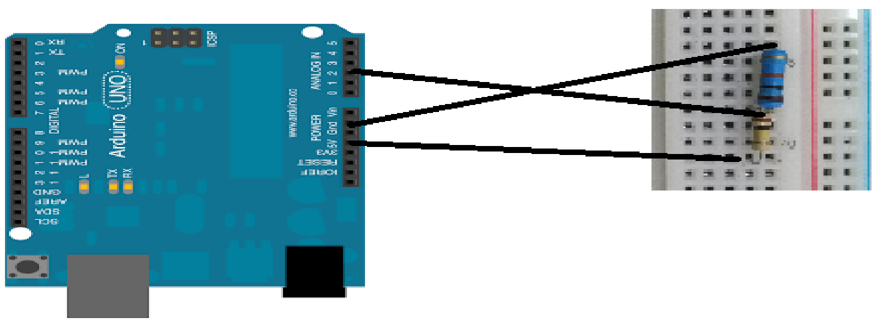


Figure 6.2(d) voltage sensor connection

Real Implemenation of the Project :

Figure 6.4 PV cell

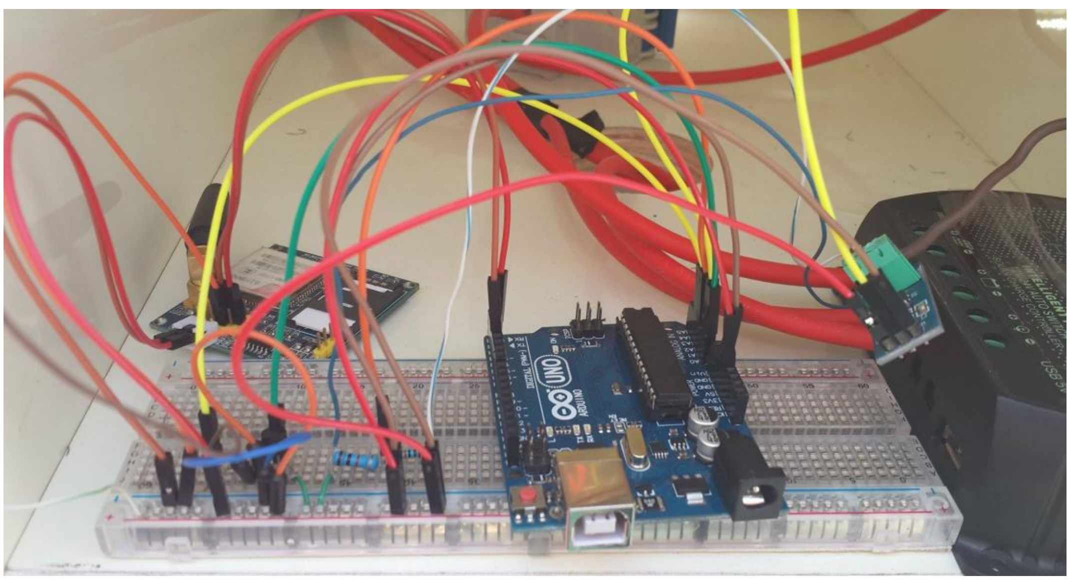


Figure 6.4(a) system connection

Figure 6.4(b) system connection

6.4 Monitoring Protocol:

The protocol code A [5] designed to be able to send and receive messages to and from the SIM shield. One of these messages is an alarm message that will be sent when there's a fault in the PV system, this fault will occurs as a loss in the desired power needed for the repeater to work efficiently, also the user can monitor all the parameters through sending a check message from the mobile.

6.5 Implementation of the Energy Estimated models on Matlab :

The code in A[6] for the ideal photovoltaic module (first energy estimated model) and the Figure [6.5] bellow show pv-curve in standard temperature and radiation at voltage maximum point(Vmp).

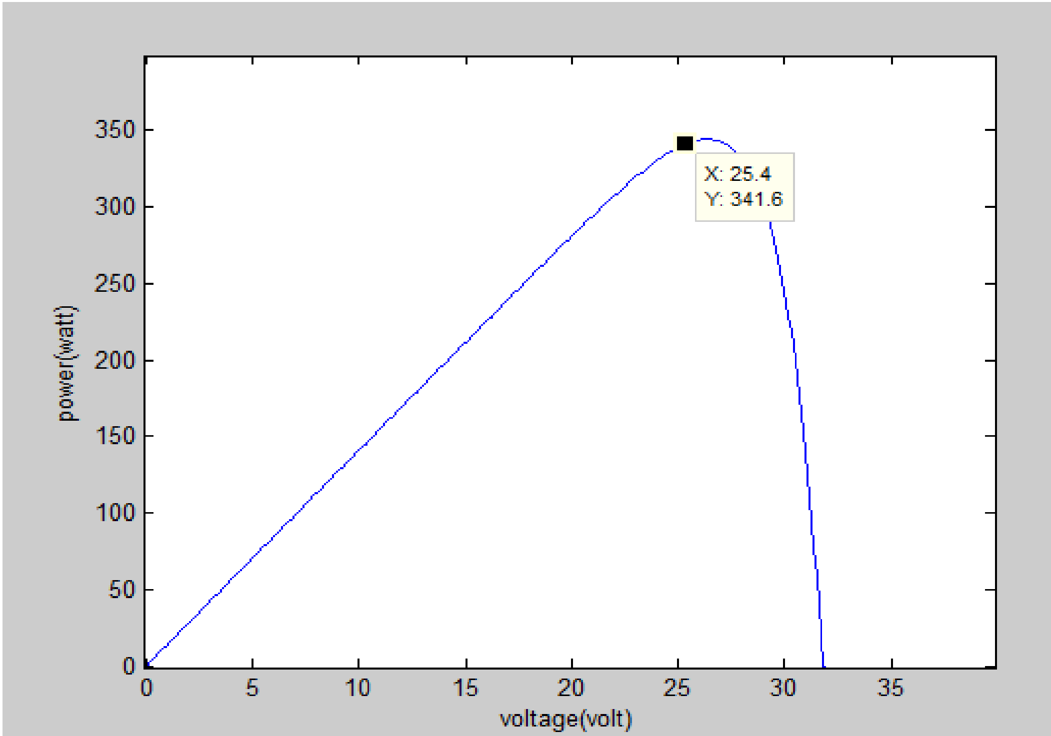


Figure 6.5 PV curve for first energy estimated model

The code in A[7] for the photovoltaic module with series resistance (second energy estimated model) and the Figure [6.6] bellow show pv-curve in standard temperature and radiation at voltage maximum point(Vmp).

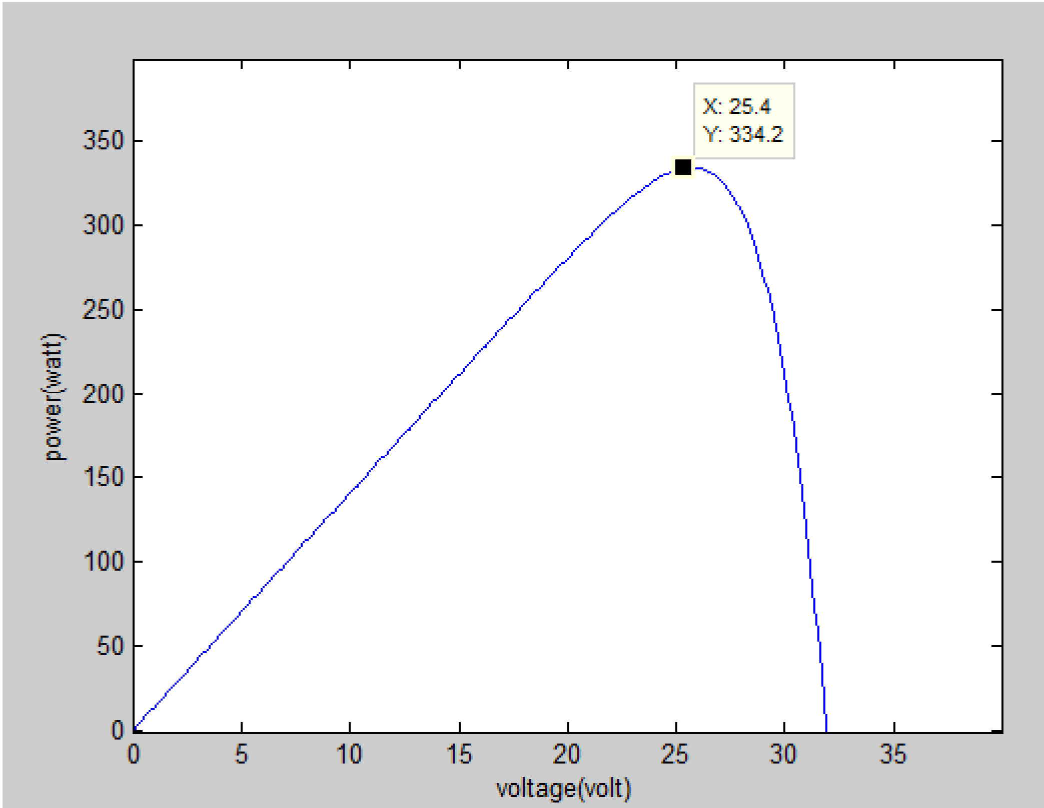


Figure 6.6 PV curve for second energy estimated model

The code in A[8] for the photovoltaic module with series and parallel resistance (third energy estimated model) and the Figure [6.7] bellow show pv-curve in standard temperature and radiation at voltage maximum point(Vmp).

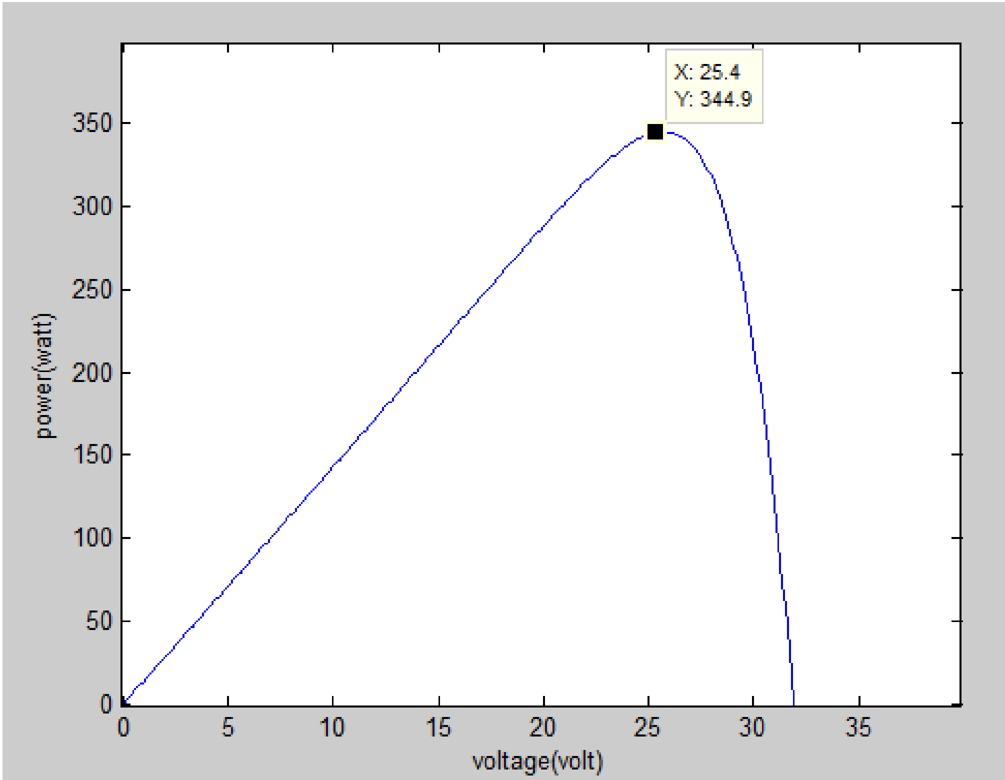


Figure 6.7 PV curve for third energy estimated model

CHAPTER SEVEN

Results

7.1 Introduction

7.2 Sub System Testing.

7.3 Energize Cellular Base Station.

7.4 Energy Estimated Model.

7.5 Monitoring System.

7.1 Introduction

This chapter presents the results of the project. These results include energizing the cellular base station using PV cells, the best energy estimation model from three energy estimation models, and finally the performance of the monitoring system.

7.2 Subsystem Testing:

- Checking the connection of the PV system.
- Checking the connection of the monitoring system.
- Receiving each sensor value from the sensor via the monitoring protocol.
- Receiving an alarm message from the arduino when power level decrease.
- Testing the load (the repeater) by operating it and detect its output signal.

7.3 Energize Cellular Base Station

To energize cellular base station (R22), W e used 3-module of PV cells and connect them in parallel , also we connect (voltage ,current ,radiation and temperature) sensors with these modules ,and the results were as shown in the bellow table[7.1].

Table [7.1] Real readings of PV cells

	Temperature (C)	Radiation (w/m2)	Current (A)	Voltage (V)	Power (W)
1	33.20	900	12.59	12.00	151.08
2	30.40	880	12.40	12.13	150.41
3	29.00	877	12.27	12.20	149.69
4	25.40	766	10.59	12.50	132.37
5	23.22	628	8.62	12.93	111.45
6	21.12	615	8.37	13.14	109.98
7	20.72	550	7.58	13.40	101.57
8	19.51	530	7.28	13.52	98.42
9	18.30	500	6.90	13.71	94.59
10	18.00	440	6.09	13.93	84.83

We can recognize that the power from the PV cells increases when current increases. This is because the PV modules are current source, which means that the PV modules affect the current more than the voltage.

7.4 Energy Estimated Model

We make a comparison between three energy estimated models using Arduino programming.

First energy estimated model:

We use the code in A [9] to get the values of current and voltage for different readings of temperature and radiation

Table [7.2] First Energy Estimated Model

	Temperature (C)	Radiation (W/m2)	Current (A)	Voltage (V)	Power (W)
1	33.20	900	11.31	12.00	135.70
2	30.40	880	11.11	12.13	134.76
3	29.00	877	10.80	12.20	131.76
4	25.40	766	9.62	12.50	120.25
5	23.22	628	7.81	12.93	100.98
6	21.12	615	7.43	13.14	97.63
7	20.72	550	6.51	13.40	87.23
8	19.51	530	6.25	13.52	84.50
9	18.30	500	5.72	13.71	78.42
10	18.00	440	5.20	13.93	72.43

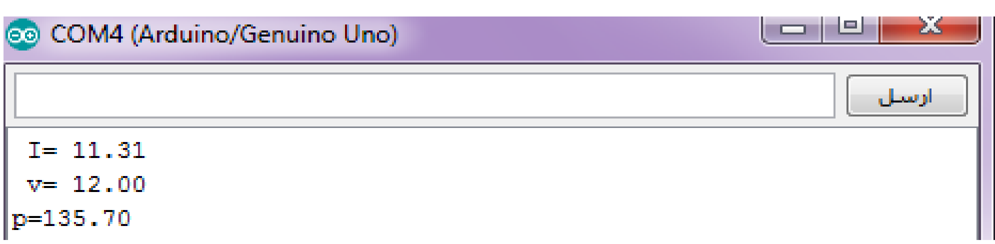


Figure 7.1 resulted power from the first energy estimated model

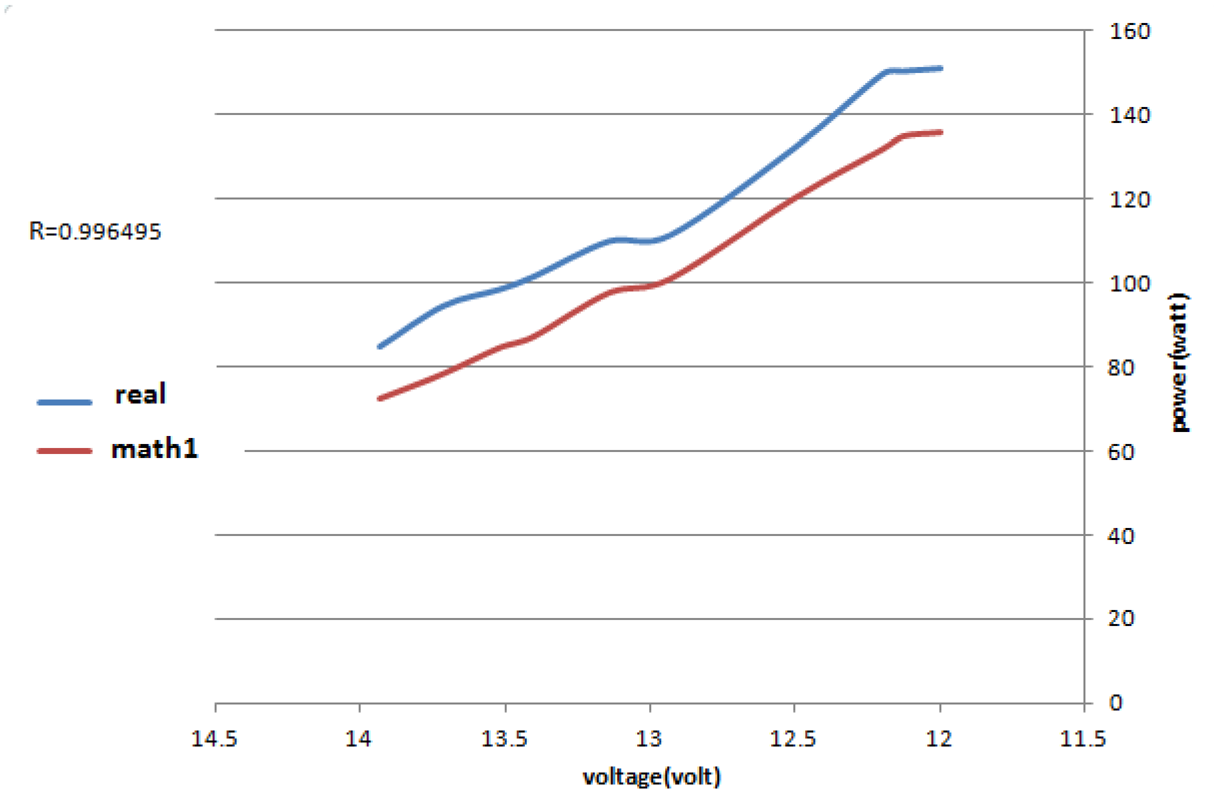


Figure 7.2 power vs voltage of first energy estimated model and real reading

Figure 7.2 show the relation between voltage and power of PV panels and the first energy estimated model , and the correlation between this model and real reading from PV was 0.996495.

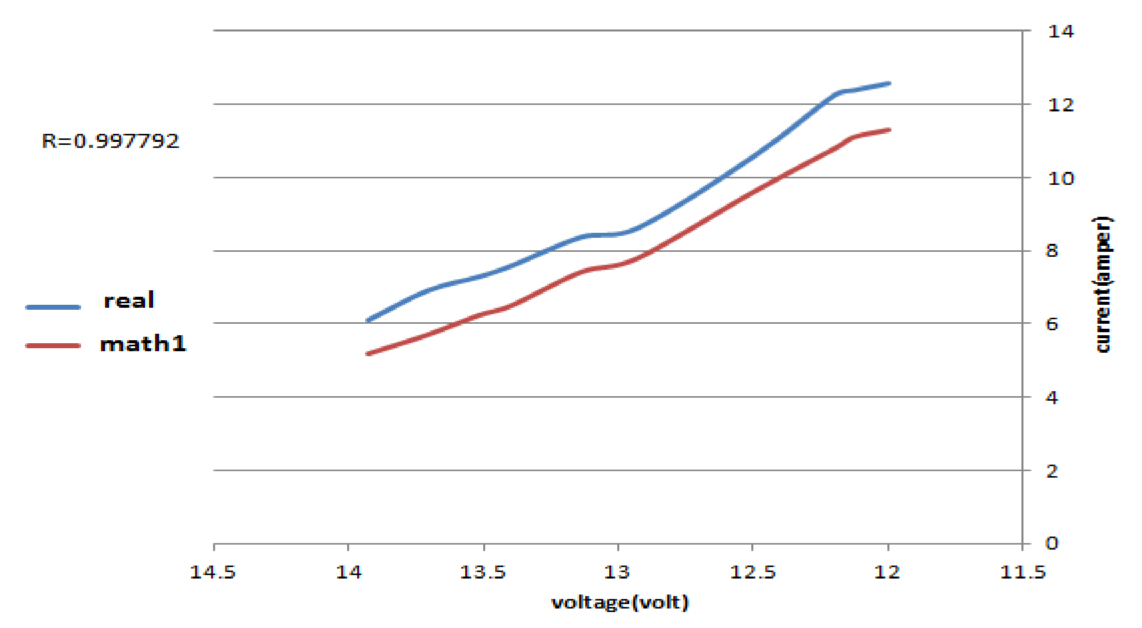


Figure 7.3 current vs voltage of first energy estimated model and real reading

Figure 7.3 show the relation between voltage and current of PV panels and the first energy estimated model , and the correlation between this model and real reading from PV was 0.997792.

Second Energy Estimated Model:

We use the code in A[10] to get the values of current and voltage for different readings of temperature and radiation .

Table [7.3] Second Energy Estimated Model

	Temperature (C)	Radiation (W/m2)	Current (A)	Voltage (V)	Power (W)
1	33.20	900	12.33	12.00	147.92
2	30.40	880	12.11	12.13	146.89
3	29.00	877	11.92	12.20	145.42
4	25.40	766	10.73	12.50	134.12
5	23.22	628	8.95	12.93	115.72
6	21.12	615	8.50	13.14	111.70
7	20.72	550	7.63	13.40	102.24
8	19.51	530	7.38	13.52	99.77
9	18.30	500	6.88	13.71	94.32
10	18.00	440	6.40	13.93	89.15

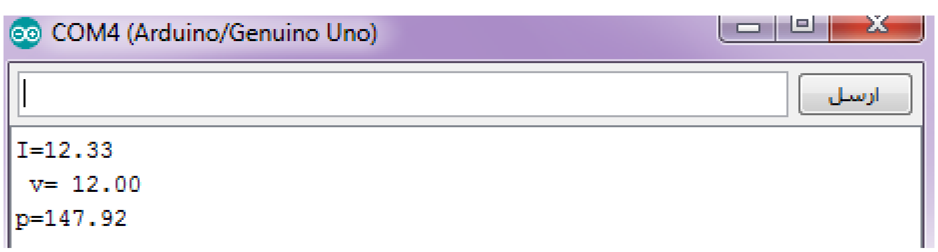


Figure 7.4 resulted power from the second energy estimated model

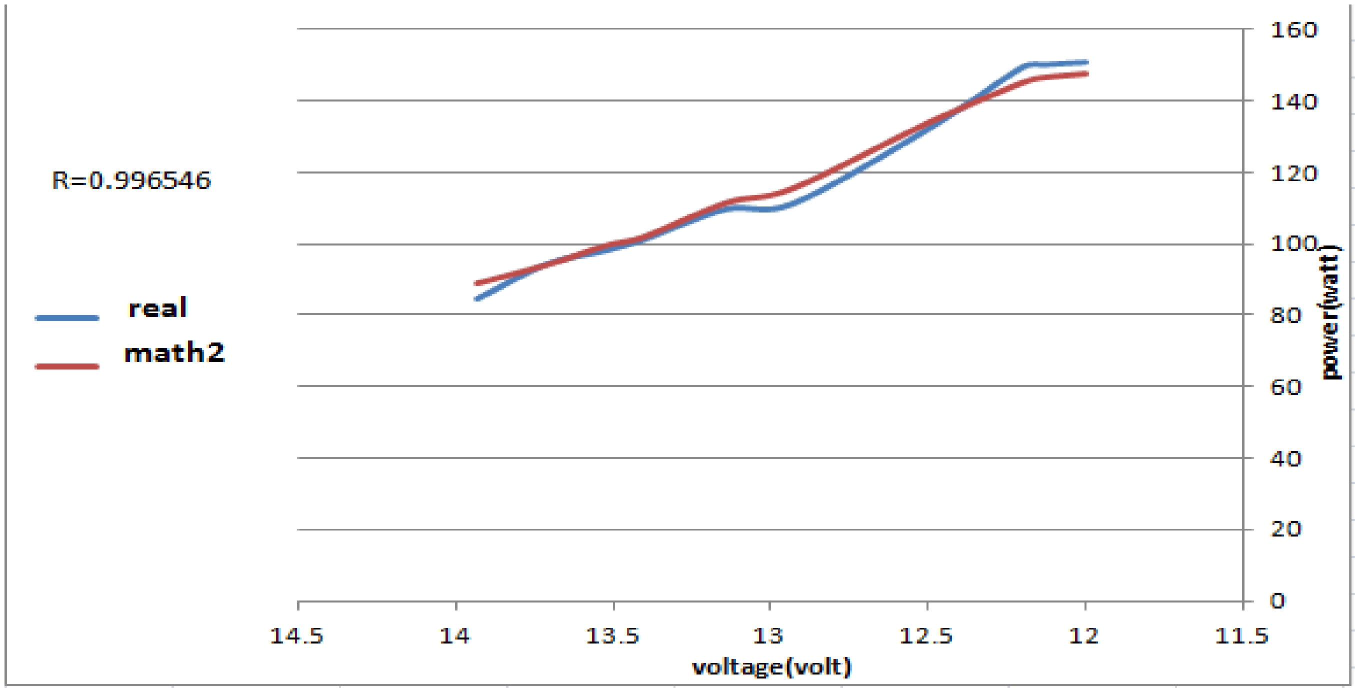


Figure 7.5 power vs voltage of second energy estimated model and real reading

Figure 7.5 show the relation between voltage and power of PV panels and the second energy estimated model , and the correlation between this model and real reading from PV was 0.996546.

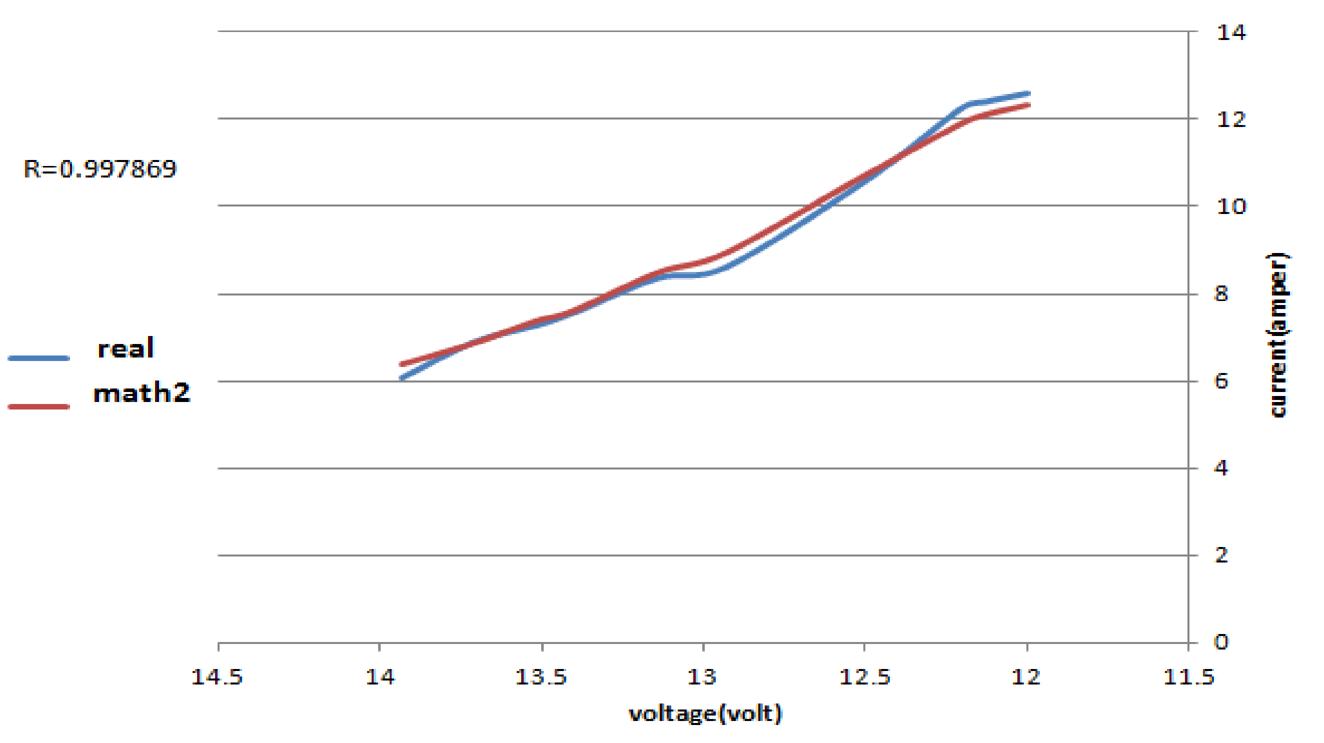


Figure 7.6 current vs voltage of second energy estimated model and real reading

Figure 7.6 show the relation between voltage and current of PV panels and the second energy estimated model , and the correlation between this model and real reading from PV was 0.997869.

Third Energy Estimated Model:

We use the code in A[11] to get the values of current and voltage for different readings of temperature and radiation .

Table [7.4] Third Energy Estimated Model

	Temperature (C)	Radiation (W/m2)	Current (A)	Voltage (V)	Power (W)
1	33.20	900	12.63	12.00	151.61
2	30.40	880	12.34	12.13	149.68
3	29.00	877	12.29	12.20	149.93
4	25.40	766	10.71	12.50	133.87
5	23.22	628	8.76	12.93	113.26
6	21.12	615	8.56	13.14	112.47
7	20.72	550	7.65	13.40	102.51
8	19.51	530	7.36	13.52	99.50
9	18.30	500	6.96	13.71	95.42
10	18.00	440	6.00	13.93	83.58

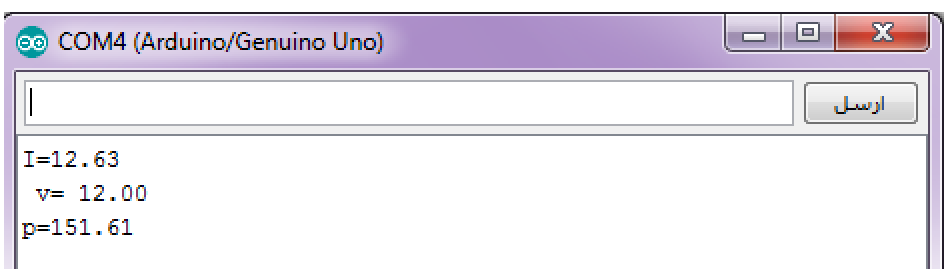


Figure 7.7 resulted power from the third energy estimated model

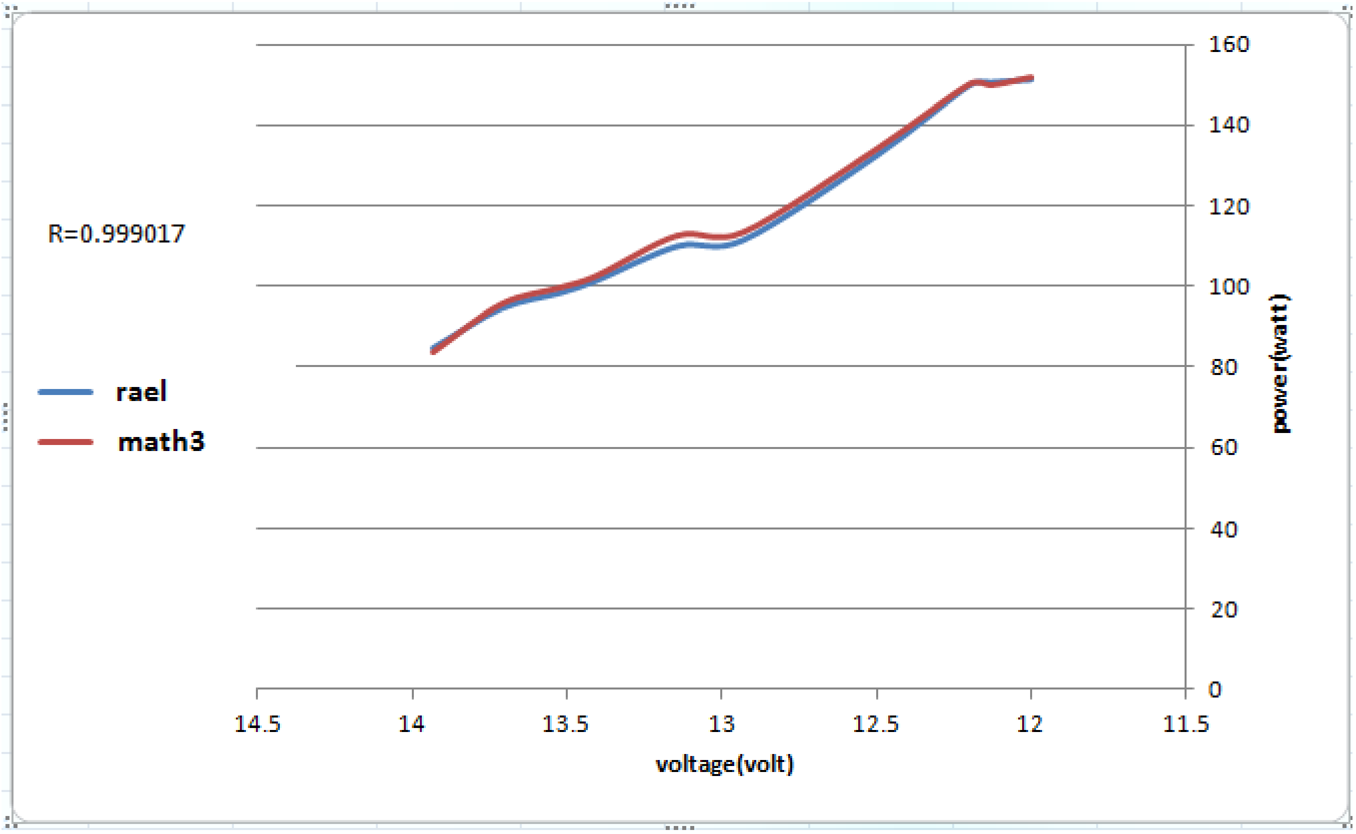


Figure 7.8 power vs voltage of third energy estimated model and real reading

Figure 7.8 show the relation between voltage and power of PV panels and the third energy estimated model , and the correlation between this model and real reading from PV was 0.999017.

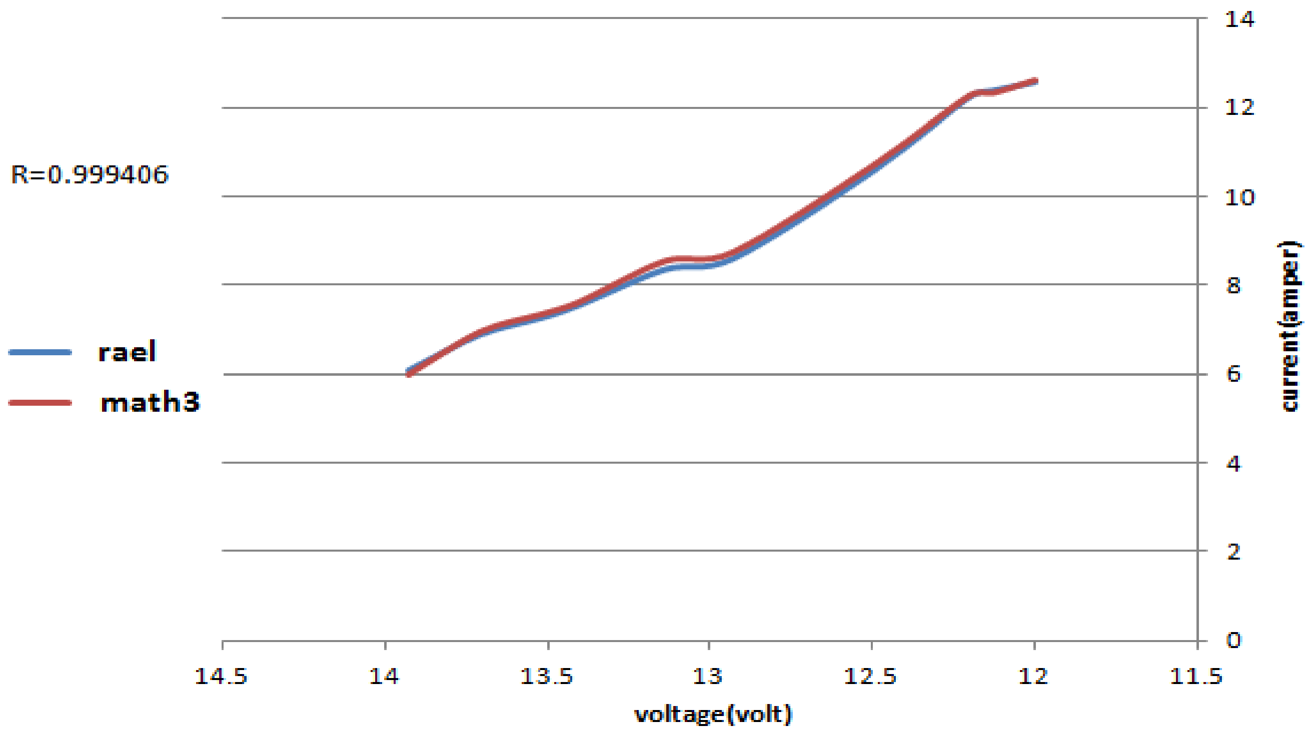


Figure 7.9 current vs voltage of third energy estimated model and real reading

Figure 7.9 show the relation between voltage and current of PV panels and the third energy estimated model , and the correlation between this model and real reading from PV was 0.999406.

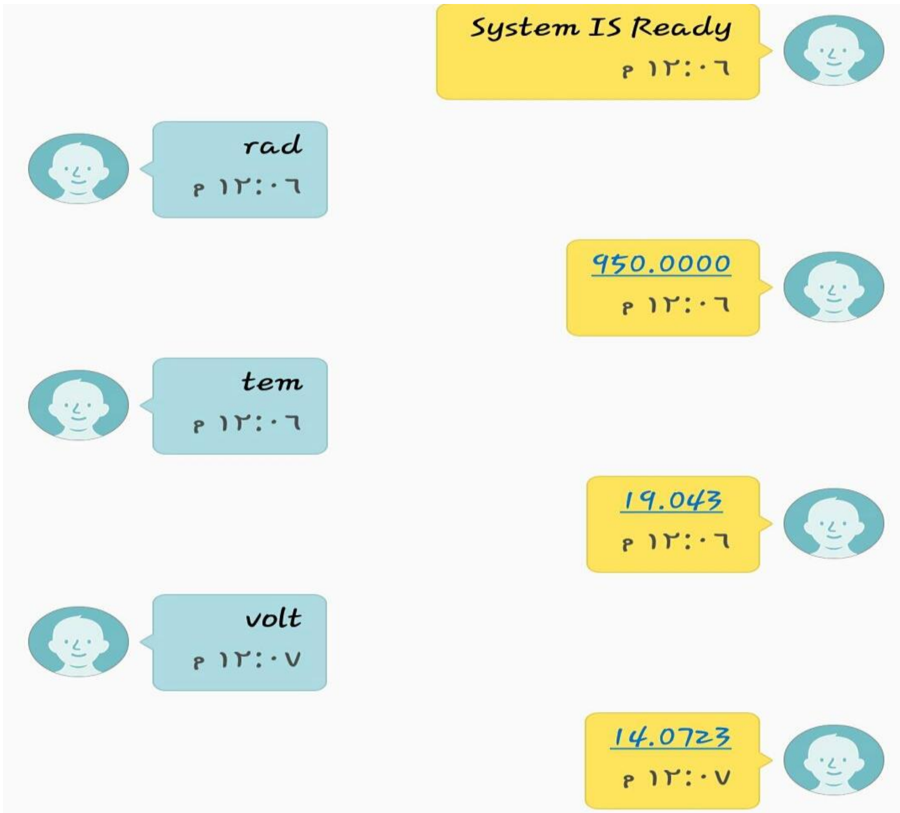
The result from the correlation between the real reading of PV and the three energy estimated models was the third energy estimated model have more correlation to the real than the other models , so we use third energy estimated model in the monitoring system.

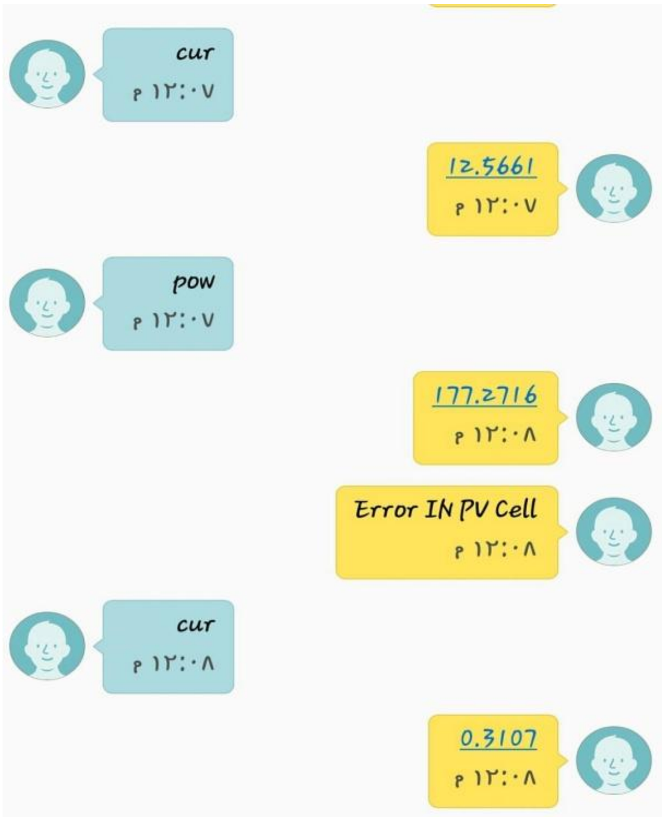
7.5 Monitoring System

After connecting the sensors and SIM 900 shield with Arduino and applying the protocol code in A[5], we can monitor many important parameters (voltage ,current ,radiation ,temperature ,power).

This protocol designed to send the values of these parameters when the user need them, also to send SMS to the user to tell him if there's error in PV cell or not .

The protocol in this system depend on third energy estimated model, by comparing between the energy of PV system and the energy from the third estimated model ,then it will send SMS " Error IN PV cell" if there is a difference between the two values .the final code in A[12].




cur
١٢:٠٧ م
12.5661
١٢:٠٧ م
pow
١٢:٠٧ م
177.2716
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Error IN PV Cell
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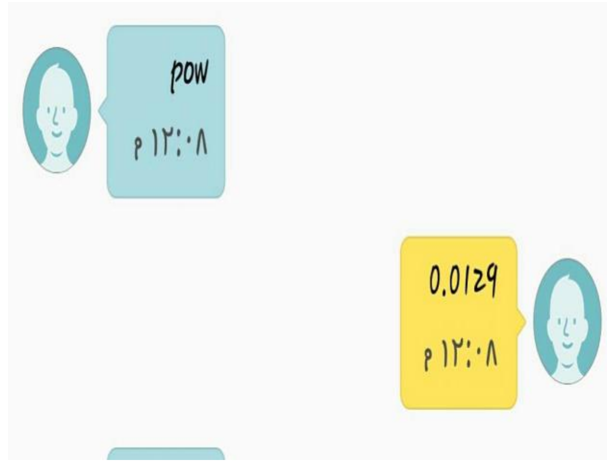
pow
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CHAPTER EGHIT

CONCLUSION

8.1 Conclusion.

8.2 Recommendations.

8.1 Conclusions

- In this project, we designed a new system that energizes and monitors cellular base stations in rural areas that can't be reaching by electric grid.

- We compare between three energy estimation models using real temperature and radiation readings from sensors. We found that the third model which consist of Rs and Rp is the best one because these resistors makes the power more efficient than the first and second models that doesn't have Rs and Rp.

- After choosing the third model as the best energy estimation model, we used it to monitor the power of PV system by comparing it with the real power that come from the pv cells.

- We could energize our load (the R22 repeater) and turn it on and measure the signal of it with specific software and make sure that it is working well.

8.2 Recommendation

- In the future, we can use GPRS instead of SMS for less cost, more efficient data saving and keep readings in database.

- We can use more sensors for monitoring as humidity sensor.

References:

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APPENDIX

A[1]

```
int val;
int tempPin = 0;//analog A0
void setup()
{
Serial.begin(9600);
}
void loop()
{
val = analogRead(tempPin);
float mv = ( val/1024.0)*5000;// to convert from analog to digital reading
float cel = mv/10;//to convert from digital value to Celsius
Serial.print("TEMPRATURE = ");
Serial.print(cel);
Serial.print("*C");
Serial.println();
delay(1000);
}
```

A[2]

```
void setup() {
  Serial.begin(9600);
}

void loop() {
unsigned int x=0;
float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,AcsValueF=0.0;

  for (int x = 0; x < 150; x++){
  AcsValue = analogRead(A1); // current reading to analog number 1
  Samples = Samples + AcsValue; //take current reading every sample
  delay (3);
}
AvgAcs=Samples/150.0;
AcsValueF =(-1* ((AvgAcs * (5.0 / 1024.0)) - 2.5 )/0.066);//convert current reading to DC and digital reading
Serial.print(AcsValueF);
Serial.println("A");
delay(1000);
}
```

A[3]

```
int LDR_Pin = A3;//analog A
float  rad;
void setup(){
Serial.begin(9600);
  }
  void loop(){
  rad=((0.013349*pow(analogRead(LDR_Pin),2))-(4.1068*analogRead(LDR_Pin))+404); //convert LDR reading to radiation reading
  Serial.print("rad=");
  Serial.println(rad,2);
  delay(1000);
  }
```

A[4]

```
int analogInput = A2;//analog A2
float vout = 0.0;
float vin = 0.0;
float R1 = 100000.0;
float R2 = 10000.0;
int value = 0;
void setup(){
  Serial.begin(9600);
}
void loop(){
   value = analogRead(analogInput);
   vout = (value * 5.0) / 1024.0;
   vin = vout / (R2/(R1+R2));//voltage divider
Serial.print("INPUT V= ");
Serial.println(vin,2);
delay(1000);
}
```

A[5]

```
#include "SIM900.h"
#include "sms.h"
#include <SoftwareSerial.h>
SMSGSM sms;
int numdata;
boolean started=false;
char smsbuffer[160];
char n[20];
char sms_position;
char phone_number[20];
char sms_text[100];
char number[]="0569995928";
int i;
int j=0;
int r;
int analogInput = A2;
void setup()
{
    pinMode(analogInput, INPUT);
    if (gsm.begin(19200))
    {
        started=true;
    }

    if(started)
    {   for(r=1;r<=20;r++)
       {
```

```
          sms.DeleteSMS(r);
        }
        sms.SendSMS(number, " System IS Ready");
    }
};

void loop()
{
    if(started)
    {
char x [15];
char y [15];
char z [15];
char w [15];
char e [15];
float t;
float v=0.0;
float p;
float  rad;
unsigned int m=0;
float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,c=0.0;
int val;
float mv;
float vout=0.0;
float R1 = 100000.0;
float R2 = 10000.0;
int valuev ;

rad=((0.013349*pow(analogRead(A3),2))-(4.1068*analogRead(A3))+404);//radiation(A3)

val = analogRead(A0);//tempreture(A0)
mv = ( val/1024.0)*5000;
t = mv/10;

  for (int m = 0; m < 150; m++){ //current(A1)
  AcsValue = analogRead(A1);
  Samples = Samples + AcsValue;
  delay (3);
}
AvgAcs=Samples/150.0;
c =(-1* ((AvgAcs * (5.0 / 1024.0)) - 2.5 )/0.066);

 valuev = analogRead(analogInput);//voltage(A2)
 vout = (valuev* 5.0) / 1024.0;
 v = vout / (R2/(R1+R2));

 p=v*c;
 if((p<100) && (j==0)){
                       if( sms.SendSMS(number, "Error IN PV Cell")){j=1;}}

dtostrf(t, 7, 3, x);
dtostrf(p, 5, 4, e);
dtostrf(rad, 5, 4, y);
```

```
dtostrf(c, 5, 4, w);
dtostrf(v, 5, 4, z);


        sms_position=sms.IsSMSPresent(SMS_UNREAD);
        if (sms_position)
        { int l =(sms_position,DEC);
       if(l>15){sms.SendSMS(number, "FULL MEMORY!!");}
            sms.GetSMS(sms_position, phone_number, sms_text, 100);

String test ="";

        for (int i =0;i<100;i++) {
         test = test + sms_text[i];
        }

                      if(test.indexOf("tem")> -1) {

                      sms.SendSMS(number , x);
                      }

                      if(test.indexOf("pow")> -1) {
                      sms.SendSMS(number , e);
                      }

                      if(test.indexOf("rad")> -1) {
                      sms.SendSMS(number , y);


                     }

                     if(test.indexOf("cur")> -1) {
                       sms.SendSMS(number ,w);
                     }

                     if(test.indexOf("volt")> -1) {
                     sms.SendSMS(number ,z);
                     }
                     if(test.indexOf("ok")> -1) {
                      if(sms.SendSMS(number ,"System IS Ready")){j=0;}
                     }

         if(test.indexOf("del")> -1) { for(r=1;r<=20;r++)
      {
         sms.DeleteSMS(r);
      }}

        test ="";

       }
       }
   };
```

A[6]

```
clc;
clear all;
vocn=31.9;
iscn=4.7;
vmp=25.4;
imp=4.5;
Tn=25+273;
Gn=1000;
Ns=54;
Rs=0/3;
Rp=0;
 ns=1;
 np=3;
 k = 1.3806503e-23;
q = 1.60217646e-19;
kv=-158e-3;
ki=1.46e-3;
a=1.5;
eg=1.12;

T=25+273;
G=1000;


vtn=Ns*k*Tn/q;
I0n = iscn/((exp(vocn/ns/(a*vtn)))-1);
I0=I0n*((T/Tn)^3)*exp(((q*eg/(a*k))*((1/Tn)-(1/T))));
Ipvn=iscn;
Ipv = Ipvn+(ki*(T-Tn))*(G/Gn);
vt=Ns*(k*T/q);
I=zeros(10,1);
i=1;

I(1,1)=0;
for v=31.9:-0.1:0
 I_part=I0*np*(exp((v+(I(i,1)*Rs)/ns)/(vtn*a))-1);
    I(i+1)=(np*Ipv-I_part);
    v1(i)=v;
    P(i)=v*I(i);
    i=i+1;
end
v1(i)=v1(i-1);
P(i)=P(i-1);
v1=transpose(v1);
%plot(v1,I);
plot(v1,P);
```

A[7]

```
clear all;
vocn=32;
iscn=4.7;
vmp=25.4;
imp=4.5;
Tn=25+273;
Gn=1000;
Ns=54;ns=1;np=3;
Rs=0.2/3;
Rp=0;
k = 1.3806503e-23;
q = 1.60217646e-19;
kv=-158e-3;
ki=1.46e-3;
a=1.5;
eg=1.12;


T=25+273;
G=1000;


vtn=Ns*(k*Tn/q);
I0n = iscn/((exp(vocn/(a*vtn)))-1);
I0=I0n*((Tn/T)^3)*exp(((q*eg/(a*k))*((1/Tn)-(1/T))));
Ipvn=iscn;
Ipv = Ipvn+(ki*(T-Tn))*(G/Gn);
vt=Ns*(k*T/q);
I=zeros(10,1);
i=1;
I(1,1)=0
```

```
for v=31.9:-0.1:0
    I_part=I0*np*(exp((v+(I(i,1)*Rs)/ns)/(vtn*a))-1);
    I(i+1)=(np*Ipv-I_part);
    v1(i)=v;
    P(i)=v*I(i);
    i=i+1;
end
v1(i)=v1(i-1);
P(i)=P(i-1);
v1=transpose(v1);

%plot(v1,I);
plot(v1,P);


PMAX=vmp*(Ipv-I0*(exp(q*(vmp+(Rs*imp))/(k*T*a*Ns)-1))-(vmp+Rs*imp)/Rp );
 I_part=I0*np*(exp((v+(iscn*Rs)/ns)/(vtn*a))-1)
    I=(np*Ipv-I_part)
```

A[8]

```
clc;
clear all;
vocn=31.9;
iscn=4.7;
vmp=25.4;
imp=4.5;

Ns=54;
ns=1;
np=3;
Rs=0.2/np;
Rp=165/np;
k = 1.3806503e-23;
q = 1.60217646e-19;
ki=1.46e-3;
a=1.5;
eg=1.12;

T=25+273;
G=1000;
Tn=25+273;
Gn=1000;

vtn=Ns*(k*Tn/q);
I0n = iscn/((exp(vocn/(a*vtn)))-1);
I0=I0n*((Tn/T)^3)*exp(((q*eg/(a*k))*((1/Tn)-(1/T))));
Ipvn=iscn;
Ipv =Ipvn+(ki*(T-Tn))*(G/Gn);%
vt=Ns*k*T/q;
I=zeros(15,1);
i=1;
I(1,1)=0
```

```
for v=31.9:-0.1:0
  I_part=I0*np*((exp((v+(I(i,1)*Rs))/(vt*a))-1))-((v+(Rs*I(i,1)))/Rp);
    I(i+1)=(np*Ipv-I_part);
    v1(i)=v;
    P(i)=v*I(i);
    i=i+1;
end
v1(i)=v1(i-1);
P(i)=P(i-1);
v1=transpose(v1);

%plot(v1,I);
plot(v1,P);

```

A[9]

```
void setup() {
Serial.begin(9600); //first estimated model
}
void loop() {
float T = 33.2;
float Tcref=298.0;
float Tc=T+273;
float Ns=54.0;
float G=800.0;
float Gref=1000.0;
float Ishref=4.7;
float K=1.381*pow(10,-23);
float q=1.602*pow(10,-19);
float A =1.3;
float usc=0.00146;
float Vocref = 31.9;
float eg=1.12;
float Id,Vt,I0,a,Iph,I,I0ref,Iphref,p;
float vot=12.00;
Iphref=Ishref;
Vt=(K*Tc)/q;
a=Ns*A*Vt;
I0ref=Ishref*exp((-1.0*Vocref)/(a));
I0=I0ref*((exp((-1*Vocref)/a))*(pow((Tc/Tcref),3))*(exp(((q*eg)/(A*K))*((1/(Tcref))-(1/(Tc))))));
Iph=((G/Gref)*(Iphref+(usc*(Tc-Tcref))));
Id=I0*(exp(vot/(a))-1);
I=3*(Iph-Id);


p=I*vot;
 Serial.print(" I= ");
 Serial.println(I);
 Serial.print(" v= ");
 Serial.println(vot);
 Serial.print("p=");
 Serial.println(p);
 delay(10000);
}
```

A[10]

```
void setup() {//second energy estimated model
 Serial.begin(9600);
}

void loop() {
float Id,Vt,I0,a,Iph,I,p;
float T =33.2;
float Tcref=298.0;
float Tc=T+273;
float Ns=54;
float G=872;
float Gref=1000;
float Ishref=4.7;
float Iphref=4.7;
float K=1.381*pow(10,-23);
float q=1.602*pow(10,-19);
float A =1.3;
float usc=0.00146;
float Vocref = 31.9;
float I0ref;
float eg=1.12;
float Rs=0.54;
float vot=12.00;
 Iph=((G/Gref)*(Iphref+(usc*(Tc-Tcref))));
 Vt=(K*Tc)/q;
 a=Ns*A*Vt;
 I0ref=Ishref*exp((-1*Vocref)/a);


 I0=I0ref*(exp((-1*Vocref)/a))*(pow((Tc/Tcref),3))*(exp(((q*eg)/(A*K))*((1/(Tcref))-(1/(Tc)))));
 Id=I0*(exp((vot+(I*Rs))/(A*Ns*Vt))-1);
I=3*(Iph-Id);
p=I*vot;

Serial.print("I=");
Serial.println(I);
Serial.print(" v= ");
Serial.println(vot);
Serial.print("p=");
Serial.println(p);
delay (1000);
}
```

A[11]

```
void setup() {//third energy estimated model
 Serial.begin(9600);
}
void loop() {
float Id,Vt,I0,a,Iph,I,Ip,vot,p;
float T =33.20;
float Tcref=298.0;
float Tc=T+273;
float Ns=54;
float G=900.00;
float Gref=1000;
float Ishref=4.7;
float Iphref=4.7;
float K=1.381*pow(10,-23);
float q=1.602*pow(10,-19);
float A =1.3;
float usc=0.00146;
float Vocref = 31.9;
float I0ref;
float eg=1.12;
float Rs=0.54;
float Rp=410;
vot=12.00;
 Iph=((G/Gref)*(Iphref+(usc*(Tc-Tcref))));
 Vt=(K*Tc)/q;
 a=Ns*A*Vt;
  I0ref=Ishref*exp((-1*Vocref)/a);

  I0=I0ref*(exp((-1*Vocref)/a))*(pow((Tc/Tcref),3))*(exp(((q*eg)/(A*K))*((1/(Tcref))-(1/(Tc)))));
  Id=I0*(exp((vot+(I*Rs))/(A*Ns*Vt))-1);
  Ip=(vot+(Rs*I))/Rp;
  I=3*(Iph-Id-Ip);
p=I*vot;
 Serial.print("I=");
 Serial.println(I);
 Serial.print(" v= ");
 Serial.println(vot);
 Serial.print("p=");
 Serial.println(p);
 delay (10000);
}
```

A[12]

```
#include "SIM900.h"
#include "sms.h"
#include <SoftwareSerial.h>
#include "sms.h"
SMSGSM sms;
int numdata;
boolean started=false;
char smsbuffer[160];
char n[20];
char sms_position;
char phone_number[20];
char sms_text[100];
char number[]="0569995928";
int i;
int j=0;
int r;
void setup()
{

    if (gsm.begin(19200))
    {
        started=true;
    }

    if(started)
    {   for(r=1;r<=20;r++)
       {
```

```
          sms.DeleteSMS(r);
        }
         sms.SendSMS(number, " System IS Ready");
    }
};

void loop()
{
    if(started)
    {
char x [15];
char y [15];
char z [15];
char w [15];
char e [15];
float t;
float v;
float p;
float  rad;
unsigned int m=0;
float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,c=0.0;
int val;
float mv;
int  A3;
float vout;
float R1 = 100000.0;
float R2 = 10000.0;
```

```
int valuev ;

rad=((0.013349*pow(analogRead(A3),2))-(4.1068*analogRead(A3))+404);//radiation(A3)
                       if(  rad>1000){rad=950;}
                       if(  rad<200){rad=300;}

val = analogRead(A0);//tempreture(A0)
mv = ( val/1024.0)*5000;
t = mv/10;

  for (int m = 0; m < 150; m++){ //current(A1)
  AcsValue = analogRead(A1);
  Samples = Samples + AcsValue;
  delay (3);
}
AvgAcs=Samples/150.0;
c =(-1* ((AvgAcs * (5.0 / 1024.0)) - 2.5 )/0.066);

 valuev = analogRead(A2);//voltage(A2)
 vout = (valuev* 5.0) / 1024.0;
 v = vout / (R2/(R1+R2));
 p=v*c;


 float Id,Vt,I0,a,Iph,I,Ip,vot,P,Tc;
float Tcref=298.0;
float Ns=54;
```

```
float G;
float Gref=1000;
float Ishref=4.7;
float Iphref=4.7;
float K=1.381*pow(10,-23);
float q=1.602*pow(10,-19);
float A =1.3;
float usc=0.00146;
float Vocref = 31.9;
float I0ref;
float eg=1.12;
float Rs=0.53;
float Rp=41;
float o;
 vot=14;
Tc=t+273;
G=rad;
 Iph=((G/Gref)*(Iphref+(usc*(Tc-Tcref))));
 Vt=(K*Tc)/q;
 a=Ns*A*Vt;
  I0ref=Ishref*exp((-1*Vocref)/a);
  I0=I0ref*(exp((-1*Vocref)/a))*(pow((Tc/Tcref),3))*(exp(((q*eg)/(A*K))*((1/(Tcref))-(1/(Tc)))));
  Id=I0*(exp((vot+(I*Rs))/(A*Ns*Vt))-1);
  Ip=(vot+(Rs*I))/Rp;
  I=3*(Iph-Id-Ip);
P=I*vot;
```

```
 o=0.5*p;
 if(( p <o) && (j==0)){
                         if( sms.SendSMS(number, "Error IN PV Cell")){j=1;}}




dtostrf(t, 7, 3, x);
dtostrf(p, 5, 4, e);
dtostrf(rad, 5, 4, y);
dtostrf(c, 5, 4, w);
dtostrf(v, 5, 4, z);


         sms_position=sms.IsSMSPresent(SMS_UNREAD);
         if (sms_position)
         { int l =(sms_position,DEC);
        if(l>10){sms.SendSMS(number, "FULL MEMORY!!");}
             sms.GetSMS(sms_position, phone_number, sms_text, 100);

String test ="";

         for (int i =0;i<100;i++) {
          test = test + sms_text[i];
         }

                        if(test.indexOf("tem")> -1) {
```

```
                    sms.SendSMS(number , x);
                    }

                    if(test.indexOf("pow")> -1) {
                    sms.SendSMS("0595090511" , e);
                    }

                    if(test.indexOf("rad")> -1) {
                    sms.SendSMS(number , y);
                    }

                    if(test.indexOf("cur")> -1) {
                      sms.SendSMS(number ,w);
                    }

                    if(test.indexOf("volt")> -1) {
                    sms.SendSMS(number ,z);
                    }
                    if(test.indexOf("ok")> -1) {
                     if(sms.SendSMS(number ,"System IS Ready")){j=0;}
                    }

      if(test.indexOf("del")> -1) { for(r=1;r<=20;r++)
   {
      sms.DeleteSMS(r);
   }}


     test ="";

    }
    }
};
```