

# **Palestine Polytechnic University College Of Engineering**



## **Monitoring and Controlling of Solar Cells**

Prepared by:

Nadeen Abusharkh

Maysaa Salman

Supervisor:

Dr. Murad Abusubaih

Submitted to the Collage of Engineering

In fulfillment of the requirements for the degree of  
Bachelor degree in Communication and Electronics and Electrical Power Technology  
Engineering Hebron, May 2018

**Palestine Polytechnic University**  
**Hebron – Palestine**  
**Collage of Engineering**  
**Department of Electrical Engineering**

**Monitoring and Controlling of Solar Cells**

Team:

Nadeen Abusharkh

Maysa' Salman

**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**

-----

## **Abstract :**

Systems that convert the sunlight into electrical energy like photovoltaic (PV) have been becoming widespread worldwide.

In this project, we designed a system that allows monitoring and controlling of a PV panel. The system is able to report parameters like: Output Power, Voltage, Current, Temperature, etc. The reports is received and stored in a data base and is displayed on a web page and sent to a mobile phone.

Further, the system allows remote controlling of the PV system.

## الملخص:

أصبحت الأنظمة التي تحول ضوء الشمس إلى طاقة كهربائية مثل الخلايا الكهروضوئية على نطاق واسع في جميع أنحاء العالم. في هذا المشروع قمنا بتصميم نظام يسمح بمراقبة الألواح الكهروضوئية والتحكم بها. هذا النظام قادر على الإبلاغ عن بعض المعلومات والخصائص مثل الطاقة الناتجة من الألواح الشمسية، الجهد، التيار ودرجة الحرارة، الخ... تم استلام هذه المعلومات وتخزينها في قاعدة بيانات وعرضها على صفحة ويب خاصة قمنا بإنشائها لهذا الغرض، كما تم إرسال البيانات إلى الهاتف المحمول. علاوة على ذلك يسمح النظام بالتحكم عن بعد في النظام الكهروضوئي.

## List of contents

Abstract .....	3
List of Contents.....	5
Table of Figures.....	8
List of Tables.....	9
Important Abbreviations.....	9

## Chapter one: Introduction

1.1 Overview.....	12
1.2 Introduction.....	12
1.3 Project Objectives.....	12
1.4 Project Importance.....	13
1.5 Related Work.....	13
1.6 Economical Study.....	15
1.7 Project Schedule.....	16

## Chapter two: Background

2.1 Introduction.....	18
2.2 Global System for Mobile Communication.....	18
2.3 Second-Generation Technology.....	18

2.4 Third-Generation Technology.....	19
2.5 Photovoltaic System.....	20
2.5.1 Major System Components.....	20
2.5.2 Off-Grid Photovoltaic System.....	20
2.5.3 Grid Photovoltaic System.....	21
2.6 Photovoltaic Cell.....	22
2.7 Photovoltaic Panel.....	24
2.8 Photovoltaic Inverter.....	25
2.9 Photovoltaic Battery.....	26
2.10 Photovoltaic Charge Controller.....	28
2.11 Photovoltaic Diesel Hybrid System.....	29
2.11.1 Photovoltaic Diesel Hybrid System Operation.....	30
2.11.2 Advantages of a Photovoltaic Diesel Hybrid System.....	30

**Chapter three: System Design.**

3.1 Introduction .....	32
3.2 Block Diagram.....	33
3.3 Hardware Design.....	34
3.3.1 Voltage Sensor.....	34
3.3.2 Current Sensor.....	34
3.3.3 Arduino Board.....	35
3.3.4 PV System Design.....	36

3.3.5GSM modem.....	37
3.4Software Design.....	38
3.4.1Flow chart.....	38
3.4.2Mathematical Module of PV Cell.....	39

3.

**Chapter Four: Detailed System Design.**

4.1Introduction.....	50
4.2 Hardware and software detailed design .....	50
4.2.1Arduino UNO.....	50
4.2.2Photovoltaic cell.....	52
4.2.3Mobile phone.....	54

**Chapter Five: Implementation.**

5.1 Introduction .....	56
5.2 Photovoltaic System.....	56
5.3 Monitoring System.....	58
5.3.1 Temperature Sensor.....	59
5.3.2 Voltage Sensor.....	59
5.3.3 Current Sensor.....	60
5.4 Controlling System.....	61
5.5 Monitoring and Controlling protocol.....	62

**Chapter Six: Results.**

6.1 Introduction.....	66
-----------------------	----

6.2 Subsystem Testing.....	66
6.3 Monitoring System.....	66
6.4 Controlling System.....	67
Chapter Seven: Conclusion.	
7.1 Conclusion.....	69
References.....	70

### List of Figures

Figure No.	Content	Page
Figure 2.1	PV System	21
Figure 2.2	Off-Grid System	22
Figure 2.3	Grid-Tied Solar System	23
Figure 2.4	PV Cell	24
Figure 2.5	PV Panel.	25
Figure 2.6	Types of PV Inverters.	26

Figure 2.7(a)	Micro Inverter	27
Figure 2.7(b)	Hybrid Inverter	27
Figure 2.8	PV Battery	28
Figure 2.9	Solar Charge Controller	30
Figure 3.10	Payback time of a PV diesel hybrid system.	32
Figure 3.1	Block diagram of project	34
Figure 3.2	Voltage Sensor	35
Figure 3.3	Current Sensor	35
Figure 3.4	Arduino Board	36
Figure 3.5	System block diagram	37
Figure 3.6	GSM modem	39
Figure 3.7	Flow chart	40
Figure 3.8	Equivalent Circuit Models of PV Cell.	41
Figure 4.1	Arduino Uno	51
Figure 4.2	Hardware detailed design	52
Figure 4.3	PV cells system design	53
Figure 4.4	Mobile phone	55
Figure 5.1	Photovoltaic System	57
Figure 5.2	Monitoring System	59
Figure 5.3	Temperature Sensor Connection	60
Figure 5.4	Voltage Sensor Connection	60
Figure 5.5	Current Sensor Connection	61
Figure 5.6	Controlling System	61
Figure 5.7	Table on database	62
Figure 5.8	Real Implementation	63

## List of tables

Table no.	Content	Page
Table1.1	Project Hardware Cost	13
Table1.3	Distribution of tasks Schedule (first semester)	14
Table 3.1	Factor A dependent on PV Technology	40
Table 4.1	Load Specification	

## List of Abbreviations

PV	Photo voltaic
GSM	Global System for Mobile Communication
2G	Second Generation Technology
3G	Third Generation Technology
GPRS	General Packet Radio Service
EDGE	Enhanced Data GSM Environment
WCDMA	Wideband Code Division Multiple Access
UMTS	The Universal Mobile Telecommunications System
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
SMS	Short Message Service
PWM	Pulse-width-modulation
SIM	Subscriber Identity Module
AC	Alternating Current
DC	Direct Current

GaAr	Gallium Arsenide
STC	Standard Test Condition
MPPT	Maximum Power Point Tracking
Wh	Watt hour
Wp	Watt Peak
Tc	cell's working temperature
q	electron charge
Is	cell saturation of dark current
Tc	cell's working temperature
Isc	Short circuit current
IRS	cell's reverse saturation current
Tref	cell's reference temperature
Eg	band-gap energy of the Si solar cell
KI	cell's short-circuit current temperature coefficient
Voc	Open circuit voltage

# Chapter ONE

## Introduction

---

- 1.1 Overview.
- 1.2 Introduction.
- 1.3 Objectives.
- 1.4 Project Importance.
- 1.5 Literature Review.
- 1.6 Economical Study.
- 1.7 Project Schedule.

## **1.1 Overview:**

Monitoring and control of photovoltaic systems is essential for reliable functioning and maximum yield of any solar electric system. The simplest monitoring of an inverter can be performed by reading values on display (usually LCD). Values like PV array power, AC grid power, and PV array current are usually available. For sophisticated monitoring and control purposes environmental data - like module temperature, ambient temperature, solar radiation, can also be data logged, stored and analyzed later. Remote control and monitoring can be performed by various remote connections: GSM. For wireless connection, Bluetooth and Wi-Fi are most common used.

## **1.2 Introduction:**

Systems that convert sunlight into electrical energy have become pervasive throughout the world. Monitoring and controlling of PV systems is necessary for reliable performance and maximum yields of any solar electric system. The main idea of this project is to design and implement a monitoring and control of electrical consumer business operations.

## **1.3 Objectives:**

1. Design a system that allows monitoring and controlling PV parameters.
2. Receive, store and display the parameters in a web page.
3. Allow remote controlling of the PV system.

## **1.4 Project Importance:**

The importance of monitoring and controlling PV systems lies in the following features and characteristics:

1. The project is related to a system that will make the monitoring of PV parameters available.
2. The system provides means for controlling the system.
3. The innovative and secured protocol is an important part of the system which allows it to operate according to users' needs.

## **1.5 Literature Review:**

There have been many research studies about monitoring and controlling of solar cells to minimize problems that occur in such systems. Below are some relevant work and studies:

- In November 2014, a data logger system is designed by M Fuentes, M Vivar, JM Burgos, J Aguilera, JA Vacas to solve specific problems of monitoring PV systems at low cost, characterized all the relevant requirements in terms of precision contained in the standards of the International Electro technical Commission photovoltaic systems. Initial cost model has 60€ and have been tested in southern Spain during the period of 6 months in harsh environment conditions in summer and winter. And the results indicated that the new system is reliable and offers performance similar to commercial systems.[1]

- The Ronay Karoly, Cristian Dragos Dumitru have written a scientific paper titled the monitoring and control processes of a renewable energy management system. This paper presents and in monitoring and surveillance as an important part of renewable energy management system and is the main purpose of business to build commercial consumption management system. The proposed method is to use a micro- controller for the measuring of electrical and non-electrical parameters of the system, to process the data and to adapt a control process to the technological flux. The monitoring and control processes are implemented locally with USB-Serial connections to a PC , or from a web application.[2]
  
- “Monitoring Of Photovoltaic System: Good Practices and Systematic Analysis” done by group of researchers and presented at the 28<sup>th</sup> European PV solar energy conference and exhibition, 30 September – 4 October, 2013, Paris, France. 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.[3]

## 1.6 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.

**Table1.1 Project Hardware Cost**

Category	Number of pieces needed	Price per Piece (NIS)
Arduino	1	45
GSM	1	180
Sensors	3	50
Charge Controller	1	<b>250</b>
Total	-	525

## 1.7 Project Schedule:

This section lists the phases and time schedule for the project for the second semester. Table 1.2 details the distribution of the phased among the working weeks.

**Table1.2 Distribution of tasks Schedule (first semester)**

Time (week)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Discussion Idea																
Collecting Data																
Design The System																
Implementation																
Documentation of the System																

# Chapter TWO

## Background

---

2.1 Introduction.

2.2 Global System for Mobile Communication.

2.3 Second-Generation Technology

2.4 Third-Generation Technology.

2.5 Photovoltaic System.

2.5.1 Major System Components

2.5.2 Off-Grid Photovoltaic System

2.5.3 Grid Photovoltaic System

2.6 Photovoltaic Cell.

2.7 Photovoltaic Panel.

2.8 Photovoltaic Inverter.

2.9 Photovoltaic Battery.

2.10 Photovoltaic Charge Controller.

2.11 Photovoltaic Diesel Hybrid System.

2.11.1 Photovoltaic Diesel Hybrid System Operation

2.11.2 Advantages of a Photovoltaic Diesel Hybrid System

## **2.1 Introduction:**

This chapter describes the system components including hardware technologies to be used in the project.

## **2.2 Global System for Mobile Communication (GSM):**

It is an abbreviation for the term for the Global System for Mobile communications is a protocol for the transmission of data in the field of communications through the mobile phone, where it is in a fixed frequency allocation for each user on the network without changing it, where the GSM system uses the DMA standard with a narrow frequency packet, which provides 8 simultaneous calls on the same Wireless frequency, also allows data transfer speeds of up to 9.5 kbps, which are special for second-generation networks, and this system first appeared in 1991, and by the end of 1997, the GSM service has become available in more than 100 special countries in Europe and Asia.

The GSM setup will give access to 2G (and 2.5G) data networks using GPRS or edge data standards and speeds.

The downside to choosing GSM is that it will stop the phone's high-speed connectivity 3G data networks, but will save energy as 3G (WCDMA) chips and the antenna will not be used.

## **2.3 Second-Generation Cellular Technology (2G):**

It is an abbreviation for the term for the **second generation** of mobile communications and is based on the digital system principle rather than the analog system. The digital system is a pattern of communication that information is transmitted digitally. It was a technique launched in 1991 in Finland. It is based on the technology known as the Global system for mobile communication (GSM).

The second generation and its techniques are characterized by the advantages of digital systems, which vary between improving the quality of communication and the purity of sound. The digital system serves to mitigate the effect of interference with communications and hence the low level and number of errors. This technology uses encoding (decompression compression) and algorithms to compress multiple audio data. It offers services such as SMS and e-mail.

The downside of 2G is that it is very dependent on the location of the towers and its digital character will not exacerbate this problem.

## **2.4 Third-Generation Cellular Technology (3G):**

It is an abbreviation for the term for the **third generation** and depends on a number of global transport Association standards to serve mobile technology. 3G techniques to establish inter came from the most sophisticated and advanced services in the hands of the user, and features high speed and capacity and a system capable of adjustment and channel capable Transfer of these speeds. The most prominent wireless telephony services so the extended coverage.

Where the difference between 2G and 3G is in terms of services, the second generation does not exceed its SMS and voice calls while the third generation offers services SMS and voice calls and MMS animation too. Moreover, there is a difference in the quality of data and signal transmission between the parties to the communication process and its speed. Another difference is that the second generation uses digital radio signals, while the third generation uses acoustic beams; data also at speeds exceeding 2 MB, the third generation is able to provide services, user applications such as video calls, and TV.

As the generation progresses, the speed and quality of communication increases.

## 2.5 Photovoltaic System (Solar System):

Photovoltaic technology converts sunlight into electricity and is emerging as a major power source due to its numerous environmental and economic benefits and proven reliability. A complete system includes different components that should be selected taking into consideration, your individual needs, site location, climate and expectations.

### 2.5.1 Major System Components

The functional and operational requirements will determine which components the system will include. It may include major components as; DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and sometimes the specified electrical loads (appliances). [3]

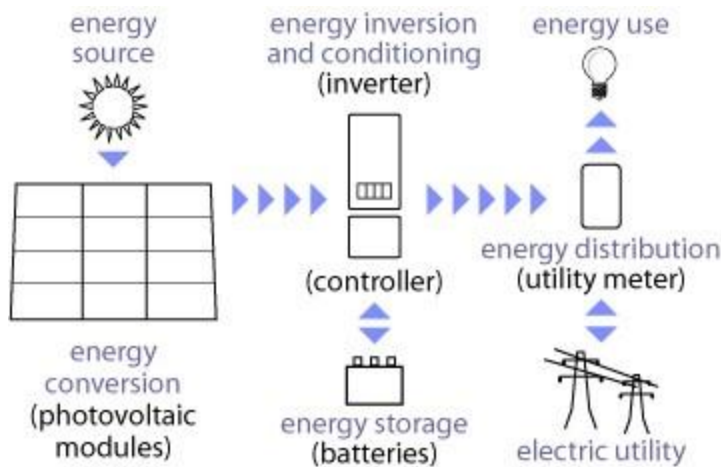
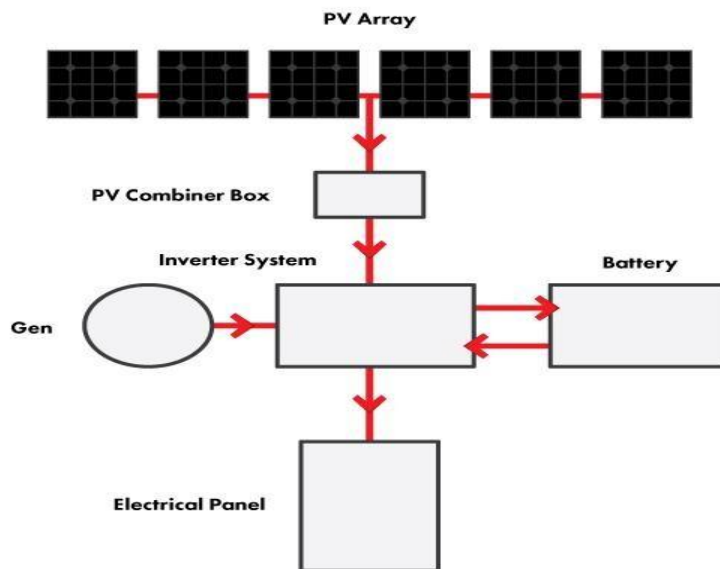


Figure 2.1: PV System.

### 2.5.2 Off-Grid Photovoltaic System:

This type of Photovoltaic (PV) system provides electricity in situations where utility power is not available. An off-grid system is ideal for locations where grid connections are not accessible, such as cottages and remote home locations, or for anyone craving greater energy

independence. Typically, the PV system has a fossil-fueled generator connected for back-up purposes. A group or array of PV panels are connected together in groups or strings, usually 3 panels. These strings or groups are all connected together in a Combiner Box, which is located near the array. The DC electricity from the PV panels flows through Combiner Box to a Controller/Regulator in the inverter system. The Controller regulates the DC power to the batteries. The Inverter converts the DC battery power to AC electricity which is normal household power (DC power is sometimes used for lights and small appliances in small camps or cottages). The AC electricity goes to the main electrical panel. Once in the electrical panel, the loads connected to the panel, such as lights or appliances use the electricity. During periods of no sun, the generator is used to provide power to the loads and charge the batteries. [4]



**Figure 2.2: Off-Grid System.**

### 2.5.3 Grid Photovoltaic System:

In recent years, however, the number of solar powered homes connected to the local electricity grid has increased dramatically. These Grid Connected PV Systems have solar panels that provide some or even most of their power needs during the day time, while still being connected to the local electrical grid network during the night time.

Solar powered PV systems can sometimes produce more electricity than is actually needed or consumed, especially during the long hot summer months. This extra or surplus electricity is either stored in batteries or as in most grid connected PV systems, fed directly back into the electrical grid network. [5]

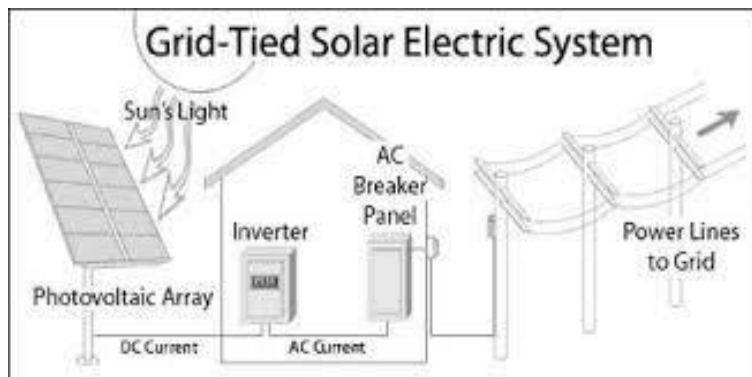


Figure 2.3: Grid-Tied Solar System.

### 2.6 PV Cell:

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. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as

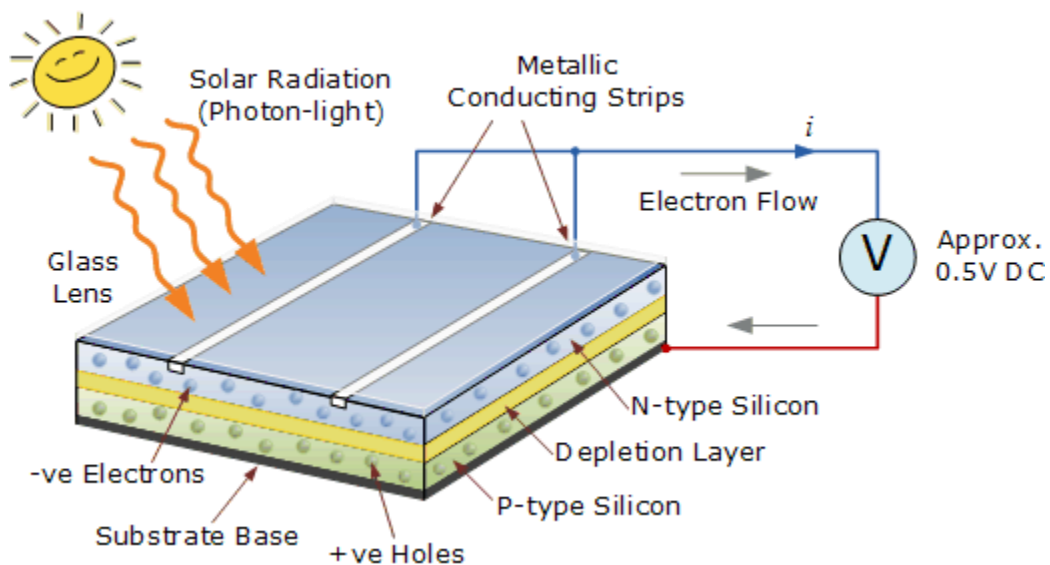
a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

▪ **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.

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.

- Gallium Arsenide (GaAs) 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.



**Figure 2.4: PV Cell.**

## 2.7 PV Panel:

Solar panels absorb sunlight as a source of energy to generate electricity or heat.

A photovoltaic (PV) module is a packaged; connect assembly of typically 6x10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications.

Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 Watts (W). The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 W module will have twice the area of a 16% efficient 230 W module. A few commercially available solar modules exceed efficiency of 22% and reportedly exceeding 24%.

A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes an array of photovoltaic modules, an inverter, a battery pack for storage, interconnection wiring, and optionally a solar tracking mechanism.



**Figure 2.5: PV Pan**

## 2.8 PV Inverter:

Inverters play a crucial role in any solar energy system and are often considered to be the brains of a project, whether it is a 2-kW residential system or a 5-MW utility power plant. An inverter's basic function is to “invert” the direct current (DC) output into alternating current (AC). AC is the standard used by all commercial appliances, which is why many view inverters as the “gateway” between the photovoltaic (PV) system and the energy off-taker.

Inverter technologies have advanced significantly, such that in addition to converting DC to AC, they provide a number of other capabilities and services to ensure that the inverter can operate at an optimal performance level, such as data monitoring, advanced utility controls, applications and system design engineering.



Figure 2.6: Types of PV Inverters.

### ▪ Types of PV Inverters:

#### 1) Micro Inverter:

Almost all inverters have some level of monitoring and fault finding however; it can only see the combined output from every solar panel in the series string. A micro inverter however, can monitor each solar panel individually, allowing you to easily

identify exactly what is happening more quickly and easily. Micro Inverter shown in **Figure 2.7(a)**. [6]

## 2) Hybrid or Multi-Mode Inverters:

The most economical type of hybrid system uses an all-in-one hybrid inverter. All-in-one inverters combine a solar inverter, charger and battery inverter together with software, which can be programmed to determine the most efficient use of your available energy. Having all the components in one simple plug and play unit, means hybrid inverters are generally much lower cost and easier to install but they do have several limitations, in particular lower surge power output (as they are typically transformer less) and low backup power.

Hybrid Inverters shown in **Figure 2.7(b)**. [7]



**Figure 2.7 (a) Micro Inverter**



**Figure 2.7 (b): Hybrid Inverter**

## 2.9 PV Battery:

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 types of lead-acid batteries used in PV systems are lead antimony batteries, lead-calcium batteries, and lead-antimony/lead-calcium hybrid 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).

The optimal type of battery for a PV lighting system is a deep-cycle (or deep discharge) battery that can be repeatedly drained of much of its energy and recharged. The maximum depth of discharge for low-maintenance (sealed) batteries is 30%. The maximum depth of discharge of a battery is a measure (in percentage) of the amount of energy that can be removed from the battery during a cycle, without damaging the battery. Batteries should generally be located in a weather resistant, nonmetallic enclosure in order to prevent corrosion. Batteries should be maintained according to manufacturers' instructions, and it is important to keep them clean to ensure maximum performance over time. [8]



**Figure 2.8: PV Battery.**

## **2.10 PV Charge Controller:**

A charge controller or charge regulator is basically a voltage and/or current regulator to keep batteries from overcharging. It regulates the voltage and current coming from the solar panels going to the battery. Most "12 volt" panels put out about 16 to 20 volts, so if there is no regulation the batteries will be damaged from overcharging. Most batteries need around 14 to 14.5 volts to get fully charged. [9]

### **▪ Charge Controller Types:**

Charge controls come in all shapes, sizes, features, and price ranges. They range from the small 4.5 amp control, up to the 60 to 80 amp MPPT programmable controllers with computer interface. Often, if currents over 60 amps are required, two or more 40 to 80 amp units are wired in parallel. The most common controls used for all battery-based systems are in the 4 to 60-amp range, but some of the new MPPT controls such as the Outback Power FlexMax go up to 80 amps. [9]

#### **i. Simple 1 or 2 stage controls:**

Which rely on relays or shunt transistors to control the voltage in one or two steps. These essentially just short or disconnect the solar panel when a certain voltage is reached. For all practical purposes, these are dinosaurs, but you still see a few on old systems - and some of the super cheap ones for sale on the internet. Their only real claim to fame is their reliability - they have so few components, there is not much to break.[9]

#### **ii. 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. [9]

- iii. **Maximum Power Point Tracking Solar Charge Controllers (MPPT):**  
Are different from the traditional PWM solar charge controllers in that they are more efficient and in many cases, more feature rich. MPPT solar charge controllers allow your solar panels to operate at their optimum power output voltage, improving their performance by as much as 30%. Traditional solar charge controllers reduce the efficiency of one part of your system in order to make it work with another. [10]



Figure 2.9: Solar Charge Controller.

## **2.11 Photovoltaic Diesel Hybrid System**

In many regions of the world, power grids are either inadequate or nonexistent. As a result, industrial consumers often ensure their power supply through diesel gensets. Five hundred gigawatts of power from diesel gensets provide industrial companies with electricity worldwide. However, fuel costs for the gensets continue to rise. The price for one liter of diesel has already exceeded one U.S. dollar.

In addition, if the fuel has to be transported to remote regions, the effective costs increase even more as a result of the necessary storage. At the same time, PV system costs have dropped by more than 50 percent within the last three years; therefore, solar power is often the most economical alternative energy source for remote regions in the world's Sun Belt. It simply makes sense to combine PV and diesel systems so that solar irradiation – which is both abundant and free – can profitably be used as an energy source in industrial applications. [11]

### **2.11.1 Photovoltaic Diesel Hybrid System Operation:**

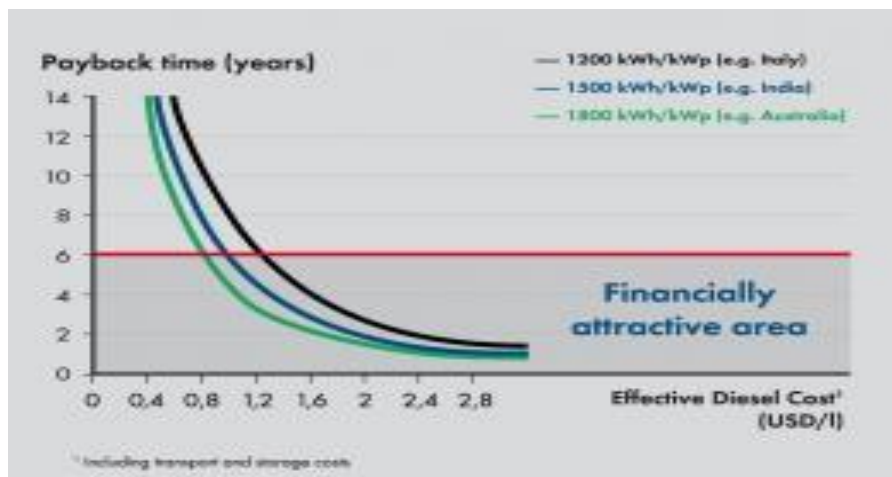
Basically, the PV system complements the diesel gensets can supply additional energy when loads are high or relieve the genset to minimize its fuel consumption. In the future, excess energy could optionally be stored in batteries, making it possible for the hybrid system to use more solar power even at night. Intelligent management of various system components ensures optimal fuel economy and minimizes CO<sub>2</sub> emissions. [11]

### **2.11.2 Advantages of a Photovoltaic Diesel Hybrid System:**

In contrast to power supply systems using diesel gensets, and despite their higher initial cost, PV systems can be amortized in as little as four to five years, depending on the site and system size, and they have low operating costs.

In addition, PV systems are flexible and can be expanded on a modular basis as the energy demand grows. Compared to pure genset systems, a photovoltaic diesel hybrid system provides numerous advantages:

- Lower fuel costs
- Reduced risk of fuel price increases and supply shortages, thanks to optimized planning
- Minimal CO<sub>2</sub> emissions (protects the environment and facilitates CO<sub>2</sub> certificate trading)



**Figure 2.10: Payback time of a PV diesel hybrid system**

# Chapter Three

## System Design

---

3.1 Introduction.

3.2 Block Diagram.

3.3 Hardware Design.

3.3.1 Voltage Sensor.

3.3.2 Current Sensor.

3.3.3 Arduino Board.

3.3.4 PV System Design.

3.3.5 GSM modem.

3.4 Software Design.

3.4.1 Flow chart

3.4.2 Mathematical Module of PV Cell.

### 3.1 Introduction:

This chapter describes the system block diagram and the system design including the hardware and software components used in the project. It explains the monitoring part of the PV system.

### 3.2 Block Diagram:

Block diagram represents the monitoring and control of PV, PV system converts sunlight into electrical energy and using sensors temperature, current and voltage are measured stream system PV and entered to the Arduino and compared to the estimated values and send messages to mobile phone the controlled by mobile.

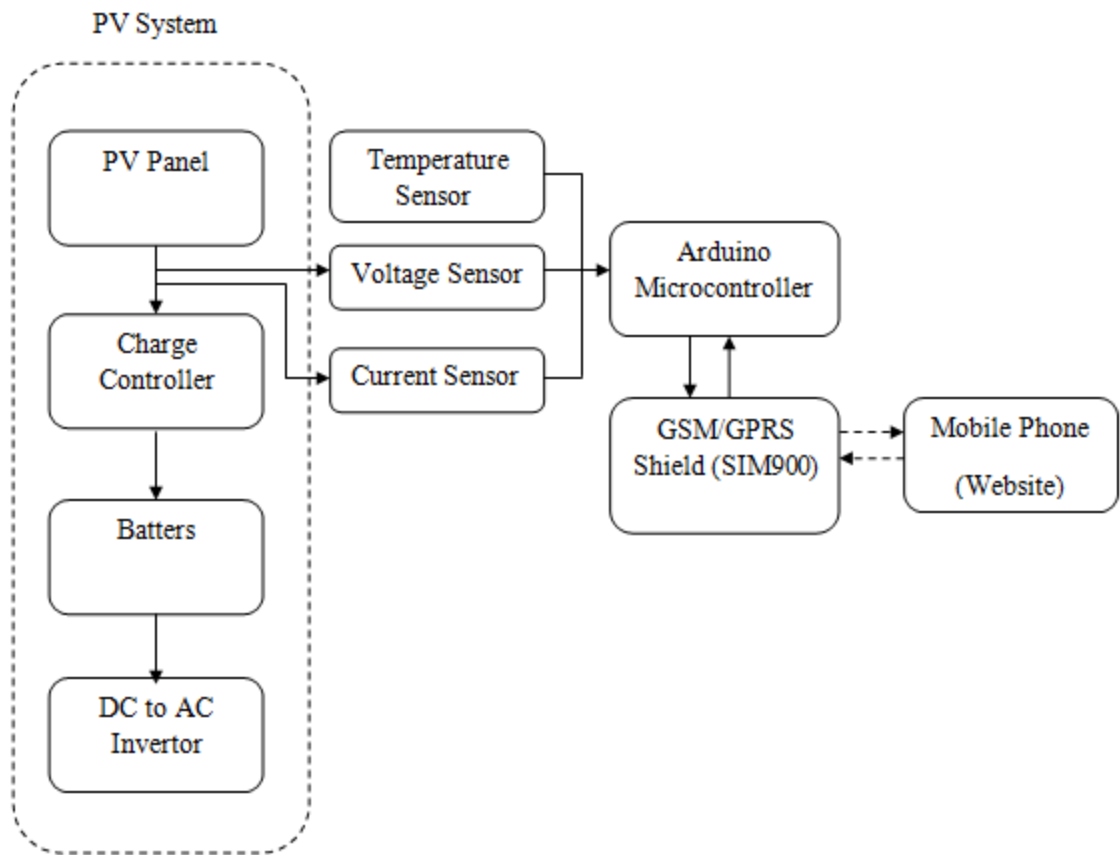


Figure 3.1 Block diagram

### 3.3 Hardware Design:

#### 3.3.1 Voltage Sensor:

A voltage sensor is going to be able to determine and even monitor and measure the voltage supply. It is then able to take those measurements and turn them into a signal that will then be able to read. The signal will often go into a specialized electronic device for recording.

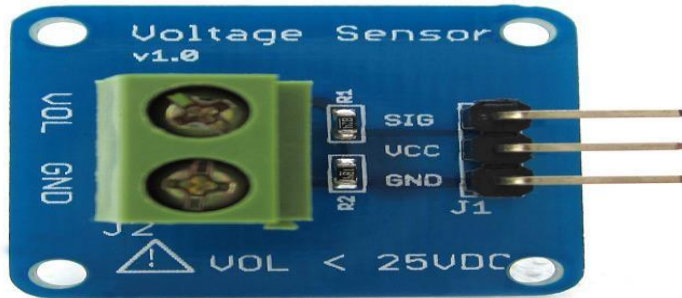


Figure 3.2 Voltage Sensor

#### 3.3.2 Current sensor:

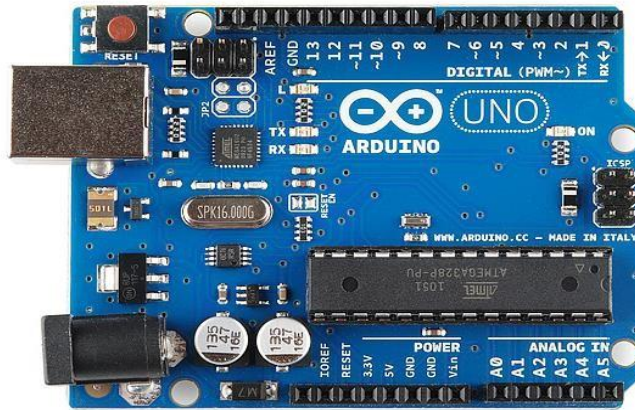
Is a device that detects electric current in a wire, and generates a signal proportional to that current. The generated signal could be analog voltage or current or even a digital output. The generated signal can be then used to display the measured current in an ammeter, or can be store for further analysis in a data acquisition system, or can be used for the purpose of control.



Fig 3.3: Current Sensor

### 3.3.3 Arduino Board:

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



**Figure 3.4: Arduino Board**

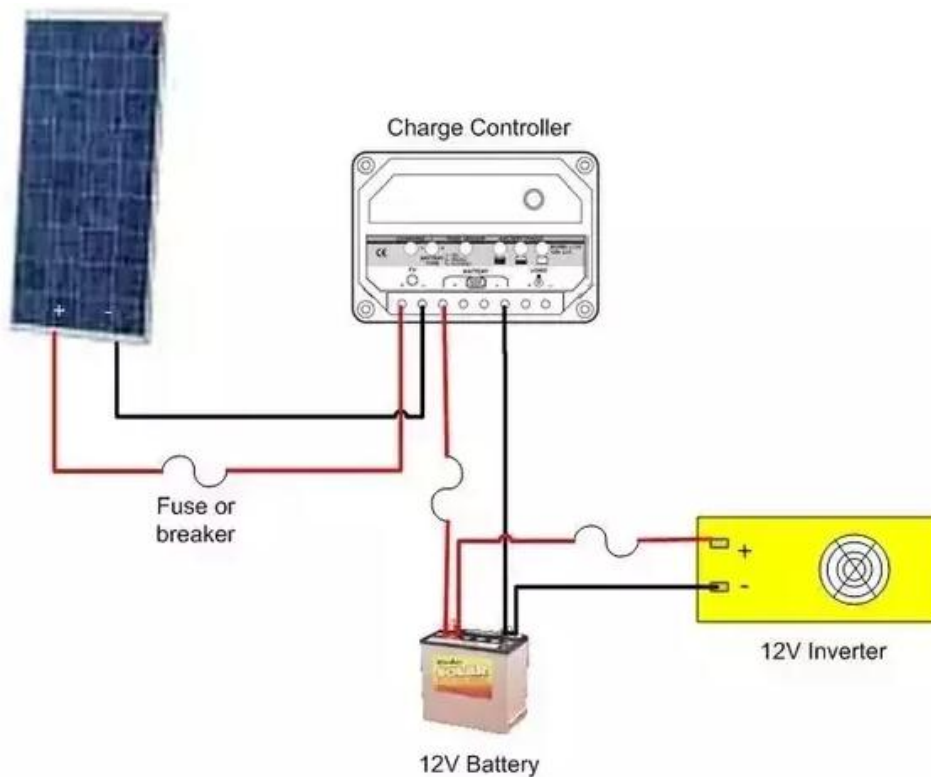
The Arduino will receive a voltage and current signal from voltage sensor and current sensor that are connected to the PV Cell as an input, and using a specified code the data will be sent to the web page.

### 3.3.4 PV System Design:

#### ▪ Off-Grid PV System Components:

We will design an Off-Grid PV system, which allows energy storage using solar batteries.

The main components of an Off-Grid system are:



**Figure3.5 Main components of the Off-Grid System.**

### Solar Panels

As the name suggests, solar panels are an obvious first ingredient. The precise size and production capabilities of your individual solar panel array will depend on the amount of available sunlight in your region, the usable space of your roof, and your energy consumption needs.

### **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.

### **Solar Batteries**

A solar battery will also be necessary, to allow your home to continue to run after the sun goes down. Throughout the day, your solar storage device will charge as your panels generate excess electricity.

### **Solar Inverters**

In order to convert the direct current (DC) collected by your solar panel array into the alternating current (AC) required running most of your common household appliances and electronics.

### **3.3.5 GSM modem:**

A GSM modem also called GSM module is a GSM phone without display, keypad and battery. Is a specialized type of modem that accepts the SIM card, It is just like a mobile phone where it works to subscribe to the mobile operator. A GSM modem exposes an interface that allows applications such as SMS deliverer to send and receive messages over the modem interface.

Using many GSM modems to send and receive SMS as this modem is the most used to provide mobile internet connection. The advantages of a GSM modem is that it is a quick and efficient way to start with SMS, because your subscription to the service provider is not required.

GSM modem supports one or more protocols in the GSM development family, including the 2.5G technologies GPRS and EDGE, as well as the 3G technologies WCDMA, UMTS, HSDPA and HSUPA.

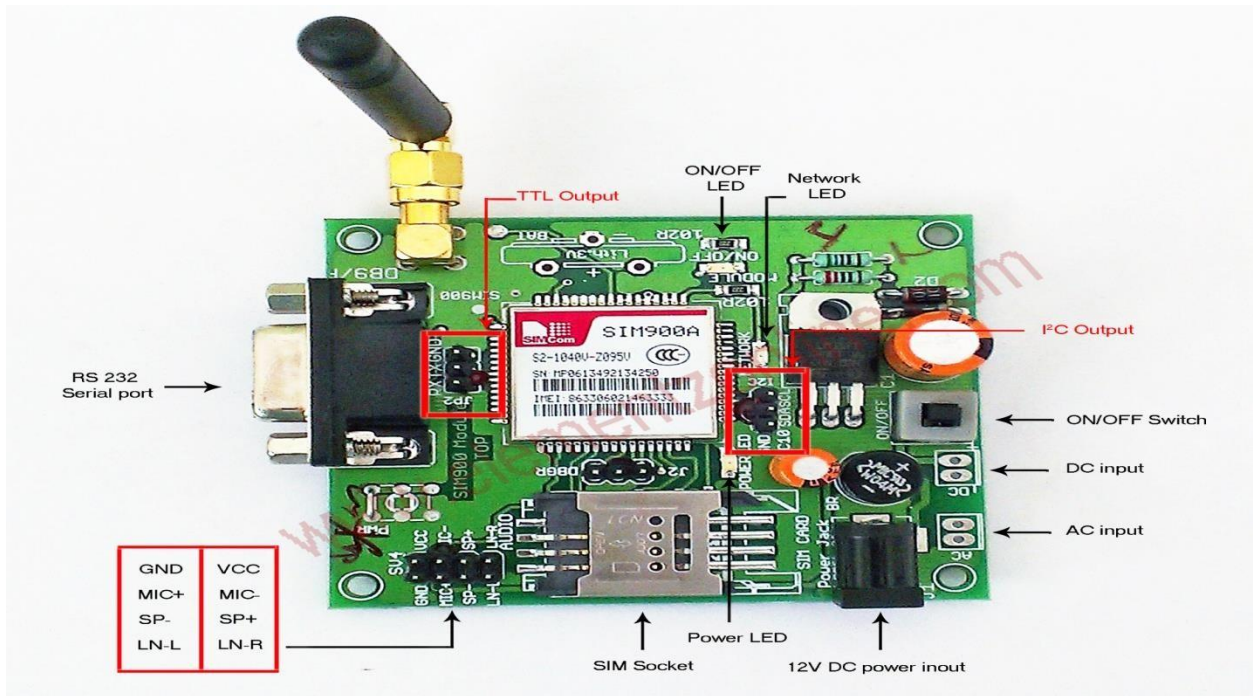
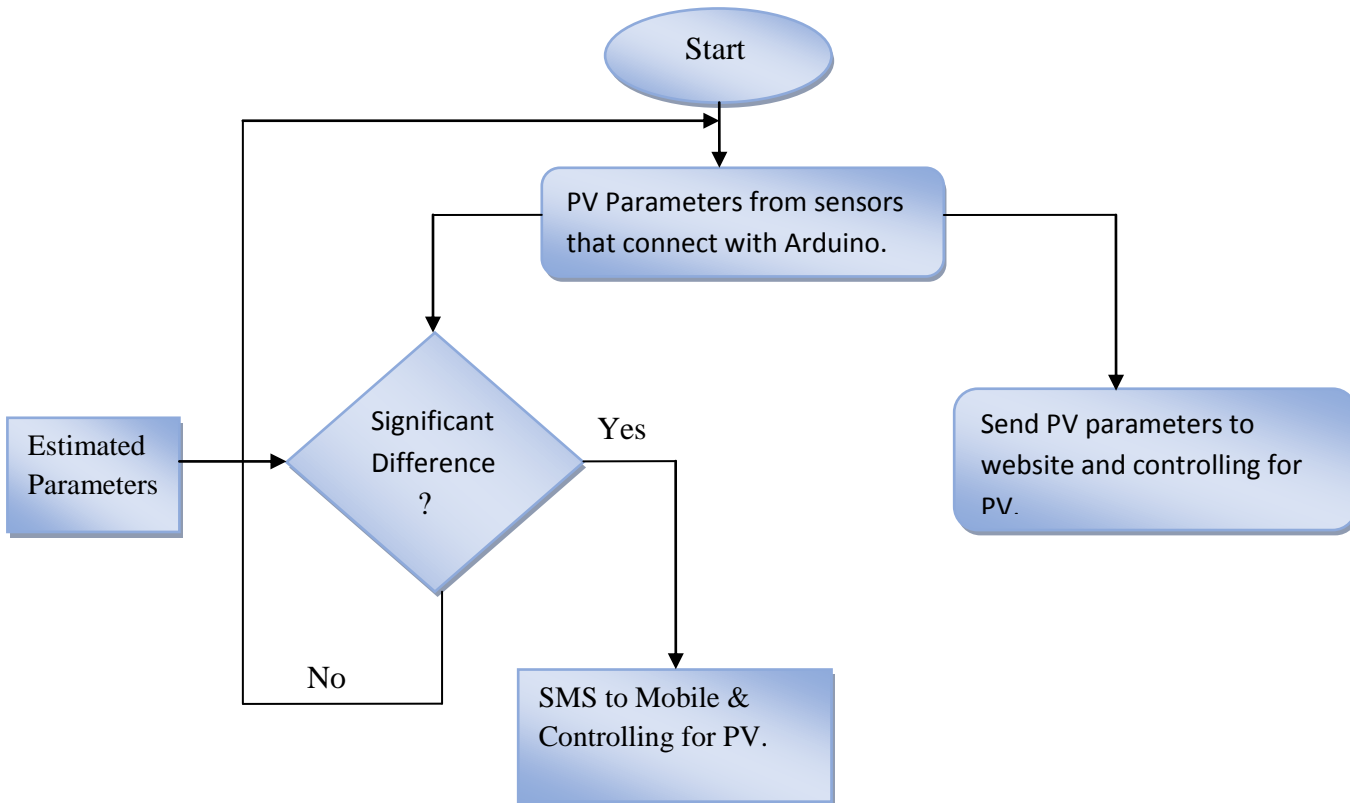


Figure3.6 GSM modem.

### 3.4 Software Design:

#### 3.4.1 Flow Chart:

The graph in Figure 3.7 represents process monitoring and controlling of PV when the system is running and convert sunlight into electrical energy by PV system the voltage and current that resulting from PV are measured using voltage and current sensors, and sent to a web page designed specially.



**Figure 3.7 Flow chart**

### **3.4.2 Energy Estimated Model:**

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:

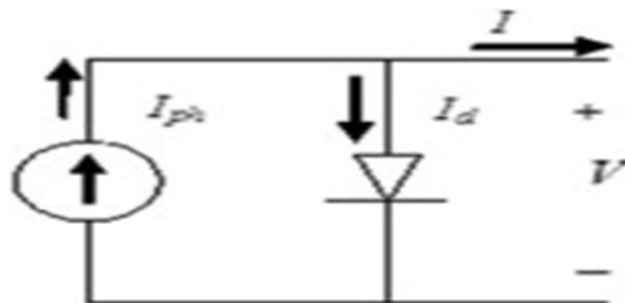
**Algorithm 1:** Ideal Photovoltaic Models

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

$$[I = I_{ph} - I_d ] \tag{1}$$

$$I_d = I_0 \left[ \exp \left( \frac{V}{A \cdot N_s \cdot V_T} \right) - 1 \right] \tag{2}$$

$$a = \frac{N_s \cdot A \cdot K \cdot T_c}{q} = N_s \cdot A \cdot V_T \tag{3}$$



**Fig4.1 ideal single diode model**

Where:

$I_s$  = cell saturation of dark current.

$I_{ph}$  =photocurrent.

$I_d$  =diode current .

$I_0$  = 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.

$N_s$ = the number of PV cells connected in series.

$a$  =constant which depends on PV cell technology.

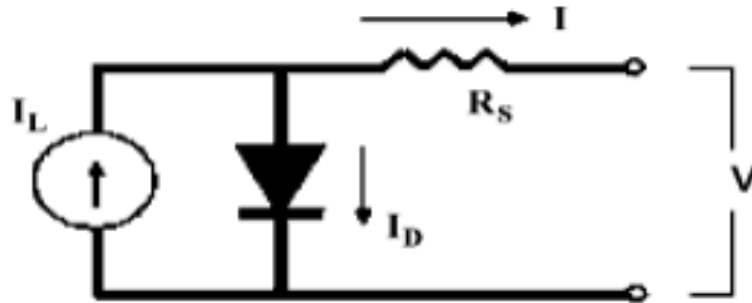
### **Non-Ideal Photovoltaic Models**

In reality, it is impossible to neglect the series resistance  $R_s$  and the parallel resistance  $R_p$  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 (2) is achieved with inclusion of series resistance  $R_s$ , hence, the output current can be derived as:

$$I_d = I_0 \exp \left( \frac{V + I \cdot R_s}{a} - 1 \right) \quad (4).$$



**Fig 4.2 Photovoltaic Model with Series Resistance.**

Where:

$R_s$  =series resistance

**Algorithm 3 :** Photovoltaic Model with Series and Parallel Resistances:

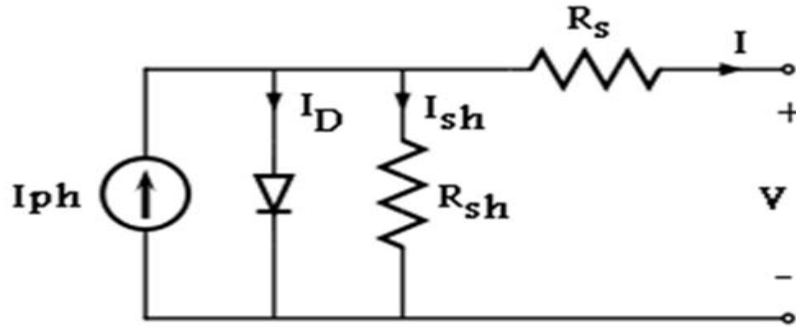
Equation (4) does not adequately represent the behavior of the cell when subjected to environmental variations, especially at low voltages. A more practical model can be seen in Figure 4.3 ,where series  $R_s$ , and parallel resistances  $R_p$ , are introduced .Series resistance is very small, which 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  $\infty$  .Applying Kirchhoff's law to the node where  $I_{ph}$ , diode,  $R_p$  and  $R_s$  meet, and one get:

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

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

$$I = N_s \left[ I_{ph} - I_0 \left[ \exp \left( \frac{V + I \cdot R_s}{a} - 1 \right) \right] - \left( \frac{V + R_s \cdot I}{R_p} \right) \right] \quad (6)$$

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



**Fig 4.3 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  $I_{ph}$ ,  $I_0$ ,  $R_s$ ,  $R_p$  and the factor ideality are five parameters that depend on the incident solar radiation and the cell temperature. The unknown parameters are  $I_{ph}$ ,  $I_0$ ,  $R_s$  and  $\gamma$ .

Where:

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

In this work the four parameters that have to be evaluated are also  $I_{ph}$ ,  $I_0$ ,  $R_s$ ,  $R_p$ . The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as :

$$I_{ph} = [I_{sc} + k_i (T_c - T_{ref})] \frac{G}{G_{ref}} \quad (8)$$

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:

$$I = I_{ph,ref} - I_0 \left[ \exp\left(\frac{V}{a_{ref}}\right) - 1 \right] \quad (9)$$

This equation allows quantifying  $I_{ph,ref}$  which cannot be determined otherwise. When the PV cell is short-circuited:

$$I_{sc} = I_{ph,ref} - I_0 \left[ \exp\left(\frac{0}{a_{ref}}\right) - 1 \right] = I_{ph,ref} \quad (10).$$

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

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

The photocurrent depends on both irradiance and temperature:

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

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:

$$I_{RS} = (I_{sc}) / \exp\left[\left(q \cdot \frac{V_{oc}}{nkT_c}\right) - 1\right] \quad (13)$$

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

The photocurrent depends on both irradiance and temperature:

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

$G$  = Irradiance (W/m<sup>2</sup>).

$G_{ref}$  = irradiance at STC = 1000 W/m<sup>2</sup>.

$\Delta T$  =  $T_c - T_{c,ref}$  (Kelvin).

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

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

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

## Determination of $I_0$

The shunt resistance  $R_p$  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:

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

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

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

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

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

So :

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

The reverse saturation current is defined by:

$$I_0 = DT_c^3 \exp \left( \frac{-q\varepsilon G}{A.k} \right) \quad (20)$$

$\varepsilon G$ = 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 :

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

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

### 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 Pmp is equal to the experimental one Pmp,ex at STC conditions. So it is possible to write the next equation:

$$\begin{aligned} I_{mp,ref} &= \frac{P_{mp,ref}}{V_{mp,ref}} \\ &= \frac{P_{mp,ex}}{V_{mp,ref}} \\ &= I_{ph,ref} - I_{0,ref} \left[ \exp\left(\frac{V_{mp,ref} + I_{mp,ref} \cdot R_s}{a}\right) - 1 \right] - \frac{V_{mp,ref} + R_s \cdot I_{mp,ref}}{R_p} \end{aligned} \quad (23)$$

Therefore:

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

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  $I_{sc}$ .

$$FF = \frac{P_{max}}{V_{oc}I_{sc}} \quad (25)$$

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

$$\Delta FF = \frac{-I_{sc}}{V_{oc}} R_s \cdot FF_{ideal} \quad (26)$$

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

# Chapter Four

## Detailed System Design

---

4.1 Introduction.

4.2 Hardware and software detailed design

4.2.1 Arduino UNO.

4.2.2 Photovoltaic cell.

4.2.3 Mobile phone.

## 4.1 Introduction:

This chapter describes the hardware requirements in designing this detailed system, including how to connect them to each other to monitor and control the PV.

## 4.2 Hardware and software detailed design

This section describes the hardware required to implement the system and how it connects to each other.

### 4.2.1 Arduino UNO (Microcontroller)

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software.

This system relies on the Arduino, basically, as the Arduino has 6 analog inputs will be used in this project, two of them to enter the values of two sensor to measure the voltage and electric current of the photoelectric effect that converts sunlight into electricity.

Where will the Arduino sensor results accounts and comparison between these values and estimated values. The short messages will be sent to your phone in case of system problems based on specific data. Then PV is controlled.

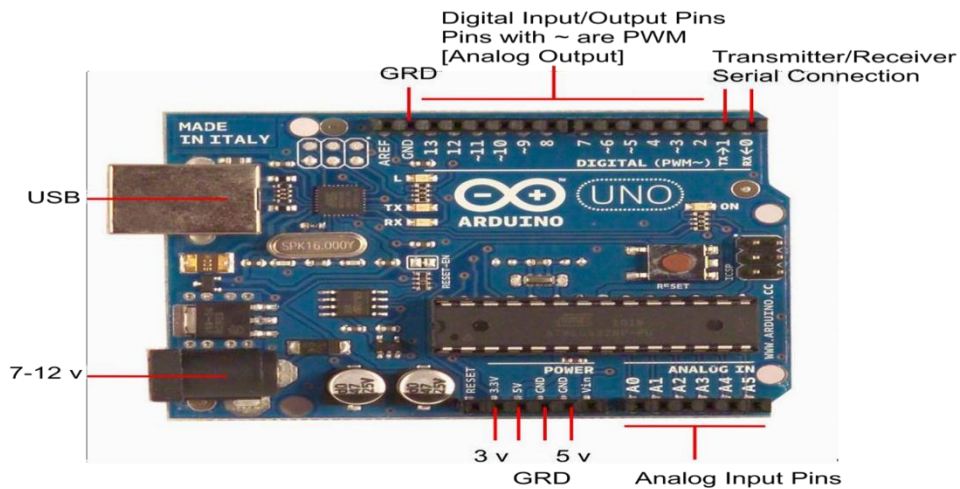


Figure 4.1 Arduino Uno

- Voltage Sensor: This sensor is connected with an Arduino analog input, uses this sensor to measure the effort out of PV and compare this reading with the estimated effort.
- Current Sensor: This sensor is connected with an Arduino analog input, uses this sensor to measure the flow out of PV and compare this reading with stream destined.
- GSM Modem: This modem is connected to the output of Arduino, this modem is used to send SMS notification phone problem occurs in PV system,

Figure 4.2 shows the voltage sensor, current sensor and GSM modem connections with Arduino.

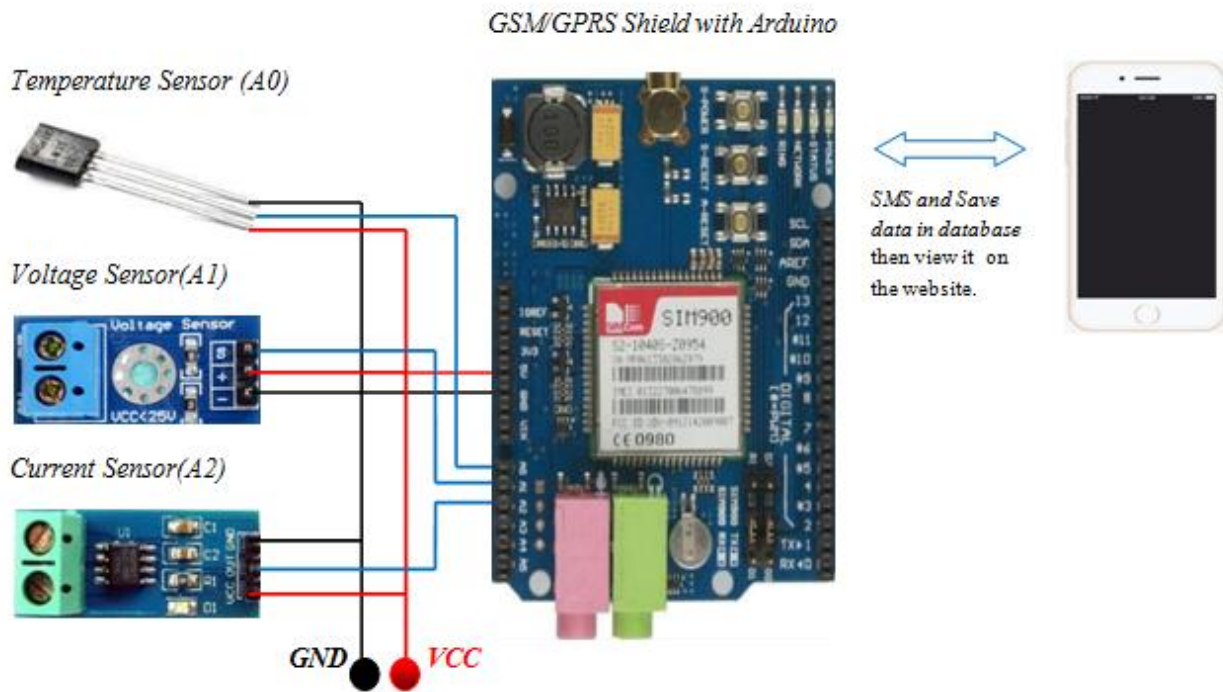
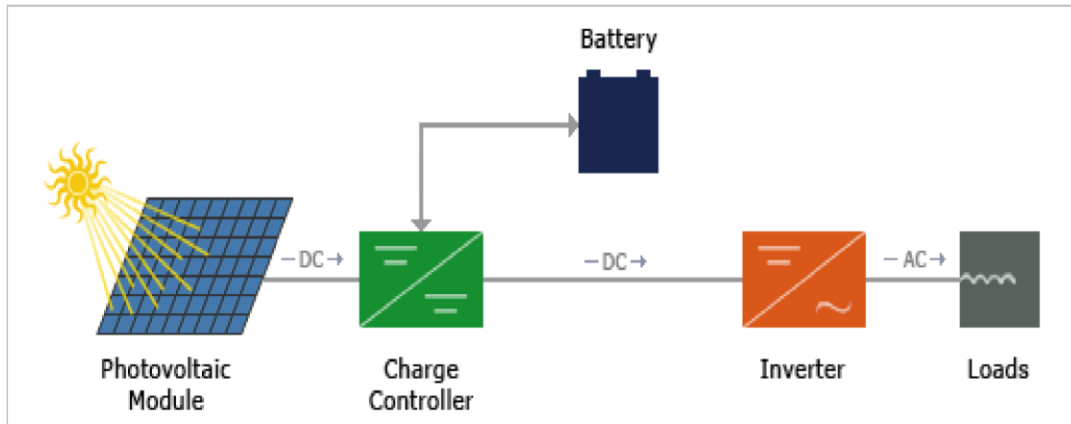


Figure 4.2 Hardware detailed design

## 4.2.2 Photovoltaic cells:

In the following figure 4.3, the design of the photovoltaic cells will be shown in details with basic components.



**Figure 4.3 PV cells system design**

- The first step the fall sunlight on PV cells then convert sunlight into electrons.
- The second step, the output of the PV cells is the input of the charge controller.
- The output of the charge controller is the input of the battery, and the input of the inverter, The charge controller used to maintain battery voltage from overload and protect cells from upstream
- The output of the inverter is the input of the load, the inverter converts the dc power from the PV module into ac power to run the load.

### ○ PV Design and Calculations

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

Application	Power(w)	Quantity	Time	Energy(Wh/day)
Load	60	1	10	600

**Fig 5.7 load specifications**

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

$$= \frac{600\text{W}}{0.9 * 0.92} = 724.6 \text{ Wh}$$

$$2. \text{ Power peak (wp)} = \frac{\text{pv energy per day} * \text{safety factor}}{\text{peak sun hours}}$$

$$= \frac{724.6 * 1.15}{5.4} = 155.7\text{W}.$$

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

$$= \frac{155.7}{115} \approx 1 \text{ module}.$$

### Battery:

$$\text{DC load} = \frac{\text{AC load}}{\eta_{\text{inverter}}}$$

$$= \frac{600}{0.9} = 666.67\text{Wh/day}.$$

$$\text{With 12v system voltage} = \frac{666.67}{12} = 55.6\text{Ah/day at 12 volt}.$$

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

$$C_{Ah} = \frac{2 * E_L}{V_B * DOD * \eta_B * \eta_V}$$

Where DOD is the depth of discharge=0.75.

$$CAh = \frac{2 * 600}{12 * 0.75 * 0.85 * 0.9} = 174.3\text{Ah}$$

And the Watt hour capacity ( C Wh ) is obtained as :-

$$C_{Wh} = C_{Ah} V_B$$

$$C_{Wh} = 174.3 * 12 = 2091.5\text{KWh}$$

**Battery:**

$$600/0.9 = 666.67\text{Wh/day}$$

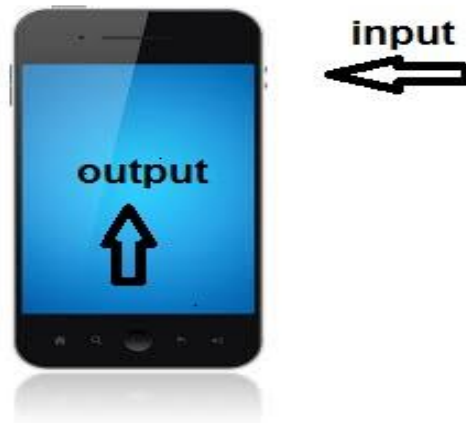
$$666.67/12 = 55.6\text{Ah/day at 12V}$$

$$\text{At 2 day}-----55.6/2 = 27.8\text{Ah}$$

For 20 Ah battery: number of battery =  $27.8/20 = 1$  battery sizing

### 4.2.3 Mobile phone:

The mobile phone is used in this project to receive short messages and PV parameters from GSM modem connected with Arduino when a problem occurs to the system and control of PV.



**Figure 4.4 Mobile phone**

# Chapter Five

## Implementation

---

5.1 Introduction.

5.2 Photovoltaic System

5.3 Monitoring System

5.3.1 Temperature Sensor

5.3.2 Voltage Sensor

5.3.3 Current Sensor

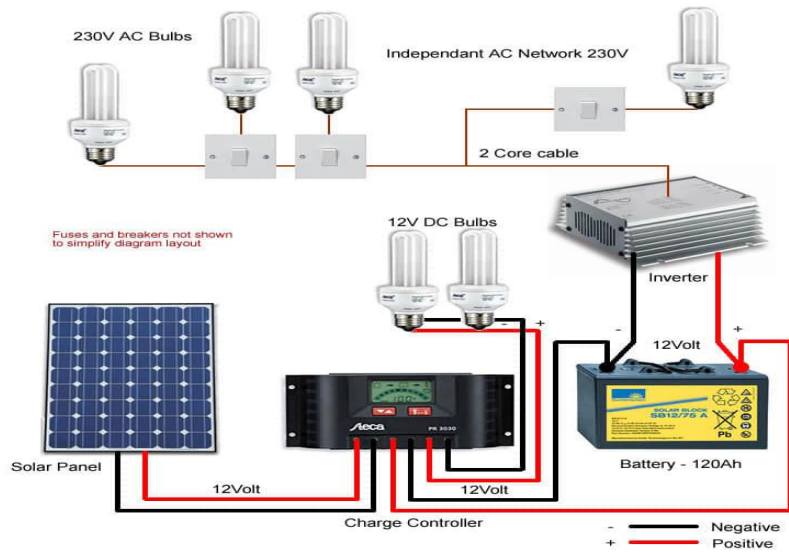
5.4 Controlling System

## 5.1 Introduction:

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

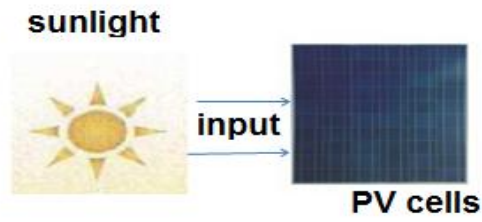
## 5.2 Photovoltaic system:

In the following figure [5.1], the design of the photovoltaic system will be shown in details with basic components and connection.



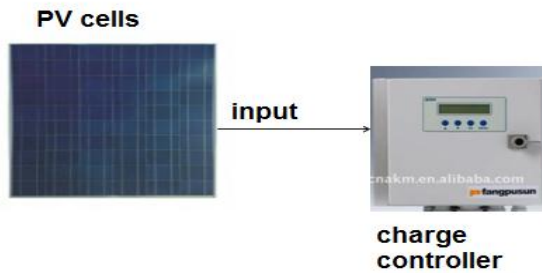
**Fig 5.1**

- The sunlight fall on the PV cells , then PV convert the light into electrons as in figure 5.1(a)



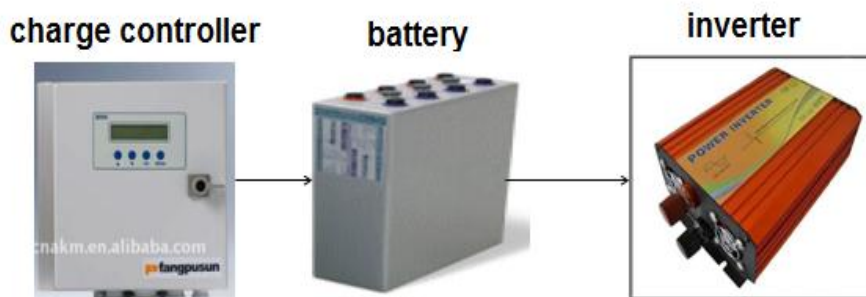
**Fig 5.1 (a)**

- The output of the PV cells is the input of the charge controller as shown in fig 5.1 (b).



**Fig 5.1 (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 fig 5.1 (c).



**Fig 5.1 (c).**

- The inverter converts DC power from the PV module into AC power to run the load.

### 5.3 Monitoring System:

In this section ,the design of the monitoring system will be shown in details with basic components and connection in figure 5.2.

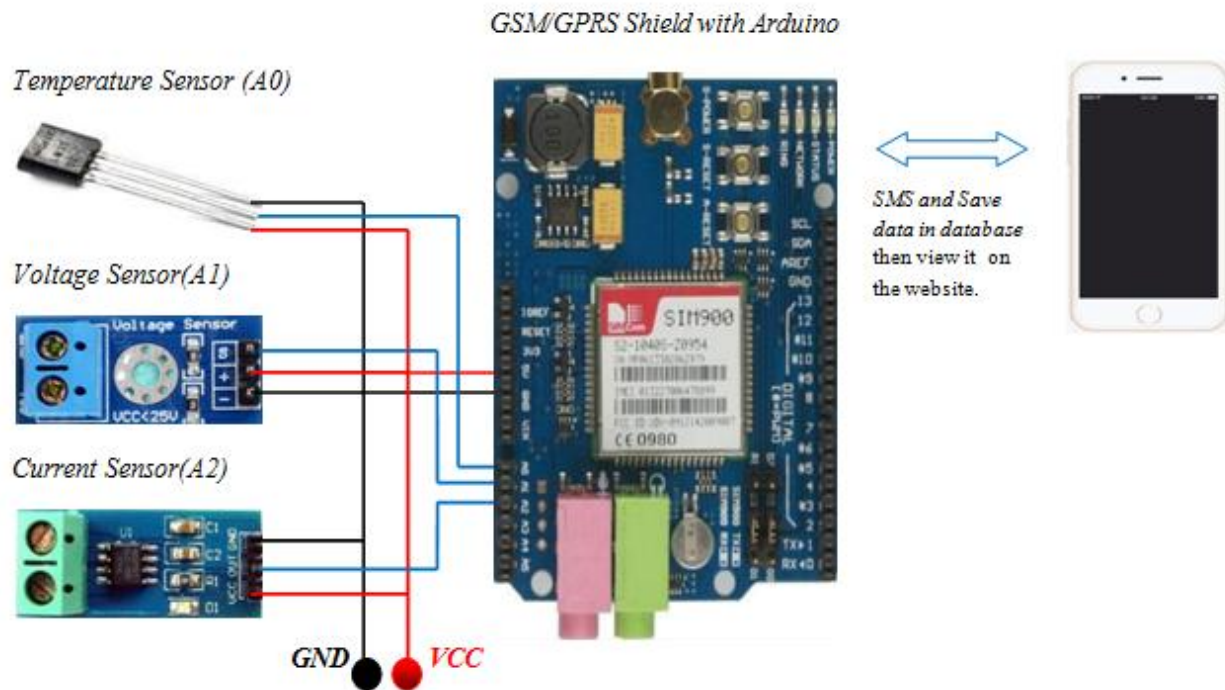


Figure 5.2 Monitoring System

### 5.3.1 Temperature Sensor:

In the figure 5.3 , the temperature sensor connected with analog pin 0 on arduino microcontroller and programmed with arduino code A[1] to measure the temperature .

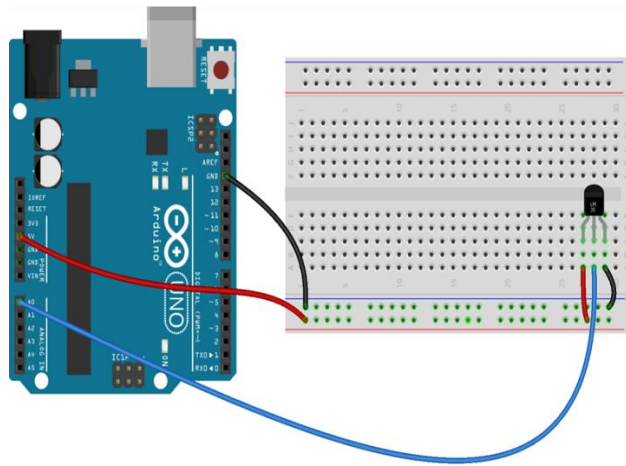


Figure 5.3 Temperature sensor connection

### 5.3.2 Voltage Sensor:

In the figure 5.4, the voltage sensor connected with analog pin 1 on arduino microcontroller and programmed with arduino code A[2] to measure the voltage from PV system.

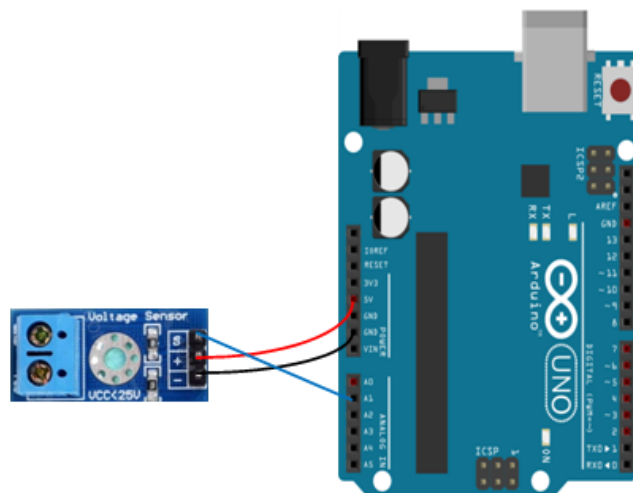


Figure 5.4 Voltage sensor connection

### 5.3.3 Current Sensor:

In the figure 5.5, the current sensor connected with analog pin 2 on arduino microcontroller and programmed with arduino code A[3] to measure the current from PV system.

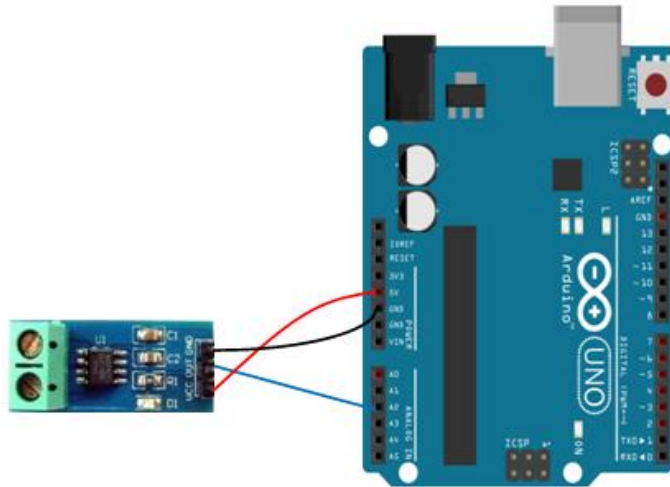


Figure 5.5 Current sensor connection

### 5.4 Controlling System:

In this section ,the design of the controlling system will be shown in details with basic components and connection in figure 5.6.

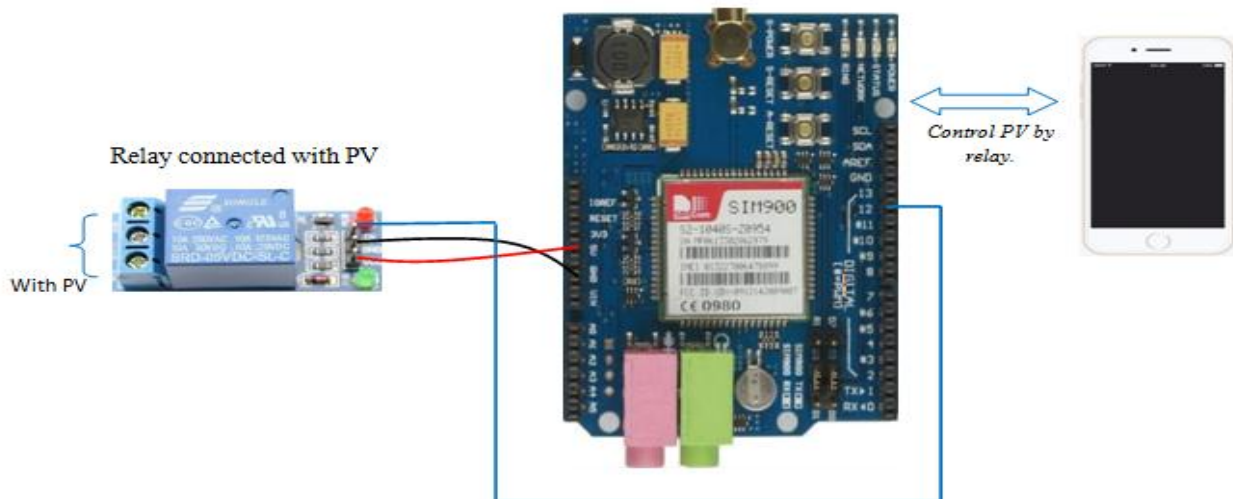


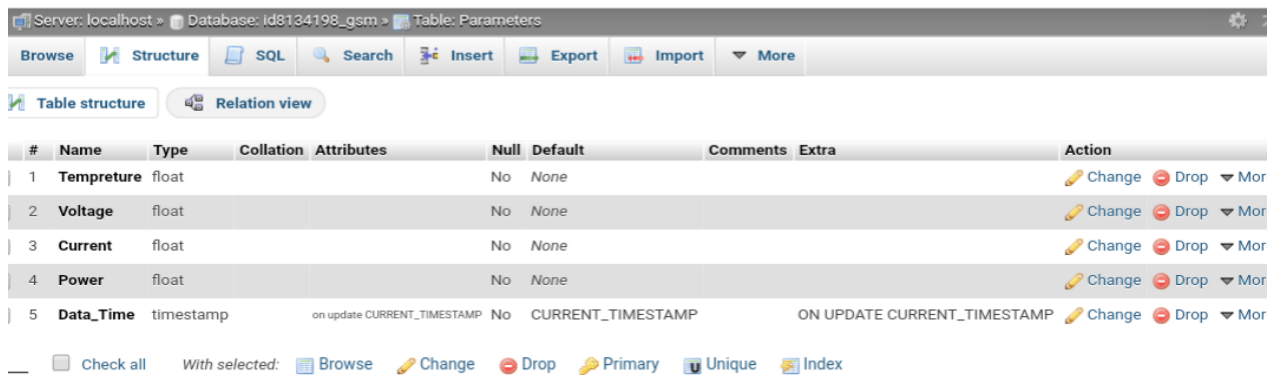
Figure 5.6 Controlling System.

## 5.5 Monitoring and controlling Protocol:

The protocol code A [4] 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 occur 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.

### Monitoring using website

In the figure 5.7, the table on phpMyAdmin to save data in database.



The screenshot shows the phpMyAdmin interface for a table named 'Parameters' in a database named 'Id8134198\_gsm'. The table structure is displayed in 'Table structure' view. The table has five columns: 'Tempreture' (float), 'Voltage' (float), 'Current' (float), 'Power' (float), and 'Data\_Time' (timestamp). The 'Data\_Time' column is set to 'on update CURRENT\_TIMESTAMP'. The interface includes navigation buttons like 'Browse', 'Structure', 'SQL', 'Search', 'Insert', 'Export', and 'Import'. At the bottom, there are options to 'Check all' and actions like 'Browse', 'Change', 'Drop', 'Primary', 'Unique', and 'Index'.

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	Tempreture	float			No	None			Change Drop Mor
2	Voltage	float			No	None			Change Drop Mor
3	Current	float			No	None			Change Drop Mor
4	Power	float			No	None			Change Drop Mor
5	Data_Time	timestamp		on update CURRENT_TIMESTAMP	No	CURRENT_TIMESTAMP		ON UPDATE CURRENT_TIMESTAMP	Change Drop Mor

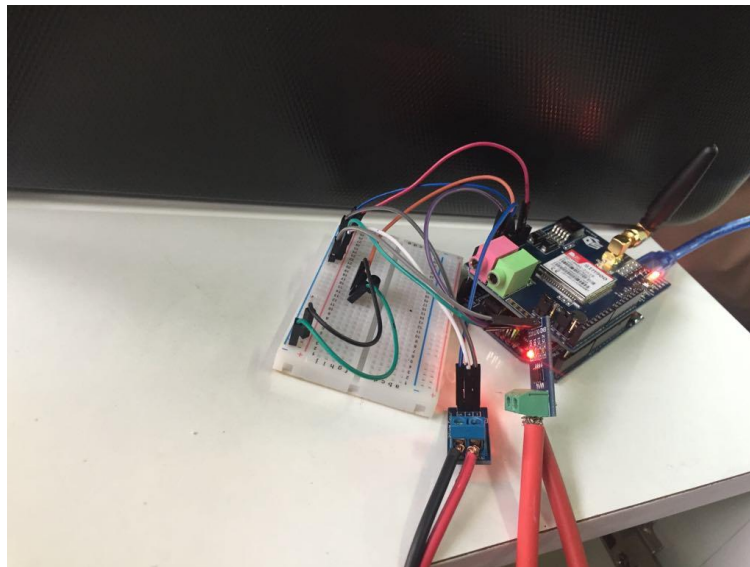
Figure 5.7 The table on database.

- Gprs code A[5] to send data from PV to database
- Php code A[6] to save data from PV on database.
- Phpcode A[6] to view database on website 145196.000webhostapp.com/mysql.php?

**Real Implementation of our project:**



**Fig 5.8(a): PV Panel**



**Fig 5.8(b): System Connection**



**Fig 5.8(c): System Connection**

# Chapter Six

## Results

---

6.1 Introduction

6.2 Sub System Testing.

6.3 Monitoring System.

6.4 Controlling System.

## 6.1 Introduction

This chapter presents the results of the project. These results include the parameters of PV cells on website and SMS and control to PV

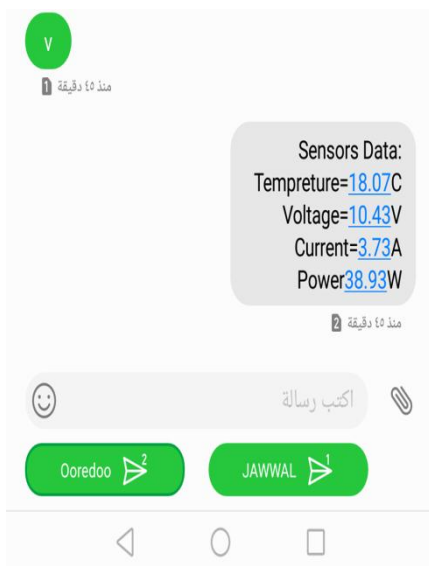
## 6.2 Subsystem Testing:

- 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 voltage level decrease.

## 6.3 Monitoring System:

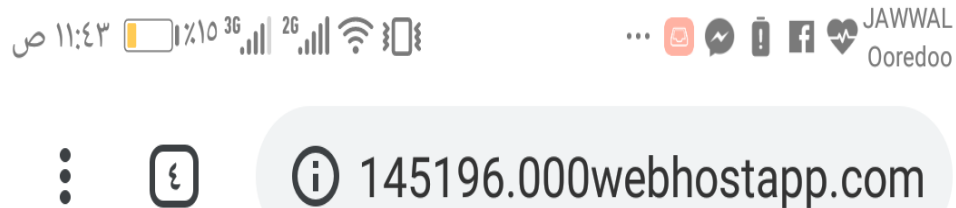
After the system is connected we can monitor system parameters by sending short messages with parameter values and alerting you to a system error and also monitoring it on the website.

### Monitoring using SMS



When we send Char. (v) the gsm send sensors data and when voltage less than 10 send (Error in PV System) .

## Monitoring using Website

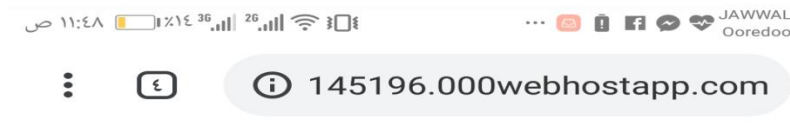


## Monitoring and Controlling Of Solar Cells

Tempreture	Voltage	Current	Power	Data_Time
12.21	10.07	3.73	37.58	2018-12-09 09:13:17
12.45	9.89	3.55	37.52	2018-12-09 09:15:16
13.15	10.05	4.15	38.52	2018-12-09 09:16:55
13.85	10.74	4.22	44.81	2018-12-09 09:21:25
12.34	10.77	3.48	37.47	2018-12-09 09:23:28

## 6.4 Controlling System.

This webpage will allow us to switch on or off the PV panel when enter 0 or 1 respectively.



Enter 1 for switch on the PV and 0 for switch off  
PV State:

إرسال

# Chapter Seven

## Conclusion

---

### 7.1 Conclusion.

## **7.1 Conclusion.**

- Finally, in the end, we would like to thank everyone who helped us, and did not spare us what he knows.
- We have designed and implemented a system that allows us to monitor and control the solar system remotely. This system is able to send information related to the solar system to the user via text messages and view it on a web site over a specified period of time.
- We aim to facilitate the process of monitoring and control and aspire to develop a system to provide everything that is new and useful to the consumer.

## References

No.	Reference
1	ScienceDirect. [online] [cited: November 2014 ]. <a href="https://www.sciencedirect.com/science/article/pii/S0927024814004310">https://www.sciencedirect.com/science/article/pii/S0927024814004310</a>
2	K. Rónay, C.D. Dumitru, A. Gligor Management of a Power System Based on Renewable Energy, January 9, 2012.
3	Monitoring of Photovoltaic System: Good Practices and Systematic Analysis. paris : s.n., 2013. the 28th European PV solar energy conference and exhibition. p. 9.
4	Nova Sun Power. [online] [Cited: November 2018]. <a href="http://novasunpower.com/index.php?/products-and-systems/photovoltaic-off-grid">http://novasunpower.com/index.php?/products-and-systems/photovoltaic-off-grid</a>
5	Alternative Energy. [online] [cited: March 19, 2015]. <a href="http://www.alternative-energy-tutorials.com/solar-power/grid-connected-pvsystem.html">http://www.alternative-energy-tutorials.com/solar-power/grid-connected-pvsystem.html</a>
6	Solarquotes. [online] [cited: <a href="https://www.solarquotes.com.au/inverters/micro/">https://www.solarquotes.com.au/inverters/micro/</a> ]
7	Clean Energy Review. [online] [cited: May 12, 2018]. <a href="https://www.cleanenergyreviews.info/blog/2015/7/2/3-all-in-one-hybridinverters">https://www.cleanenergyreviews.info/blog/2015/7/2/3-all-in-one-hybridinverters</a>
8	Lighting Research Center. [online] [cited: 2006]. <a href="https://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/photovoltaic/06-photovoltaic-batteries.asp">https://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/photovoltaic/06-photovoltaic-batteries.asp</a>
9	Wind & Sun. [online] [cited: 2018] <a href="https://www.solar-electric.com/learning-center/batteries-and-charging/solar-charge-controller-basics.html">https://www.solar-electric.com/learning-center/batteries-and-charging/solar-charge-controller-basics.html</a>
10	Altestore. [online] [cited: 2016] <a href="https://www.altestore.com/store/charge-controllers/solar-charge-controllers/mppt-solar-charge-controllers-c474/">https://www.altestore.com/store/charge-controllers/solar-charge-controllers/mppt-solar-charge-controllers-c474/</a>
11	SMA Inverter. [online] [cited August 8, 2013]. <a href="http://www.smainverted.com/what-is-a-photovoltaic-diesel-hybrid-system/">http://www.smainverted.com/what-is-a-photovoltaic-diesel-hybrid-system/</a>

## APPENDIX

### A[1]

```
int val1;
float mv;
void setup() {
  Serial.begin(9600);
}
void loop() {
  val1= analogRead(A0);
  mv = (val1/1024.0)*5000;
  t=mv/10;
  Serial.println("Temperature");
  Serial.println(t);
  delay(1000);
}
```

### A[2]

```
int val2;
float v;
int offset=20;
void setup() {
  Serial.begin(9600);
}

void loop() {
  val2 = analogRead(A1);
  v = map(val2, 0, 1023, 0, 2500)+offset;
  v/=100;
  Serial.print("Voltage");
  Serial.println(v);
  delay(1000);
}
```

A[3]

```
int mVperAmp = 185;
double Voltage = 0;
double VRMS = 0;
double c = 0;
void setup()
{
  Serial.begin(9600);
}

void loop(){
Voltage = getVPP();
VRMS = (Voltage/2.0) *0.707;
c = (VRMS * 1000)/mVperAmp;
Serial.print("Current");
Serial.println(c);
delay(1000);
}

float getVPP()
{
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 1024;

  uint32_t start_time = millis();
  while((millis()-start_time) < 1000)
  {
    readValue = analogRead(A2);
    if (readValue > maxValue)
    {
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      minValue = readValue;
    }
  }
  result = ((maxValue - minValue) * 5.0)/1024.0;
  return result;
}
```

A[4]

```
#include <SoftwareSerial.h>
char inchar;
SoftwareSerial SIM900(2,3);
String textForSMS;
int val1,val2, i=0;
float mv, v, t , p;
int offset=20;

int pv=12;
int mVperAmp = 185;
double Voltage = 0;
double VRMS = 0;
double c = 0;

void setup() {
  Serial.begin(9600);
  digitalWrite(pv,LOW);
  SIM900power();
  SIM900.begin(19200);
  SIM900.print("AT+CMGF=1\r");//set sms mode to text
  delay(1000);

  SIM900.print("AT+CNMI=2,2,0,0,0\r");
  //plurt out contents of new SMS upon receipt to the GSM shield's serial out
  delay(1000);
  SIM900.println("AT+CMGD=1,4"); //delete all sms
  delay(5000);
  Serial.println("Ready...");
  pinMode(pv , OUTPUT);}

void sendSMS(String message)
{
  SIM900.println("AT+CMGF=1\r");//AT command to send SMS message
  delay(1000);
  SIM900.println("AT+CMGS=\""+970569605073\"");
  delay(1000);
  SIM900.println(message);
  delay(1000);
  SIM900.println((char)26);
  delay(1000);
  SIM900.println();
  delay(1000);
}

void SIM900power()
{
  digitalWrite(9,HIGH);
  delay(1000);
  digitalWrite(9,LOW);
  delay(7000);
}

void loop() {
  val1= analogRead(A0);
  mv = (val1/1024.0)*5000;
  t=mv/10;
```

```

val2 = analogRead(A1);
v = map(val2,0,1023,0,2500)+offset;
v/=100;

Voltage = getVPP();
VRMS = (Voltage/2.0) *0.707;
c = (VRMS * 1000)/mVperAmp;
p=v*c;

if (v < 10 && i==0 )
{ textForSMS = " Error in PV: ";
  textForSMS = textForSMS + "The voltage=" + v + "V";
  sendSMS(textForSMS);
  i=1;}

inchar=SIM900.read();
Serial.println(inchar);
delay(20);
if(inchar=='v')
{delay(10);
Serial.println(inchar);
textForSMS = "Sensors Data:";
textForSMS = textForSMS + "\n Temperture=" + t + "C" + "\n Voltage=" + v + "V" + "\n Current=" + c + "A" + "\n Power" + p + "W";
sendSMS(textForSMS);
delay(1000);
SIM900.println("AT+CMGF=1,4"); //delete all sms
delay(2000);
Serial.println("Message Sent");
inchar = 'z'; //garbage value

}

textForSMS = "";
else if (inchar=='n')
{digitalWrite(pv,HIGH);}
else if (inchar=='f')
{digitalWrite(pv,LOW);}

}

float getVPP()
{
  float result;

  int readValue;          //value read from the sensor
  int maxValue = 0;      // store max value here
  int minValue = 1024;   // store min value here

  uint32_t start_time = millis();
  while((millis()-start_time) < 1000) //sample for 1 Sec
  {
    readValue = analogRead(A2);
    // see if you have a new maxValue
    if (readValue > maxValue)
    {
      /*record the maximum sensor value*/
      maxValue = readValue;
    }
    if (readValue < minValue)
    {

```

```

        /*record the maximum sensor value*/
        minValue = readValue;
    }
}

// Subtract min from max
result = ((maxValue - minValue) * 5.0)/1024.0;

return result;
}

```

A[5]

---

```

#include <SoftwareSerial.h>
SoftwareSerial gprsSerial(2,3);
int val1,val2;
float mv, v, t , p;
int offset=20;

int pv=12;
int mVperAmp = 185;
double Voltage = 0;
double VRMS = 0;
double c = 0;
void setup()
{
    gprsSerial.begin(19200);
    Serial.begin(9600);

    Serial.println("Con");
    delay(2000);
    Serial.println("Done!...");
    gprsSerial.flush();
    Serial.flush();

    // See if the SIM900 is ready
    gprsSerial.println("AT");
    delay(1000);
    toSerial();

    // SIM card inserted and unlocked?
    gprsSerial.println("AT+CPIN?");
    delay(1000);
    toSerial();

    // Is the SIM card registered?
    gprsSerial.println("AT+CREG?");
    delay(1000);
    toSerial();

    // Is GPRS attached?
    gprsSerial.println("AT+CGATT?");
    delay(1000);
    toSerial();

    // Check signal strength
    gprsSerial.println("AT+CSQ ");
    delay(1000);
    toSerial();

    // Set connection type to GPRS
    gprsSerial.println("AT+SAPBR=3,1,\"Contype\", \"GPRS\"");
    delay(2000);
    toSerial();

    // Set the APN
    gprsSerial.println("AT+SAPBR=3,1,\"APN\", \"internet\"");
    delay(2000);
}

```

```

    toSerial();

    // Enable GPRS
    gprsSerial.println("AT+SAPBR=1,1");
    delay(10000);
    toSerial();

    // Check to see if connection is correct and get your IP address
    gprsSerial.println("AT+SAPBR=2,1");
    delay(2000);
    toSerial();
}

void loop()
{
    val1= analogRead(A0);
    mv = (val1/1024.0)*5000;
    t=mv/10;

    delay(2000);
    val2 = analogRead(A1);
    v = map(val2,0,1023,0,2500)+offset;
    v/=100;
    delay(2000);

    Voltage = getVPP();
    VRMS = (Voltage/2.0) *0.707;
}

c = (VRMS * 1000)/mVperAmp;
delay(2000);
p=v*c;

// initialize http service
gprsSerial.println("AT+HTTPIPINIT");
delay(2000);
toSerial();

// set http param value
// To DO : send dynamic value
gprsSerial.println("AT+HTTTPARA=\"URL\", \"http://145196.000webhostapp.com/mysql.php?data1=t & data2=v & data3=c & data4=p\"");
delay(4000);
toSerial();

// set http action type 0 = GET, 1 = POST, 2 = HEAD
gprsSerial.println("AT+HTTTPACTION=1");
delay(6000);
toSerial();

// read server response
gprsSerial.println("AT+HTTTPREAD");
delay(1000);
toSerial();

//gprsSerial.println("");
gprsSerial.println("AT+HTTPTERM");
toSerial();
delay(300);
}

```

```

    gprsSerial.println("");
    delay(600000);
}

void toSerial()
{
    while(gprsSerial.available() != 0)
    {
        Serial.write(gprsSerial.read());
    }
}

float getVPP()
{
    float result;

    int readValue;           //value read from the sensor
    int maxValue = 0;        // store max value here
    int minValue = 1024;     // store min value here

    uint32_t start_time = millis();
    while((millis()-start_time) < 1000) //sample for 1 Sec
    {
        readValue = analogRead(A2);
        // see if you have a new maxValue
        if (readValue > maxValue)
        {
            /*record the maximum sensor value*/
            maxValue = readValue;
        }

        if (readValue < minValue)
        {
            /*record the maximum sensor value*/
            minValue = readValue;
        }
    }

    // Subtract min from max
    result = ((maxValue - minValue) * 5.0)/1024.0;

    return result;
}

```

---

A[6]

```
1 <?php
2     $dbusername = "id8134198_nadeen";
3     $dbpassword = "123456";
4     $server = "localhost";
5     $My_db = "id8134198_gsm";
6     $dbconnect = new mysqli($server, $dbusername, $dbpassword,$My_db);
7     $sql = "INSERT INTO Parameters (Tempreture, Voltage , Current , Power) VALUES ('".$_GET["data1"]."', '".$_GET["data2"]
8     ."', '".$_GET["data3"]."', '".$_GET["data4"]."'");
9     mysqli_query($dbconnect,$sql);
10 ?>
```

A[7]

```
1 <!DOCTYPE html>
2 <html>
3 <head>
4 <tr><th><h2>Monitoring and Controlling Of Solar Cells</h2></th></tr>
5 <style>
6 table, th, td {
7     border: 2px solid black;
8 }
9 </style>
10 </head>
11 <body>
12 <?php
13 $servername = "localhost";
14 $username = "id8134198_nadeen";
15 $password = "123456";
16 $dbname = "id8134198_gsm";
17
18 // Create connection
19 $conn = new mysqli($servername, $username, $password, $dbname);
20 // Check connection
21 if ($conn->connect_error) {
22     die("Connection failed: " . $conn->connect_error);
23 }
24
25
26 $sql = "SELECT Tempreture, Voltage, Current, Power, Data_Time FROM Parameters";
27 $result = $conn->query($sql);
28
29 if ($result->num_rows > 0) {
30     echo "<table><tr><th>Tempreture</th><th>Voltage</th><th>Current</th><th>Power</th><th>Data_Time</th></tr>";
31     // output data of each row
32     while($row = $result->fetch_assoc()) {
33         echo "<tr><td>" . $row["Tempreture"]. "</td><td>" . $row["Voltage"]. " </td><td>" . $row["Current"]. " </td><td>"
34     }
35     echo "</table>";
36 } else {
37     echo "0 results";
38 }
```