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FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

A SOLAR PV MONITOR

PROJECT INDEX: PRJ 116.

BY

EDKEVIN CHEGE MWAURA

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SUPERVISOR: PROFESSOR ELIJAH MWANGI

EXAMINER: DR. ING WILFRED MWEMA

Project report submitted in partial fulfillment of the requirement for the award of the degree of Bachelor of Science in Electrical & Electronic Engineering of the University of Nairobi.

Submitted on: 24/4/2015

DECLARATION OF ORIGINALITY

Name of Student: Edkevin Chege Mwaura

Registration Number: F17/2372/2009

College: Architecture and Engineering

Faculty: Engineering

Department: Electrical and Information Engineering

Course Name: Bachelor of Science in Electrical and Electronics Engineering

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DEDICATION

This project is dedicated to my mother and extended family whom have supported me throughout the duration of my study.

ACKNOWLEDGEMENT

First and foremost, I would like to thank the Almighty God for the far He has brought me.

I would like to acknowledge the immense contribution of my supervisor Prof. Elijah Mwangi who has assisted me in implementing new ideas to solve problems. I would also like to acknowledge everyone who has contributed to this project in one way or the other with special acknowledgement to one Kennedy Makau.

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LIST OF ABBREVIATIONS

2G – Second Generation

3G – Third Generation

AC – Alternating Current

AGM – Absorbed Glass Mat

CPU – Computer Processing Unit

CISC – Complex Instruction Set Computing

DC – Direct Current

GSM – Global System for Mobile Phone Communication

GPRS – General Packet Radio Service

I/O – Input/Output

RAM – Random Access Memory

ROM – Read Only Memory

RISC – Reduced Instruction Set Computing

SISC – Specific Instruction Set Computing

UART – Universal Asynchronous Receiver/ Transmitter

ABSTRACT

Solar energy is increasingly becoming commonplace in the society with the ever rising electricity bills and reduction in price in solar equipment. Being an 'essentially free' form of energy it is necessary to contribute to developments that support or improve the solar energy sector especially in Africa and in particular Kenya which is still a developing country and where many are still unable to afford an electricity connection for their homes, and with an electricity penetration rate of only about 20% of the entire population.

This report presents a way to monitor the voltage, current and power output from a solar panel , with the aim of monitoring and projecting the output from a solar farm.

This would essentially encourage investors to invest in the renewable energy sector in Kenya due to high irradiation capacities based on the geographical location of the country.

CHAPTER ONE: INTRODUCTION

1.1. GENERAL BACKGROUND

Solar energy is energy from the sun and is essentially a 'free' form of energy. This means that no one will charge you from harnessing power from the sun. This energy from the sun is harnessed by use of equipment called solar photo voltaic cells which have a general name of a solar panel. This harnessed energy is then converted to electrical energy which can be used in homes, industries, hospitals just like normal electricity. To convert the harnessed energy to a level which can be used in the home a couple of devices are required, which we will discuss, but we will start our discussion on what is a solar panel and what it is made of.

A solar panel is basically a device that is used to harness energy from the sun and convert it to electrical energy. It basically consists of a glass outer covering, an array of silicon cells and electrical wires carrying the electrical energy from the silicon cells. We will start our discussion on how a solar panel is made, and then discuss how it works in depth.

The production of a solar panel starts with the production of pure silicon which is not pure in its natural state. The raw materials are either silicon dioxide of quartzite gravel or crushed gravel. These are then placed into an electric furnace where a carbon arc is applied to release oxygen, giving carbon dioxide and molten silicon. This molten silicon has 99% purity but cannot be used in the solar cells. Further purification of this silicon is done using the floating zone technique whereby a rod of impure silicon is passed through a heated zone several times in one direction tending to push the impurities to one side of the rod. This silicon is then deemed pure and the impure end of the rod is removed. Silicon boules, which are polycrystalline structures that have the atomic structure of one crystal are then made using the czochralski method, are then made from which silicon wafers are made using a circular saw. The silicon is then doped, and this was first done in the czochralski method where a small amount of boron was introduced, by sealing the silicon wafers back to back and placing them in a furnace where they are heating to slightly below the melting point of silicon, around 1410 °C, in the presence of phosphorous gas. The phosphorous atoms then 'burrow' into the silicon which is more porous because it is close to becoming a liquid. The temperature and time given to the process is carefully controlled to ensure a uniform junction of proper depth. The silicon wafers are then covered with an anti-reflective coating usually titanium dioxide or silicon oxide. The finished solar cells are the sealed into silicon rubber or ethylene vinyl acetate after which they are placed into an aluminum frame that has a glass covering. The solar cells are arranged in series to form a solar module which is also called a solar panel. The finished solar panel is then ready for use according to its

ratings in Watts and this is determined by the number of silicon cells in the solar panel, generally more solar cells give more Wattage.

The figure below shows a simple cross-sectional diagram of the components of a solar panel.

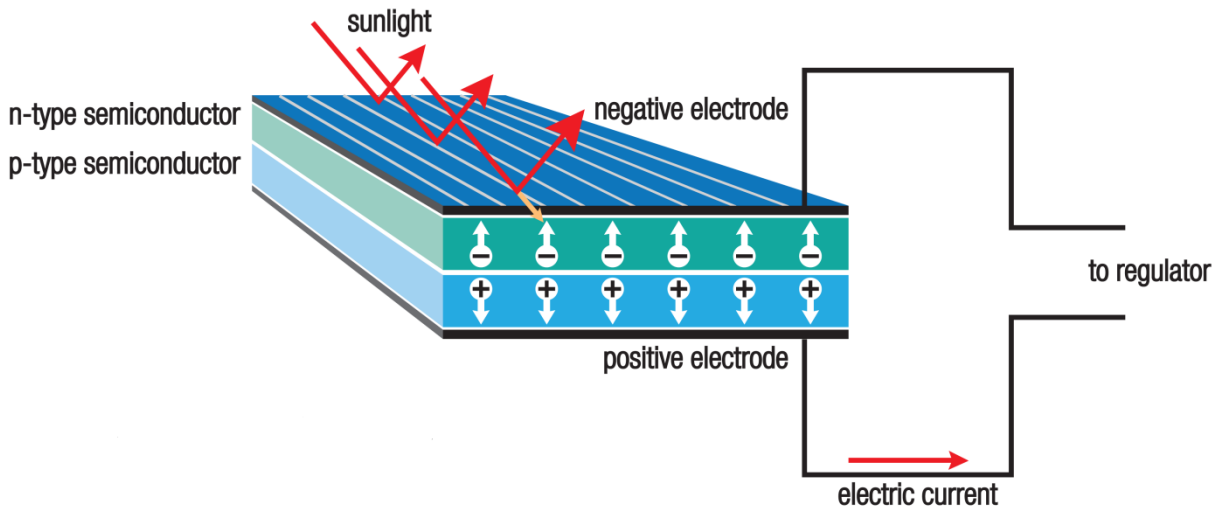


Fig 1.1: Cross-sectional diagram of a solar panel [REDARC Electronics]

There are different types of solar panel and each type affects the efficiency of the solar panel. These are namely, Monocrystalline, Polycrystalline and Amorphous.

Monocrystalline solar panels are made of monocrystalline silicon and have a uniform and rounded rectangle look indicating high purity silicon. Monocrystalline solar panels have the following advantages and disadvantages.

| Advantages | Disadvantages |
|--|--|
| Have the highest efficiency since they are made out of the highest grade silicon. The efficiency is typically around 15-20%. | They are the most expensive |
| Require the least space due to the higher power output compared to other types of solar panels | If the solar panel is partially covered with dirt, the entire circuit can break down |
| Have the longest life span with some manufacturers giving a warranty of up to 25 years. | A significant amount of silicon is wasted during the manufacturing process |
| They also tend to perform better in low light conditions as compared to other types of solar panels. | They tend to perform better in warm weather |

| | |
|--|--|
| | |
|--|--|

Table 1.1: Advantages and disadvantages of Monocrystalline Solar Panels

Polycrystalline are made of polycrystalline silicon and do not require the czochralski method during manufacture. They have the following advantages and disadvantages.

| Advantages | Disadvantages |
|---|--|
| The process used during their manufacture is simpler and less costly | They have a low efficiency typically 13-16% because of the lower silicon purity |
| They have a slightly lower heat tolerance than monocrystalline solar panels | They also have lower space efficiency as compared to monocrystalline solar panels due to their lower power output. |

Table 1.2: Advantages and disadvantages of Polycrystalline Solar Panels

Thin Film Solar Panels are made of one or several thin layers of silicon cells. The different materials are: Amorphous Silicon, Cadmium Telluride, Copper Indium Gallium Selenide and Organic Photo Voltaic Cells. They have the following advantages and disadvantages.

| Advantages | Disadvantages |
|---|--|
| Mass production is simple | They require a lot of space as compared to other types of solar panels due to their low output |
| Their homogenous appearance makes them more appealing | Setting up cost is much higher due to more support structures being needed. |
| They can be made to be flexible increasing their areas of application | They degrade faster than other types of solar panels |

Table 1.3: Advantages and disadvantages of Thin Film Solar Panels

Having looked at the different types of solar panels available, the following is an in-depth look at how a solar panel works to harness energy from the sun. The sun rays contain photons which hit the solar panels and are absorbed by the silicon. Electrons from the silicon bonds get excited and can either dissipate the energy as heat and return to their molecular orbit, or travel through the solar cell until they reach an electrode. Current then flows through the electrode and thus electricity is harnessed.

For the harnessed electricity to be used in homes, a couple of devices are needed to convert the harnessed electricity, which is in DC, to AC. These components are namely: charge controllers, batteries and inverters.

Charge controllers basically control how the solar panel charges the batteries and prevents the battery from overcharging or over discharging. They also protect the solar panel from damage by preventing current from flowing back from the batteries to the solar panel.

Batteries are basically used to store the DC power from the solar panels. They have different voltage ratings and the most common rating is 12 V. The most common type of battery used in solar systems is the Lead-Acid battery which is also a deep-cycle battery. These can be classified further into: Flooded type, Gel, AGM.

The flooded types contain an electrolyte which can be spilled. The Gel and AGM batteries can be classified into one category called the valve-regulated lead-acid batteries. The Gel type use a thickening agent like fumed silica to immobilize the electrolyte and can be used even when cracked. It is also important to control its rate of charging so as not to destroy the battery. The AGM batteries perform better than the Gel type and are the most rigid.

A deep-cycle battery means that the battery can be discharged frequently. Most deep cycle batteries can be discharged to between 45-75% of their capacity depending on the manufacturer. Discharging below the recommended discharge percentage will reduce battery life. Other types of batteries are Nickel-Cadmium, Lithium-Ion and Lithium Ion Phosphate.

Inverters basically do as the name suggests which is to convert DC to AC power. They can be classified into stand-alone inverters and grid-tie inverters.

The stand-alone inverters are used for completely off-grid areas. They may be remote homes or industries with no access to an electricity connection. They convert the DC power stored in the batteries for direct use in the homes or industries. Grid-tie inverters are more of a hybrid option and supplement the power from the batteries with power from the AC mains once the batteries are depleted. They thus help in reduction of the power bill but do not completely eliminate it. Inverters will normally have an output AC voltage of 240V which is what is required for use in the home applications. They are rated from between 50-50,000 Watts.

Most modern inverters can do Maximum Power Point Tracking to get maximum output power from the solar cells which have a complex relationship between solar irradiation, temperature and total resistance of the system that produces nonlinear output efficiency. Maximum power point tracking is not in the scope of this project and we will thus not cover it in detail.

A general connection of a solar system has the solar panels connected to the charge controller which is connected to the batteries, the inverter is then connected to the battery to give an AC output.

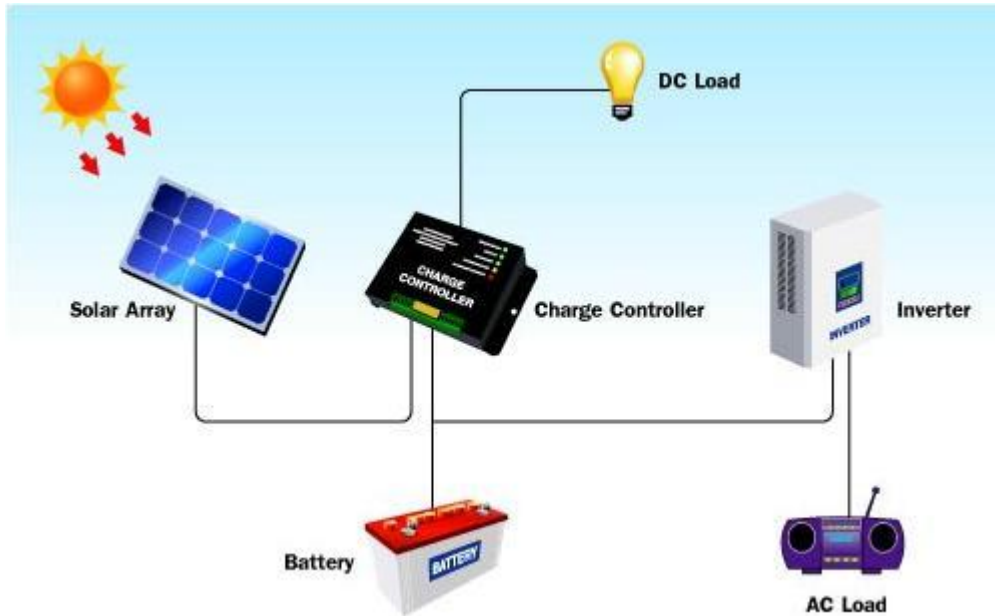


Fig 1.2: Solar system connection [Leonics Co.]

The following is how to calculate and get the correct solar system for your home by determining array of solar panels, ratings of charge controllers and inverters and the battery array.

Calculate the Watt Hours used by all your appliances. Multiply the power ratings in watts of your equipment by the number of hours it operates for each equipment and summing up the total.

$$(Watts) * (Hours) = Watt Hours$$

Repeat for all equipment and sum the total Watt Hours.

To determine the size and ratings of solar panels, take the total Watt Hours divide by the average sunshine period, allow for a cloudy day, add 20% of the total due to inefficiencies. This gives you the total power needed in Watts. Divide this with solar panel ratings of the solar panels you intend to use and this will give you the total number of panels needed i.e.

$$\frac{(Total Watt Hours) * 1.2}{(Average Sunshine Period)} = (Watts)$$

$$\frac{(Watts)}{(Rating\ of\ Solar\ Panel\ in\ Watts)} = (Number\ of\ Solar\ Panels)$$

To determine the inverter size, add the total power ratings for all equipment that can be ON at the same time. Allow for a slightly higher value of the inverter ratings i.e.

$$(Watts) + (Watts) + (Watts) + \dots \dots (for\ all\ equipment) = Watts\ (Size\ of\ Inverter)$$

To determine the battery array, take the number of solar panels and multiply by the short circuit current of each solar panel. Multiply this by the number of average sunshine hours and then multiply by the recommended battery discharge capacity percentage recommended by the manufacturer i.e.

$$(Number\ of\ Panels) * (I\ sc) * (Average\ Sunshine\ Hours) * (Discharge\ Capacity\ \%) \\ = Number\ of\ Batteries$$

Isc = Short-Circuit Current of the Solar Panel.

To get 24V for your system, multiply this number of batteries by 2.

The charge controller current rating should be slightly higher than the solar panel short-circuit current.

1.2 PROBLEM STATEMENT

Solar energy has a number of benefits to the economy:

1. Reduction in electricity bills
2. Lower carbon footprint helps in averting global warming
3. Reduces over-relying on depleteable energy sources
4. Allows for development of more economically efficient technologies like solar cars
5. Reduction in the power generation cost

An investor investing in solar power is thus bringing a lot of benefits to the economy and the people and it is therefore necessary to encourage them to invest by monitoring the output of a solar farm to determine the output power each day and enable them to calculate their daily returns and predict future returns to make it a worthwhile investment.

1.3 PROJECT OBJECTIVES

The objectives of this project are to:

1. Monitor the fluctuation of output power of the solar panel at different times of the day.
2. To monitor the time of the day there is maximum output power

1.4. SCOPE OF WORK

This project will be limited to the above objectives and will not:

1. Monitor the efficiency of the solar panels in use
2. Detect a fault in the system
3. Alert the engineer of a fault either through the system or mobile phone.

1.5. ORGANISATION OF THE REPORT

The rest of the report is organized as follows:

In chapter 2, the literature review that consists of Solar PV characteristics, Data acquisition, Data processing, Data transmission is presented.

In chapter 3, the design of the work that consists of the hardware and software design is presented.

In chapter 4, the results and discussions are presented

Lastly conclusions and recommendations for further work are given in chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.1. SOLAR PV CHARACTERISTICS

This is basically how the voltage and current behave in a solar panel with respect to solar irradiation.

EFFECT OF TEMPERATURE ON VOLTAGE AND CURRENT

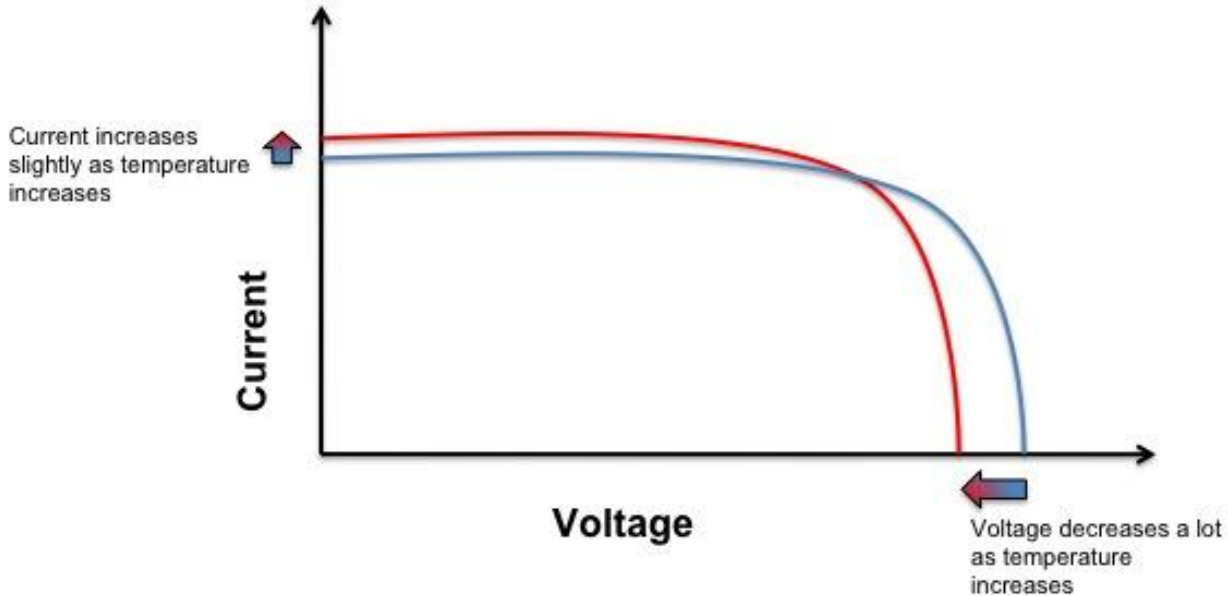


Fig 2.1: Effect of temperature on Current and Voltage [The Effect of Temperature on Electrical Parameters of Solar Cells, by Davud Mostafa, December 2013]

The figure above shows the effect that temperature has on the behavior of voltage and current inside a solar panel. The current and voltage of a solar panel are dependent on the temperatures of the solar panel. As the temperature increases, the open circuit voltage of the solar panel decreases, while the short circuit current increases slightly. Since the power output of the solar panel is given by $P=IV$, and the drop in voltage is greater than the increase in current, the net effect is a drop in the output power of the solar panel as shown in Fig 2.2, and because of this, solar panels work best at low temperatures.

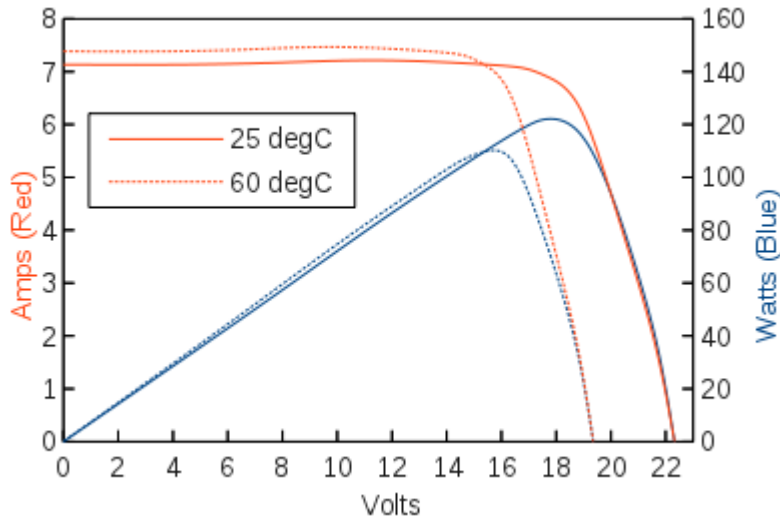


Fig 2.2: Effect of temperature on output power [The Effect of Temperature on Electrical Parameters of Solar Cells, by Davud Mostafa, December 2013]

EFFECT OF SOLAR IRRADIANCE ON VOLTAGE AND CURRENT

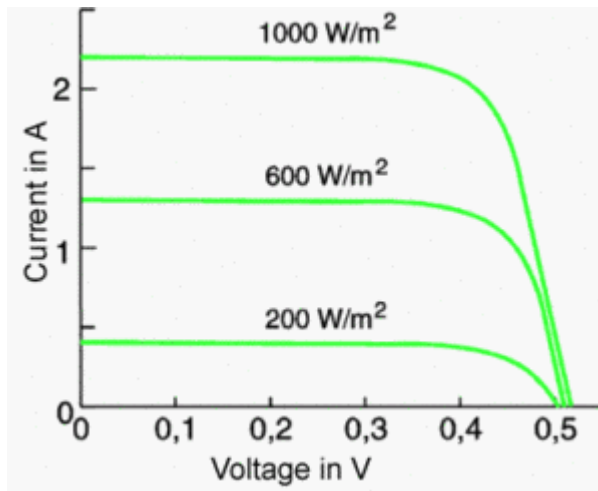


Fig 2.3 Effect of Solar Irradiance on Current and Voltage [The Effect of Temperature on Electrical Parameters of Solar Cells, by Davud Mostafa, December 2013]

Solar irradiance is the measure of power per unit area on the Earth's surface produced by the sun in form of electromagnetic radiation, commonly known as sunlight. It is measured in Watts/m². The figure above shows how this irradiance affects voltage and current inside a solar panel. The amount of usable voltage per solar cell depends on the material used and is 0.5V in silicon. The voltage is lightly dependent on solar irradiation but current output of a solar panel increases with increase in solar irradiation.

CURRENT, VOLTAGE AND MAXIMUM POWER

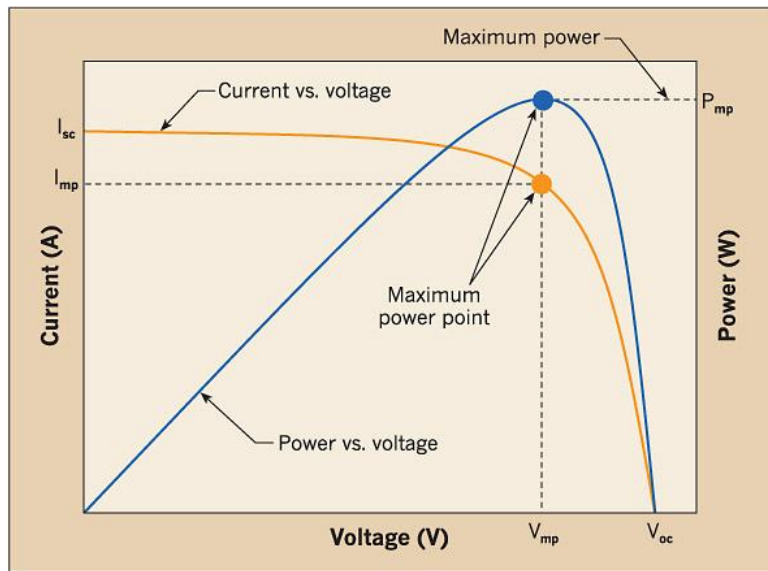


Fig 2.4: Behavior of Current, Voltage and Maximum power in a solar panel [Solmetric, Guide to Interpreting I-V Curve Measurements of PV Arrays, March 1, 2011]

The figure above shows how current and voltage increase inside a solar panel. As the current and voltage increase to their maximum value, so does the power until a point is reached where by the solar panel cannot produce more power. This is called the maximum power point.

2.2. DATA ACQUISITION

This is the method used to monitor the parameters i.e. voltage and current in the solar panel. The components used for data acquisition are sensors. We will talk about current sensors.

2.2.1. SENSORS

A sensor is a device used to sense the physical or environmental conditions. They then convert the specific parameter into a proportional voltage output. Sensors can be classified as Active or Passive, Digital or Analog, Null and Deflection.

Active sensors require an external source of power that provides the majority of the output power of the signal while in passive sensors the output power is provided entirely by the measured signal without an excitation voltage, while passive sensors do not require external power.

In digital sensors, the signal produced or reflected is binary, while in analog sensors the signal produced is continuous and proportional to the measurand.

In deflection sensors, the signal produced some physical effect closely related to the measured quantity while in null sensors, the signal produced is counteracted to minimize deflection. The opposing effect necessary to maintain zero deflection should be proportional to the signal of the measurand.

HALL EFFECT SENSORS

A Hall Effect sensor measures the current in a conductor by use of Hall Effect while providing isolation of the circuit being measured. The Hall Effect is the production of a voltage across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current.

Current contains charge carriers, typically electrons, holes and ions, which experience Lorentz force when a magnetic field is present and not parallel to the direction of motion of the charge carriers. Without the presence of the magnetic field, the charge carriers move in a straight path but when the magnetic field is present their path is curved such that they accumulate on one side of the conductor. This leaves equal and opposite charges on either side of the conductor and the result is an asymmetric distribution of charge density across the Hall element that is perpendicular to both the straight line and the applied magnetic field. This establishes an electric field which opposes further movement of charge carriers creating a steady electric potential.

For a simple metal where there is only one type of charge carrier i.e. electrons, the Hall Voltage can be computed by setting the net Lorentz force to zero.

$$F = q(E + v * B) = 0$$

Where:

$$E = \frac{V_H}{w}, v = \frac{L}{T}, I = \frac{Q}{T}, Q = n$$

Therefore,

$$V_H = \frac{-I * B}{n * t * e}$$

Where I is current across the plate length, B is the magnetic field, t is the thickness of the plate, e is the elementary charge and n is the charge carrier density of the electrons.

The Hall co-efficient is defined as:

$$R_H = \frac{E_y}{j * x * b}$$

Where:

E_y is the induced electric field and j is the current density of the electrons.

It thus becomes:

$$R_H = \frac{V_H * T}{I * B} = \frac{-1}{n * e} \quad (\text{m}^3/\text{C})$$

There are two types of Hall Effect sensors namely, linear, meaning that the output voltage is directly proportional to the magnetic flux density and the other is threshold, in which case the output voltage decreases sharply at each level of magnetic flux density.

The advantages and disadvantages of Hall Effect sensors are:

| Advantages | Disadvantages |
|--|---|
| Production of an output voltage is independent of the rate of the detected field | Since they work on the same principle as a magnetic field, external magnetic fields can interfere with their working |
| They are not affected by ambient conditions such as dust, humidity and vibrations. | Temperature affects electrical resistance of the element and the mobility of majority of the charge carriers and also their sensitivity leading to inaccuracies |
| They depend on carrier mobility which eliminates any perturbations due to surface elements making them reproducible and highly reliable. | There is an output voltage even in the absence of a magnetic field |
| They also operate over a wide temperature range and can measure a large amount of current. | When measuring current flow, they are limited to a distance of 10cm |

Table 2.1: Advantages and disadvantages of Hall Effect Sensors

2.3 DATA PROCESSING

Data processing is used to convert or process the measured signal to a form suitable for processing by a processing unit and actually process the data. The signal measured may be larger than the processing unit can handle and thus the need to condition the signal to an acceptable range and reduce noise in the process. The processing unit can be a specialized computer. Components used in data processing include filters and Operational Amplifiers.

A filter is a device that removes an unwanted component or feature. In signal processing, they are used to remove some unwanted frequencies in order to suppress interfering signal and reduce background noise. There are many types of filters which are: Linear or non-linear, time-invariant or time-variant, analog or digital, discrete-time or continuous-time, passive or active, infinite impulse response or finite impulse response. We will concentrate on linear filters.

Linear filters basically eliminate some frequencies and allow others to pass. The different frequency response can be classified into a number of different band forms describing which frequency bands the filter allows to pass and which it rejects. These are low pass filter which allows high frequencies to pass while eliminating low frequency signals, high pass filter which allows low pass frequencies to pass while eliminating high frequencies and band pass filters which allow only frequencies in a frequency band to pass.

An operational amplifier is a DC coupled, high gain electronic voltage amplifier and with a single-ended output. An Op-Amp produces an output voltage that is many times larger than the input voltage thus essentially is used as a voltage amplifier. They can also be used to buffer signals, integrate signals, differentiate signals, sum multiple signals etc. The Op-Amp can be configured as voltage follower, inverting amplifier and non-inverting amplifier.

2.3.1. MICROCONTROLLERS

These are specialized computers that perform calculations or process the conditioned signals as required. These computers are integrated in one single circuit containing a processor core, memory and programmable I/O peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP (One Time Programmable) ROM is also often included as well as a small amount of RAM. Microcontrollers are mostly designed for use in embedded applications and contain many General Purpose Input/ Output Pins which are software configurable to either an input or an output state. When configured in the input state, they are used to read sensors or external signals. When configured in the output state, they can drive external device such as motors or LEDs.

CLASSIFICATION OF MICROCONTROLLERS

This is basically how microcontrollers are classified. Microcontrollers can be divided into a number of categories and can be classified according to:

1. Bus width
2. Architecture
3. Instruction Set

1. BUS WIDTH

An address bus is a series of lines connecting two or more device that specifies a specific address. When a processor needs to read or write to a specific location, it specifies the memory address to the address bus. The address bus determines the amount of memory that the processor can address. This is given by 2^n for an n-bit bus width.

READ operations retrieve a byte of data from the specified memory address a place it on the data bus. The CPU reads the data and places it in one of its internal registers.

WRITE operations put data from CPU on the data bus and store it in the specified location.

Data bus carries information from the CPU to the memory or from the CPU to I/O devices.

Control bus carries control signals supplied by the CPU to synchronize the movement of information on the address and data bus.

Microcontrollers can have different bus widths namely 8 bit, 16 bit and 32 bit.

8 BIT MICROCONTROLLERS

When the ALU performs logical and arithmetic operations on a byte (8 bits), at an instruction the microcontroller is an 8 bit microcontroller. The resulting final range for an 8 bit microcontroller is 0x00- 0xFF (0-255) for every cycle.

16 BIT MICROCONTROLLERS

These perform greater precision and performance than the 8 bit microcontrollers. It uses 16 bit instructions to perform arithmetic and logical operations. The final range for 16 bit microcontrollers is 0x000- 0xFFF (0-65535)

32 BIT MICROCONTROLLERS

These use 32 bit instructions to perform arithmetic and logical operations.

2. ARCHITECTURE

There are mainly two categories under classification by architecture namely Von-Neumann architecture and Harvard architecture.

VON-NEUMAN ARCHITECTURE

Microcontrollers under this architecture have a single data bus that is used to fetch both instructions and data as shown in Fig 2.5. Program instructions and data are stored in a common main memory. When the controller addresses main memory, it first fetches and instruction, and then it fetches the data to support that instruction.

The main advantage of this architecture is that it simplifies the microcontroller design because only one memory is accessed.

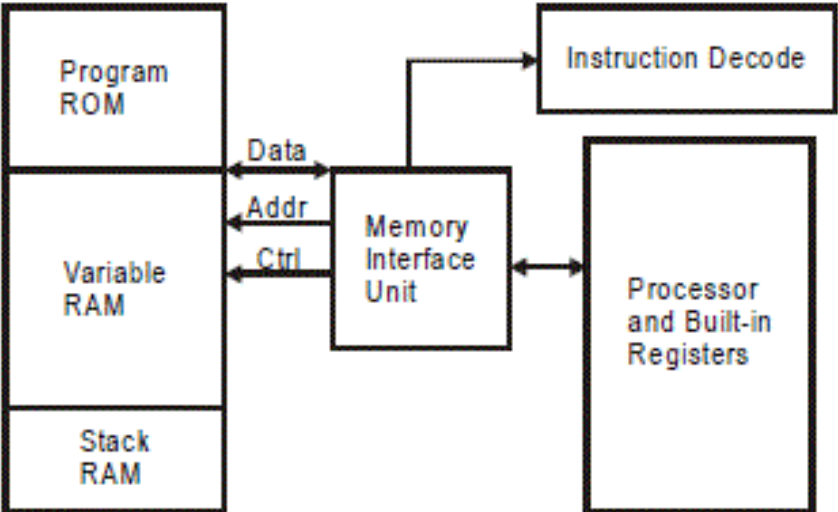


Fig2.5: Von – Neumann Architecture [NewPage Publishers, Introduction to Microcontrollers Chapter 1]

HARVARD ARCHITECTURE

This architecture has separate storage and signal pathways for instructions and data as shown in Fig 2.6. This allows for instructions to be performed in parallel. As an instruction is being pre-fetched, the current instruction executes on the data bus and once complete the next instruction is ready to go. This allows for faster execution of instructions than the Von Neumann architecture.

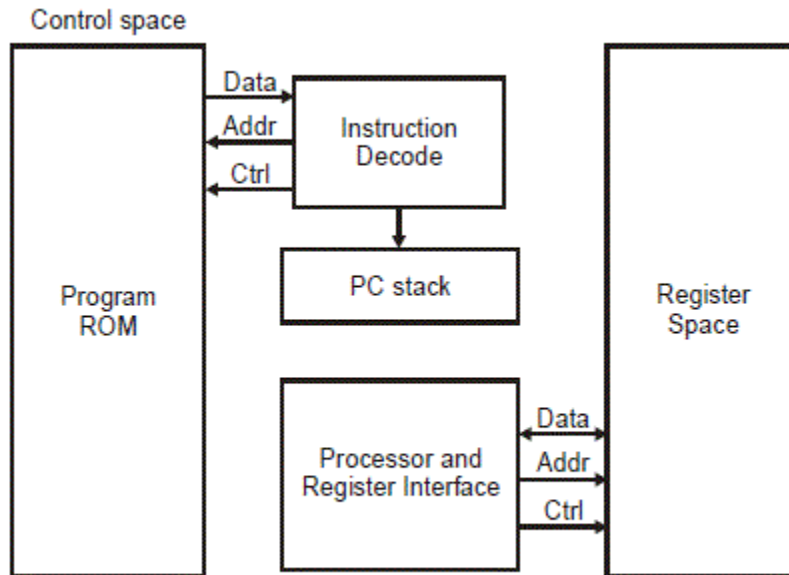


Fig 2.6: Harvard Architecture [NewPage Publishers, Introduction to Microcontrollers Chapter 1]

3. INSTRUCTION SET

Microcontrollers can also be classified according to instruction set namely CISC, RISC and SISC.

CISC (Complex Instruction Set Computing)

A microcontroller has CISC architecture when it has an instruction set that supports many addressing modes for arithmetic and logical instructions, data transfer and memory access instructions.

It uses complex instructions which are micro-coded in the ROM and are called by the software whenever required.

A microcontroller using CISC architecture has over 80 instructions.

RISC (Reduced Instruction Set Computing)

This instruction set uses fewer instructions than CISC. It is faster since it requires fewer data cycles to execute an instruction. It requires cheaper hardware and is less expensive than CISC.

The advantages are:

1. Instruction pipelining increases execution speed
2. Symmetrical instruction set for simpler programming

3. It allows any instruction to operate on any register or use any addressing mode
4. It allows simultaneous access to program and data.

SISC (Specific Instruction Set Computing)

This instruction set is designed for a specific purpose of control like powerful bit manipulation and easy and efficient I/O.

MICROCONTROLLER APPLICATIONS

Some of the applications of microcontrollers are:

1. Microwaves
2. Televisions
3. Cars
4. Hospital Equipment
5. Aviation Industry
6. Fire detection and safety devices
7. Industrial instrumentation devices
8. Hand held metering systems
9. Light sensing and controlling devices
- 10.

They can also be used for data logging to monitor environmental parameters.

2.3.2. MSP430G2553

The microcontroller used was an MSP430 from Texas Instruments. It incorporates a 16 bit RISC CPU, peripherals, and a flexible clock system that interconnect using a von – Neumann common memory address bus (MAB) and memory data bus (MDB). Some of its main features are:

- Maximum operating frequency of 16 MHz
- Operating voltage of 3.3 Volts
- A 10-bit resolution analog to digital converter.
- One addressable memory space, 128 KB in size, shared with special function registers (SFRs), peripherals, RAM, and Flash/ROM memory.

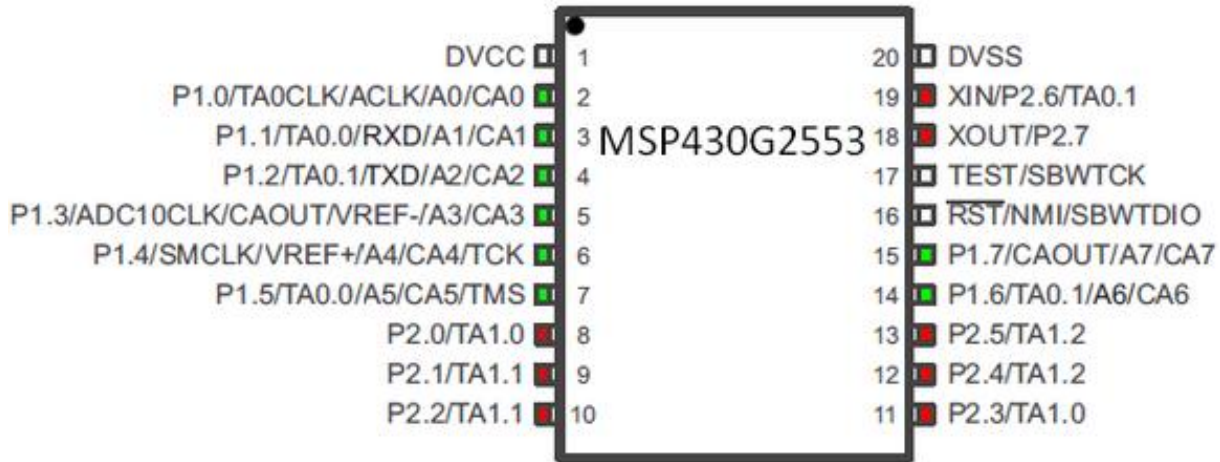


Fig 2.7: MSP430G2553 Pin Out [Texas Instruments, MSP430 Programming Guide]

The figure above shows the MSP430G2553 pin numbering and functions. It has 8 analog input pins and 9 digital pins.

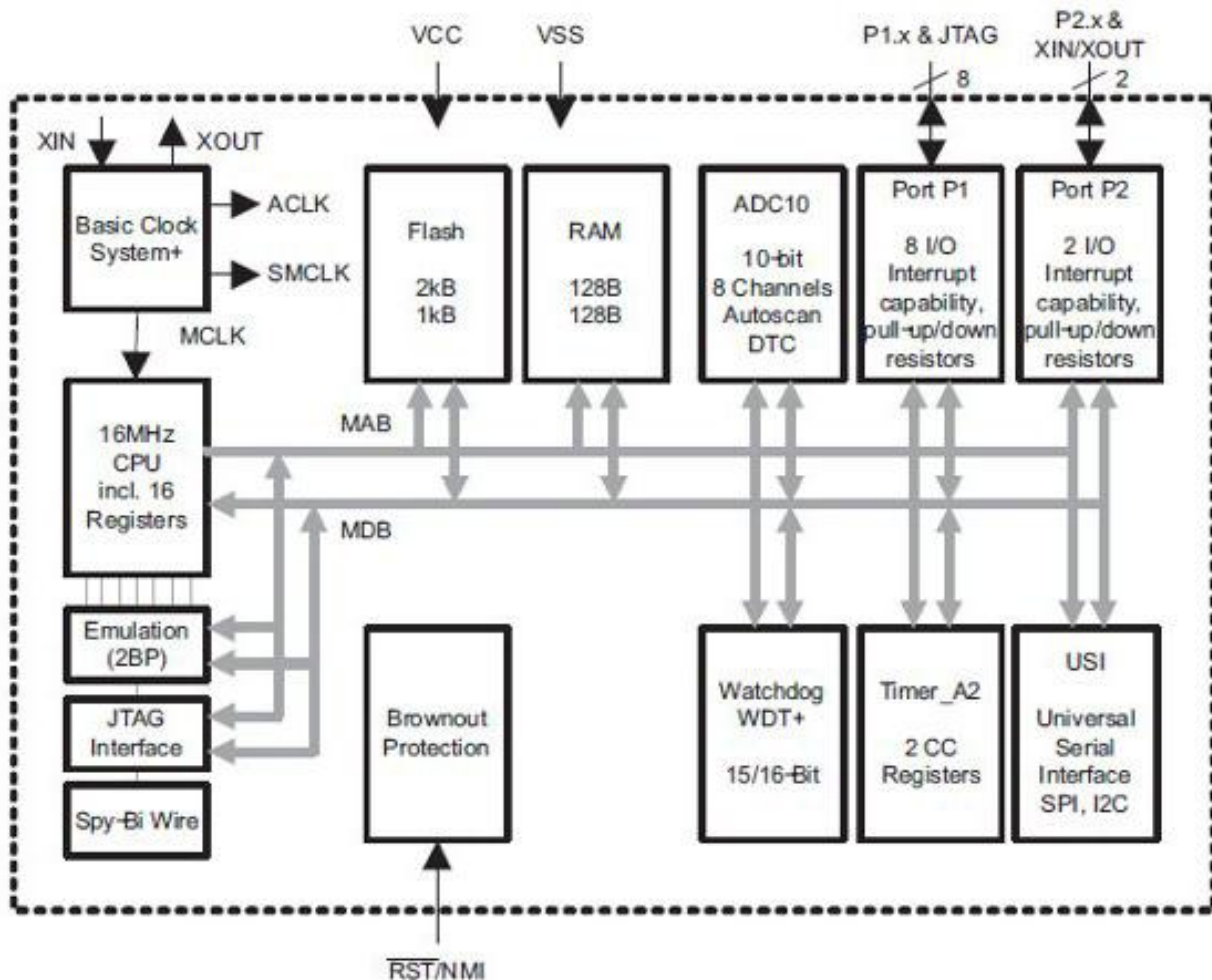


Fig 2.8: Functional Block diagram of MSP430G2553 [Texas Instruments, MSP430 Programming Guide]

The figure above shows the functional block diagram for the MSP430G2553. From the diagram, some of the features of MSP430G2553 are:

1. Brownout Protection – This protects the system when the operating voltage goes below the brownout voltage.
2. Watchdog Timer – Performs a system restart after a software problem occurs. If the selected time interval expires, the system is restarted.
3. Timer – This is 16 bit timer/counter with three capture/compare registers.
4. Universal Serial Interface SPI, I2C – This is one module which provides SPI and I2C communication.
5. 8 I/O Interrupt capability, pull up/down resistors
6. I/O Interrupt capability pull up/down resistors
7. 10 bit 8 channels Autoscan DTC – This is the analog to digital converter and converts analog signals to digital signals.
8. RAM 128 Bytes - This stores a section of the code that is needed for execution.
9. Flash 2KB – This is memory block that can be erased and reprogrammed.
10. Basic Clock System – This is basically a clock for the MSP430G2553
11. 16 MHz CPU including 16 registers – This performs calculated branching, table processing and features RISC architecture with 27 instructions and 7 addressing modes.

2.4. SERIAL COMMUNICATION

This is the process of sending data one bit at a time over a communication channel. The Serial Communication Interface (SCI) enables serial communication between the microcontroller and peripheral devices.

UNIVERSAL ASYNCHRONOUS RECEIVE/TRANSMIT (UART)

This mode is used for communication between the microcontroller and the GSM Sim900 Modem with very little load on the CPU. This mode is selected when the SYNC bit is cleared and the microcontroller is connected to an external device via two external pins URXD and UTXD.

The features of this mode include:

- 7 or 8 bit data with odd, even or non – parity.
- Independent transmit and receive shift registers
- Separate transmit and receive buffer registers
- LSB- First data transmit and receive
- Programmable baud rate with modulation for fractional baud rate support

- Status flags for error detection and suppression and address detection
- Independent interrupt capability for receive and transmit

This mode transmits and receives characters at a bit rate asynchronous to another device. Timing for each character is based on the selected baud rate. The transmit and receive functions use the same frequency.

The UART character format consists of a start bit, seven or eight data bits, an even /odd/no parity, an address bit, and one or two stop bits. The bit period is defined by the selected clock source and setup of the baud rate registers.

When the two devices are communicating asynchronously, the idle – line format is used for the protocol.

IDLE – LINE MULTIPROCESSOR FORMAT

In this format blocks of data are separated by an idle – time on the transmit or receive lines. An idle receive line is detected when 10 or more continuous ones (marks) are received after the first stop bit of a character. When two stop bits are used for the idle line the second stop bit is counted as the first mark bit of the idle period.

The first character received after an idle period is an address character. The RXWAKE bit is used as an address tag for each block of characters. This bit is set when a received character is an address and is transferred to UxRXBUF.

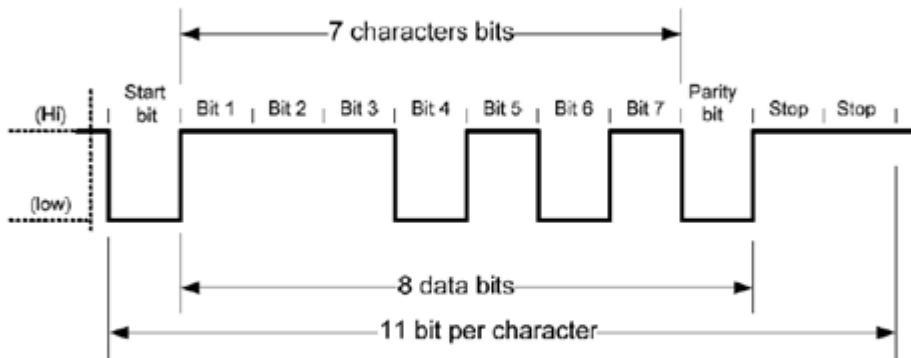


Fig 2.9: Character bits for UART [Texas Instruments, MSP430 Programming Guide]

2.5. DATA TRANSMISSION

These are the methods used for data transmission. Data transmission is process by which data is transferred from one location to another. One of the most recent developments in the communication technology is the GSM communication which we will focus on.

GSM is the standard by which the vast majority of mobile phones in the world work. It operates in a bandwidth ranging from 900 MHz to 1900 MHz. The GSM network has a number of discrete sections namely base-station subsystem, network and switching subsystem, GPRS core network, and operations support system. We will talk about the GPRS core network.

Before getting to GPRS, the advantages of the GSM network are that it uses data encryption to make data transfer more secure, supports data networking, supports SMS, supports call forwarding, supports caller ID transmission, call waiting and multiparty conferencing.

Most GSM phones are primarily used for voice communication but can also be used for mobile network internet access via the GPRS core network.

GPRS network allows 2G, 3G, WCDMA (Wideband Code Division Multiple Access), mobile networks to transmit internet protocol packets to an external network such as the internet and is an integrated part of the GSM network switching sub-system. Additional services offered by GPRS include SMS (Short Messaging Service), Always ON internet access, MMS (Multimedia Messaging Service), PoC (Push to Talk), Instant Messaging and WAP(Wireless Access Point).

It used to transmit data up to speeds of about 60kbps and has three modes of initialization namely Initialization/Idle, stand-by, ready.

It is used to transmit data at speeds of up to 60kb/s in a battery friendly way. It has three modes of operation which are:

- a. Initialization/Idle – This occur when the mobile phone is first turned on and this update the location to the network. This also authenticates the mobile phone to ensure that it is allowed to access the network while confirming GPRS capability of the mobile phone.
- b. Stand-by - In this mode, the mobile phone periodically updates its location to ensure that it has not changed base stations.
- c. Ready – In this mode, the mobile phone is attached to a network and a virtual connection is made allowing the network to know where to route the packets when they are sent and received. The mobile phone is prepared for a call or data transfer until the connection is terminated.

d. The GSM Sim900 allows for GSM and GPRS connectivity.

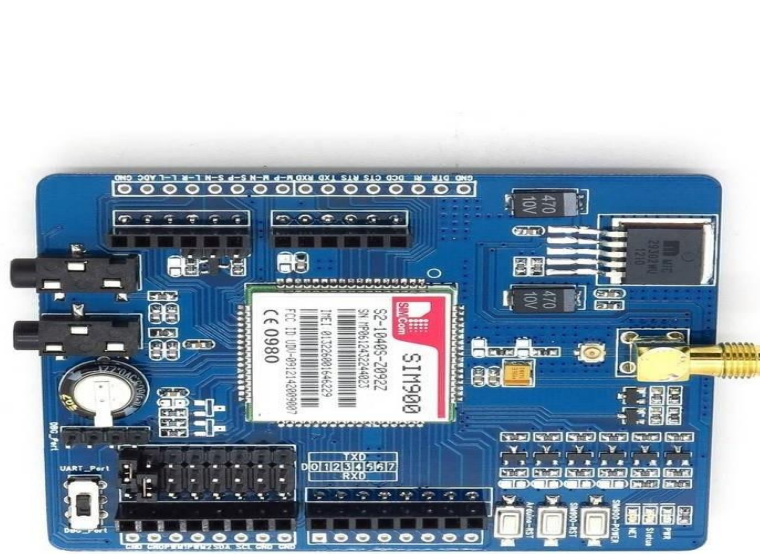


Fig 2.10: GSM Sim900 Modem [Tiny Sine Co.]

CHAPTER THREE: DESIGN AND IMPLEMENTATION

The design of the Solar PV Monitor was based on the MSP430 Microcontroller from Texas Instruments. The design process consists of two stages:

1. Hardware Design
2. Software Design

3.1. Hardware Design

The Figure below show the voltage signal conditioning circuit for the Solar PV Monitor

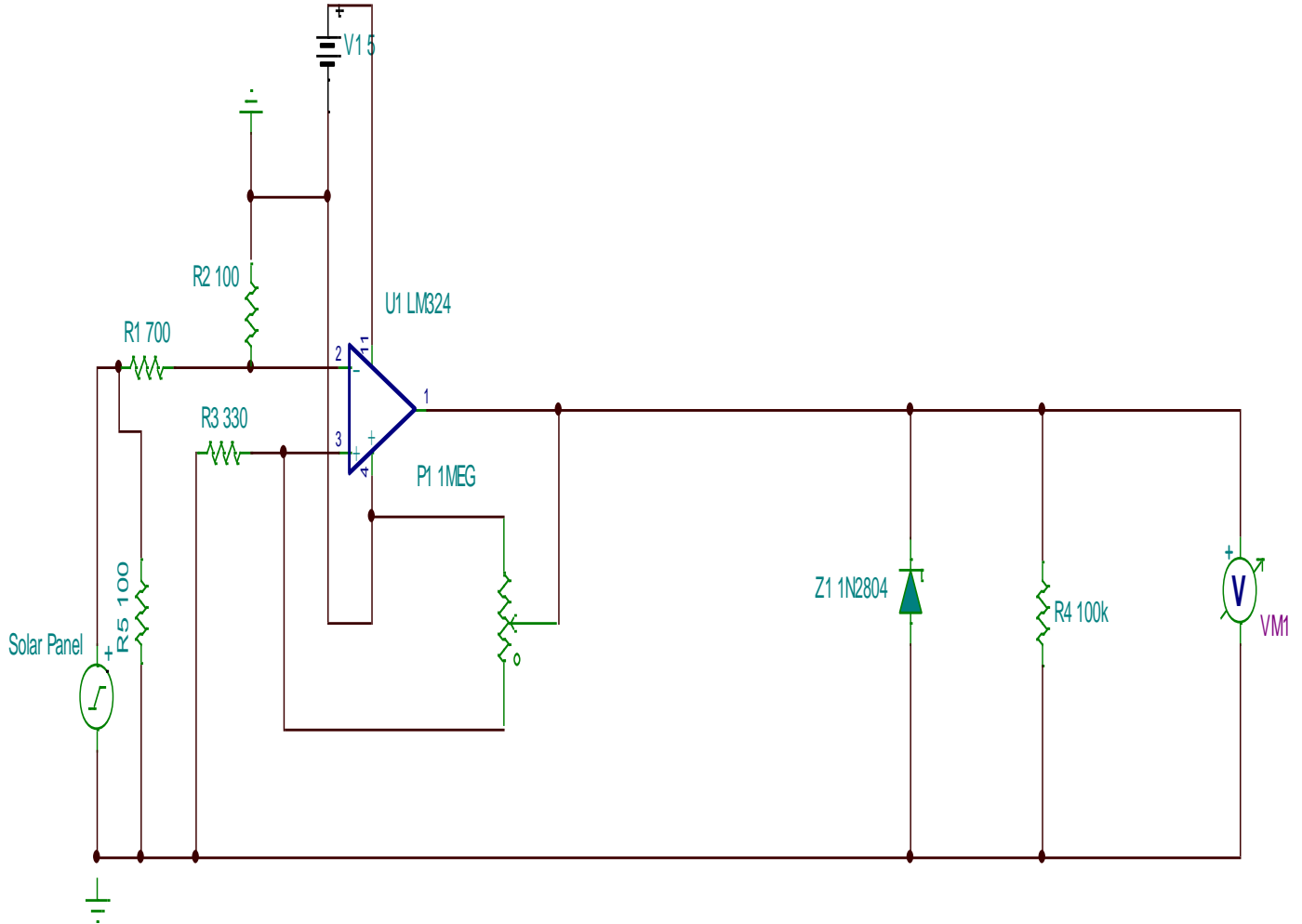


Fig 3.1: Voltage signal conditioning circuit

The solar panel was connected to a constant load in this case a 100 Ohm Resistor rated at 5Watts. The Solar Panel electrical characteristics are:

- Maximum Power: 10 Watts
- Maximum-power voltage: 17.6 Volts
- Maximum-power current: 0.57 Amps
- Open-circuit voltage: 21.2 Volts
- Short-circuit current: 0.63 Amps

By Ohms Law:

$$V = I * R,$$

V = Varying according to sunlight (0-20V Range)

R = 100 Ohms

Thus:

$$I = \frac{20 \text{ V(Maximum)}}{100} = 0.2 \text{ Amps}$$

The circuit was designed while ensuring the current is below 4 Amps so as not to damage the microcontroller.

Since I = 0.2 Amps

The power dissipated in the resistor was given by, $P = I^2 * R$

Thus $P = (0.2)^2 * 100 = 4 \text{ Watts}$.

A 5 Watts Resistor was thus chosen.

The resistors R1 and R2, form a voltage divider to reduce and divide the voltage by a certain ratio thus attenuating the voltage. In this case the resistors chosen are R1 = 700 Ohms and R2 = 100 Ohms.

Using the Voltage Divider Formula:

$$V = \frac{R2}{(R1 + R2)}$$

$$V = \frac{100}{800} = 0.124$$

Thus

$$V_{out} = V_{in} * 0.124$$

For a maximum V_{in} of 20 V:

$$V_{out} = 20V * 0.124 = 2.48 V$$

Since the internal reference voltage of the microcontroller was used, the voltage input limit to the ADC was 2.5 V. In this case the maximum voltage was 2.48 V.

The Op-Amp used was the LM324 which is configured as a voltage follower and has the following characteristics:

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V
- Low Input Bias Currents: 100 nA Maximum (LM324A)
- Four Amplifiers per Package
- Internally Compensated
- Common Mode Range Extends to Negative Supply
- Industry Standard Pin-outs
- ESD clamps on the inputs increase ruggedness without affecting device operation

ELECTRICAL CHARACTERISTICS

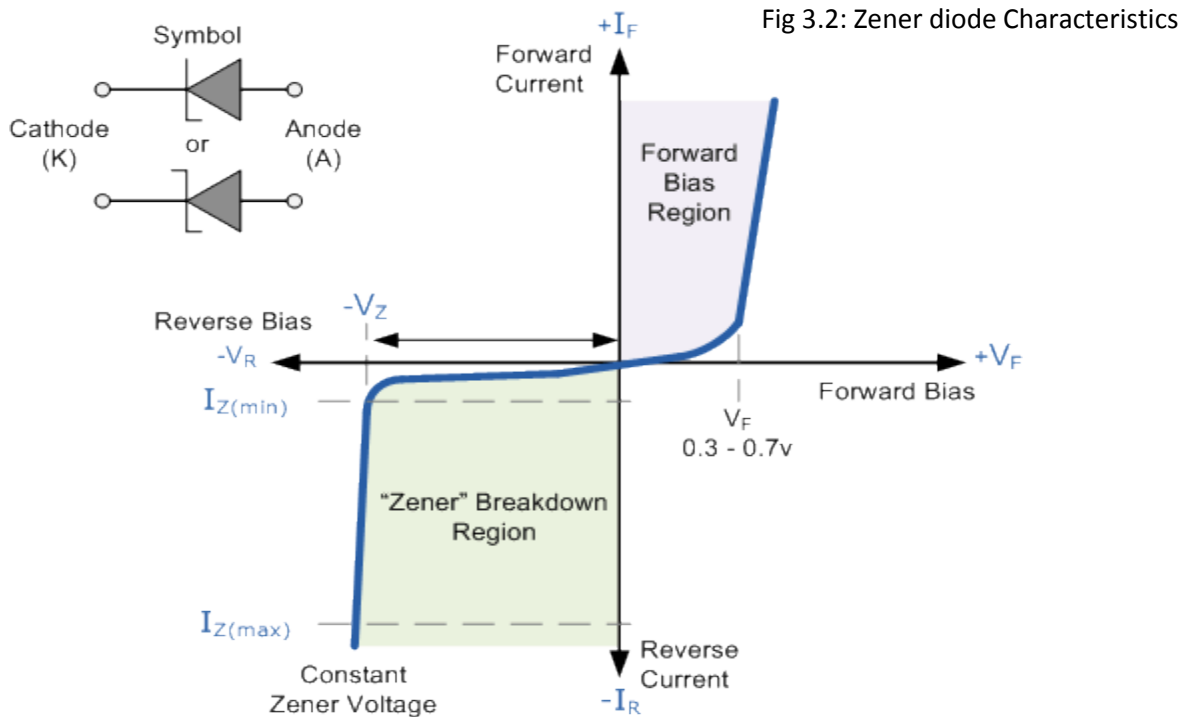
$VCC = 5 V, VEE = GND, T A = 250 C$

| Characteristics | Output |
|-----------------------------|--------|
| Output Voltage – High Limit | |

| | |
|---|-------|
| $V_{cc} = 5.0\text{ V to }30\text{ V}, R_L = 2.0\text{ K Ohms}$ | 3.5 V |
|---|-------|

Table 3.1: Electrical Characteristics of LM324

The zener diode (1N2804) and the resistor (100 K Ohms) form a voltage regulator. The characteristics of a zener diode are as shown:



The zener diode outputs a constant voltage when its breakdown voltage is reached. This protects the microcontroller from damage in case the voltage goes beyond a certain value. The zener diode was connected in its reverse biased mode, that is, the cathode was connected to the positive side of the circuit and the anode to ground. The resistor that is in parallel with the zener diode was selected so that when the input voltage is at $V_{in}(\text{min})$ and the load current is at $I_L(\text{MAX})$ that the current through the zener diode is at least $I_Z(\text{MIN})$.

The maximum power rating of the zener diode was chosen using this formula, to ensure that its maximum power rating was not exceeded:

$$I(\text{max}) = \frac{\text{Power}}{\text{Zener Voltage}}$$

3.1.1. Power Supply

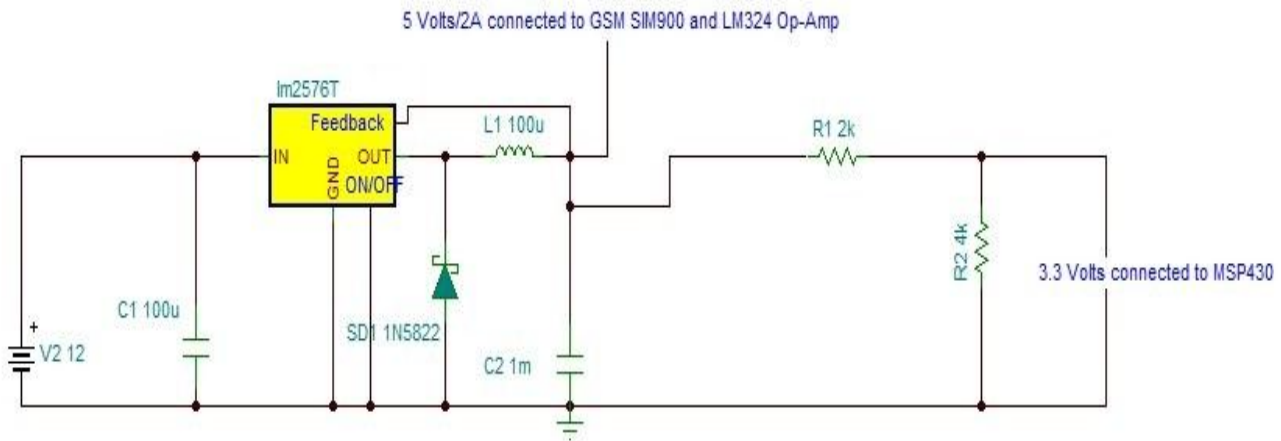


Fig 3.3: Power Supply Circuit

The LM2576T produced a constant output of 5 V with a maximum current limit of 3Amps. It was connected to a 12Volts battery. The capacitor C1 was used to filter any ripples from the battery source and any AC components that may be riding on the DC. The capacitor C2 was used as a by-pass capacitor to filter out any noise and any other high frequency components ensuring that the output is smooth.

3.1.2 MICROCONTROLLER

The microcontroller used was an MSP430 from Texas Instruments. It incorporates a 16 bit RISC CPU, peripherals, and a flexible clock system that interconnect using a von – Neumann common memory address bus (MAB) and memory data bus (MDB). Some of its main features are:

- Maximum operating frequency of 16 MHz
- Operating voltage of 3.3 Volts
- A 10-bit resolution analog to digital converter.
- One addressable memory space, 128 KB in size, shared with special function registers (SFRs), peripherals, RAM, and Flash/ROM memory.

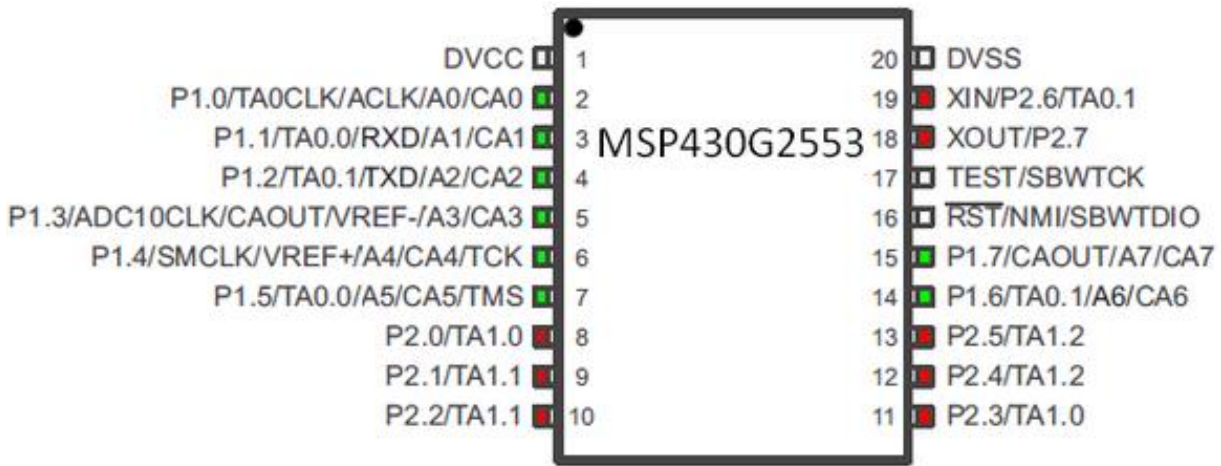


Fig 3.4: MSP430G2553 Pin Diagram [Texas Instruments, MSP430 Programming Guide]

| Pin Number and Label | Pin Description | Usage |
|----------------------|-------------------------------|---|
| 1. VCC | Input 5 V DC | |
| 2. GND | Ground | |
| 5. RXD SW | Receive Pin for Software UART | Connected to TX Pin on GSM Sim900 Modem |
| 6. TXD SW | TXD Pin for Software UART | Connected to RX Pin on GSM Sim900 Modem |

Table 3.2: MSP 430 Pin description of Used Pins

3.1.3. GSM SIM900 MODEM

This was used to send the data to a server and uses a sim card to access the internet via the GPRS network.

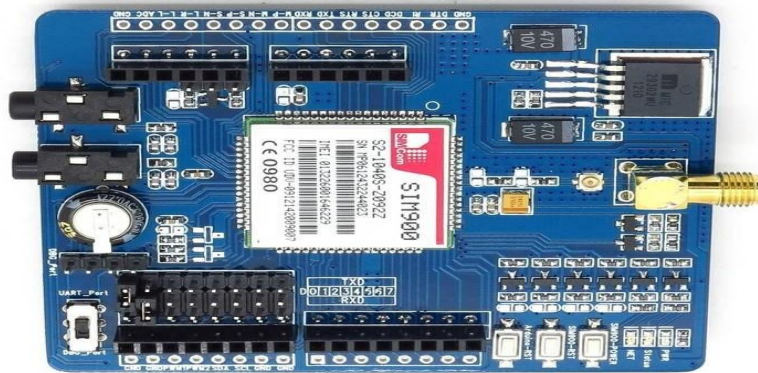


Fig 3.5: GSM Sim900 Modem [Tiny Sine Co.]

Pin D0 was used as the receive Pin and Pin D1 as the transmit pin for the software UART.

Table 3.3: Pin description of GSM Sim900 Modem

| Pin Number | Description |
|------------|--------------------------------|
| V In | 5 V DC |
| D1 | Receive pin for software UART |
| D0 | Transmit pin for software UART |
| GND | Ground |

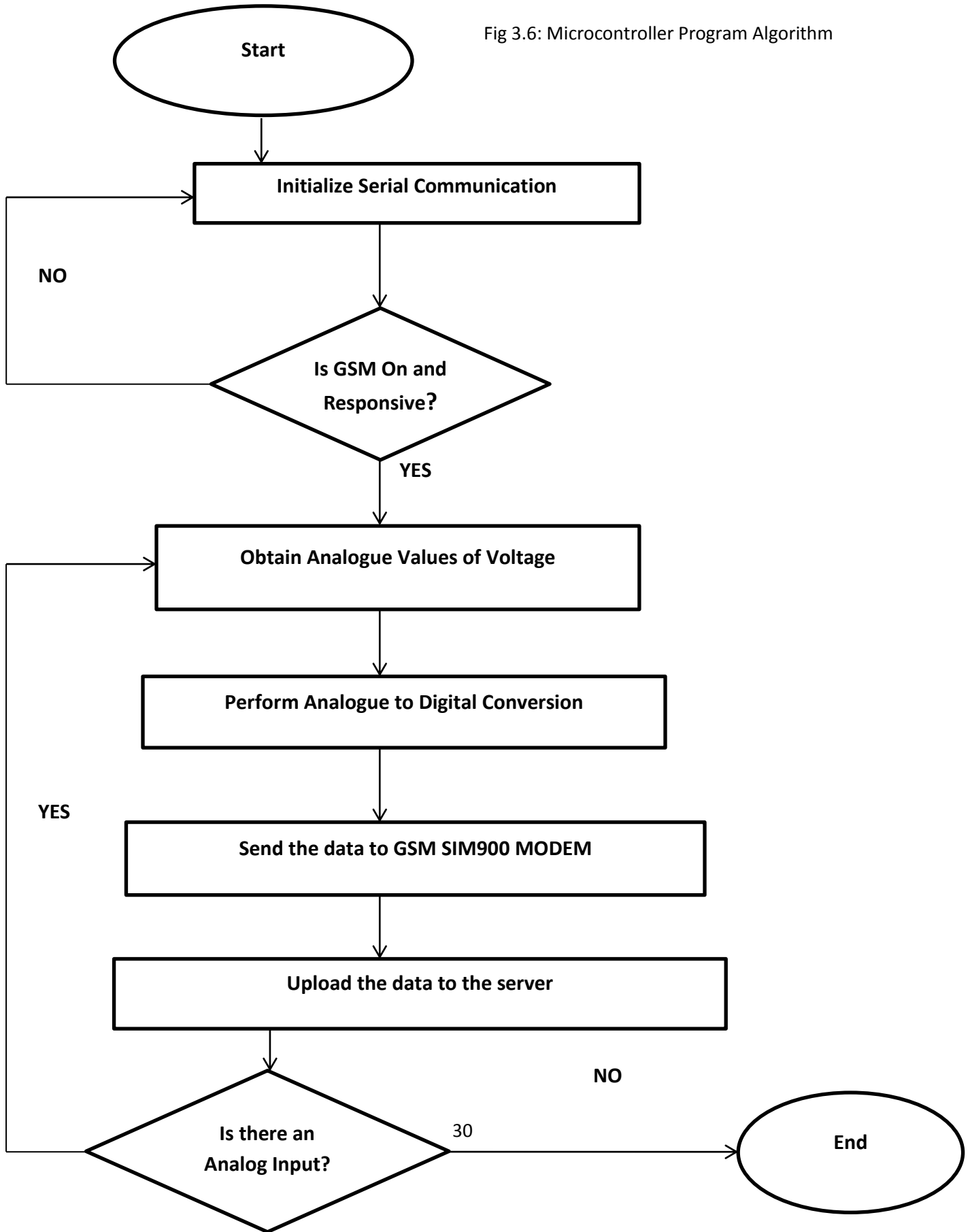
3.2. SOFTWARE DESIGN

The software design was divided into two parts and was implemented as follows:

1. Microcontroller Software
2. Server Software

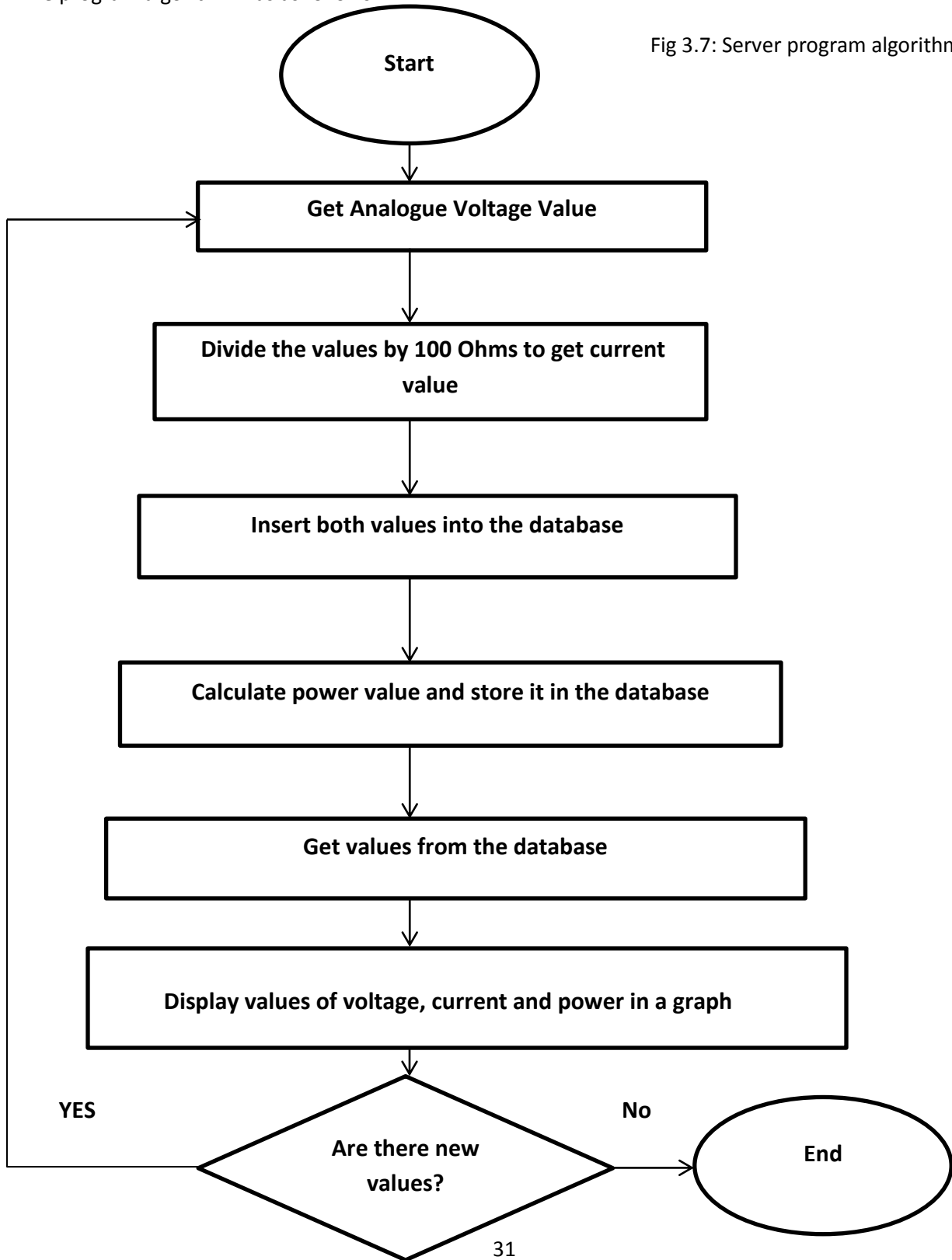
3.2.1 Microcontroller Software

The program algorithm was as follows:



3.2.2. Server Software

The program algorithm was as follows:



CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. SIMULATION RESULTS

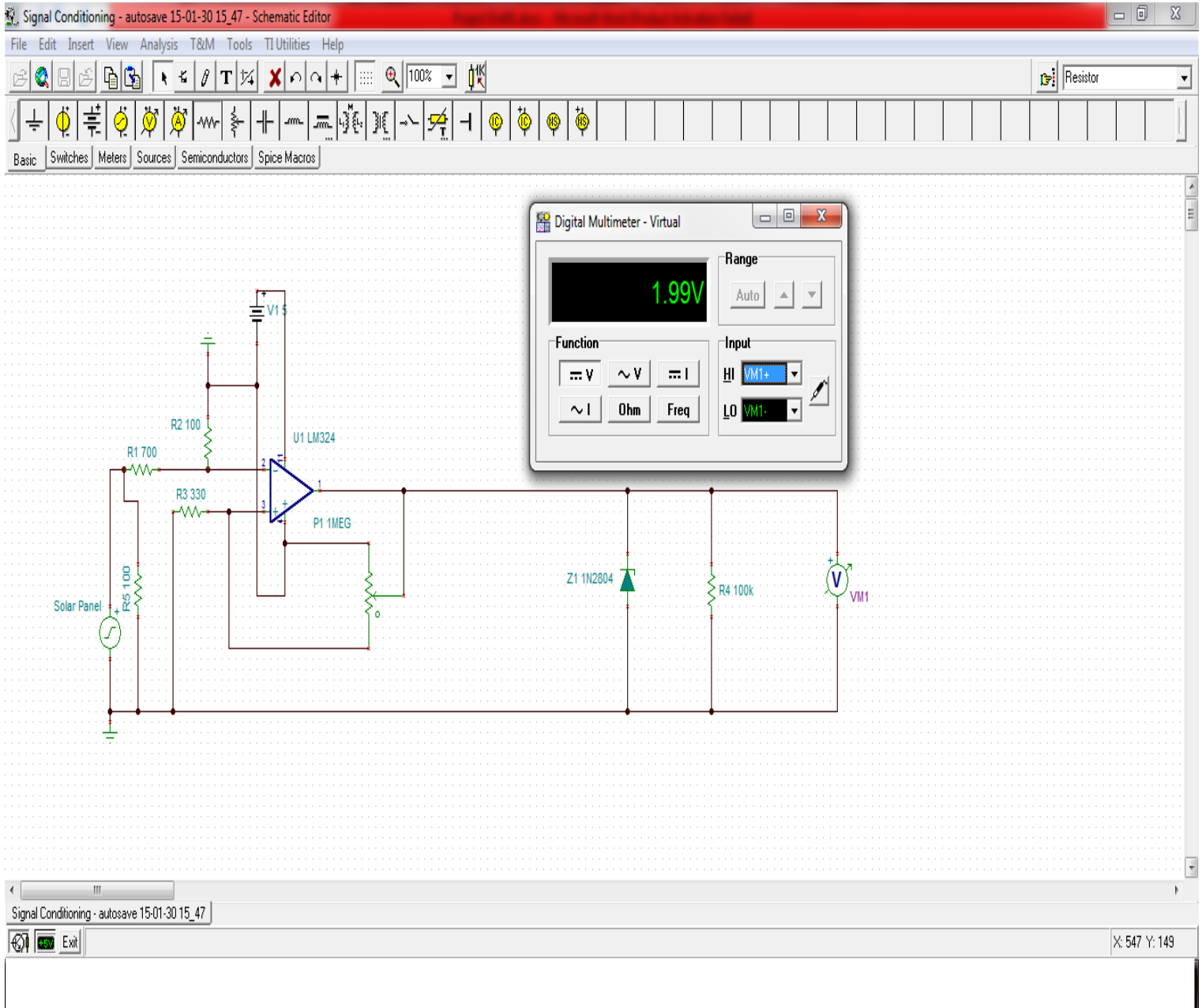


Fig 4.1: Signal Conditioning Simulation Results[From Tina TI Software]

The results in Fig 4.1. show the voltage output of 1.99Volts at a virtual multimeter for a maximum DC output voltage of 20 Volts from the solar panel. The maximum voltage the ADC

can handle is 2.5 V, and this shows that it is below the acceptable range for input to ADC of the microcontroller.

4.2. DC Transfer Characteristic

This shows that the input voltage was attenuated and for a maximum input voltage of 20 V from the solar panel, the maximum output from the circuit is 2.48 V which is acceptable for input to the ADC of the microcontroller.

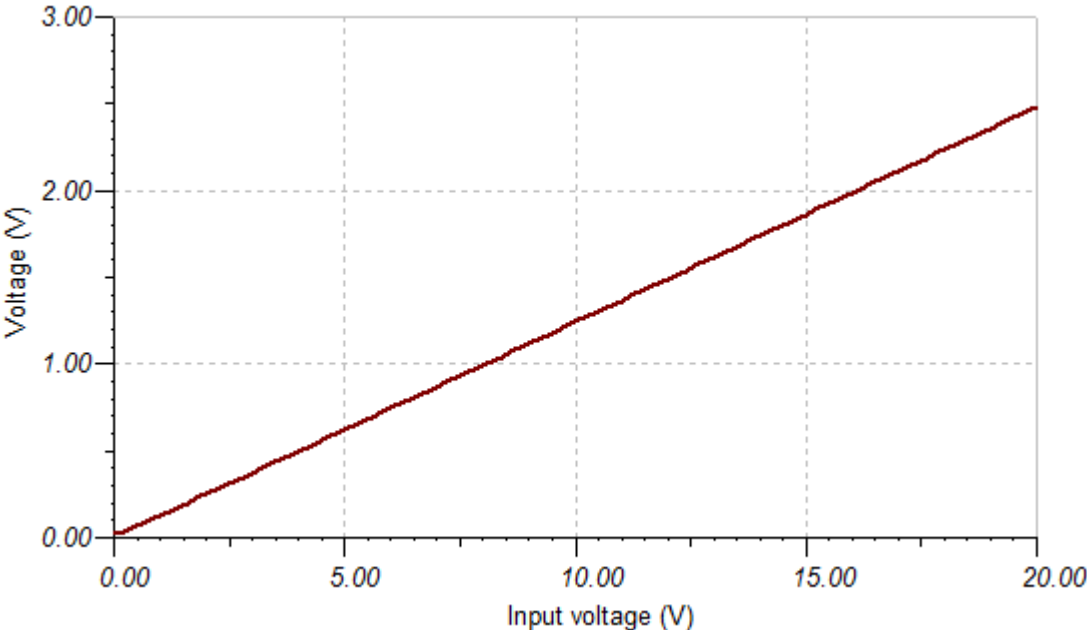


Fig 4.2: DC Transfer Characteristic[From Tina TI Software]

| Input Voltage (V) | Output Voltage (V) |
|-------------------|--------------------|
| 0 | 0 |
| 5 | 0.62223 |
| 10 | 1.24 |
| 15 | 1.86 |
| 20 | 2.48 |

Table 4.1: Signal Attenuation Analysis of Random Values

The signal was attenuated by a factor of 0.124.

4.3. PRACTICAL RESULTS

The figures below show the setup on the breadboard and Printed Circuit Board (PCB) respectively:

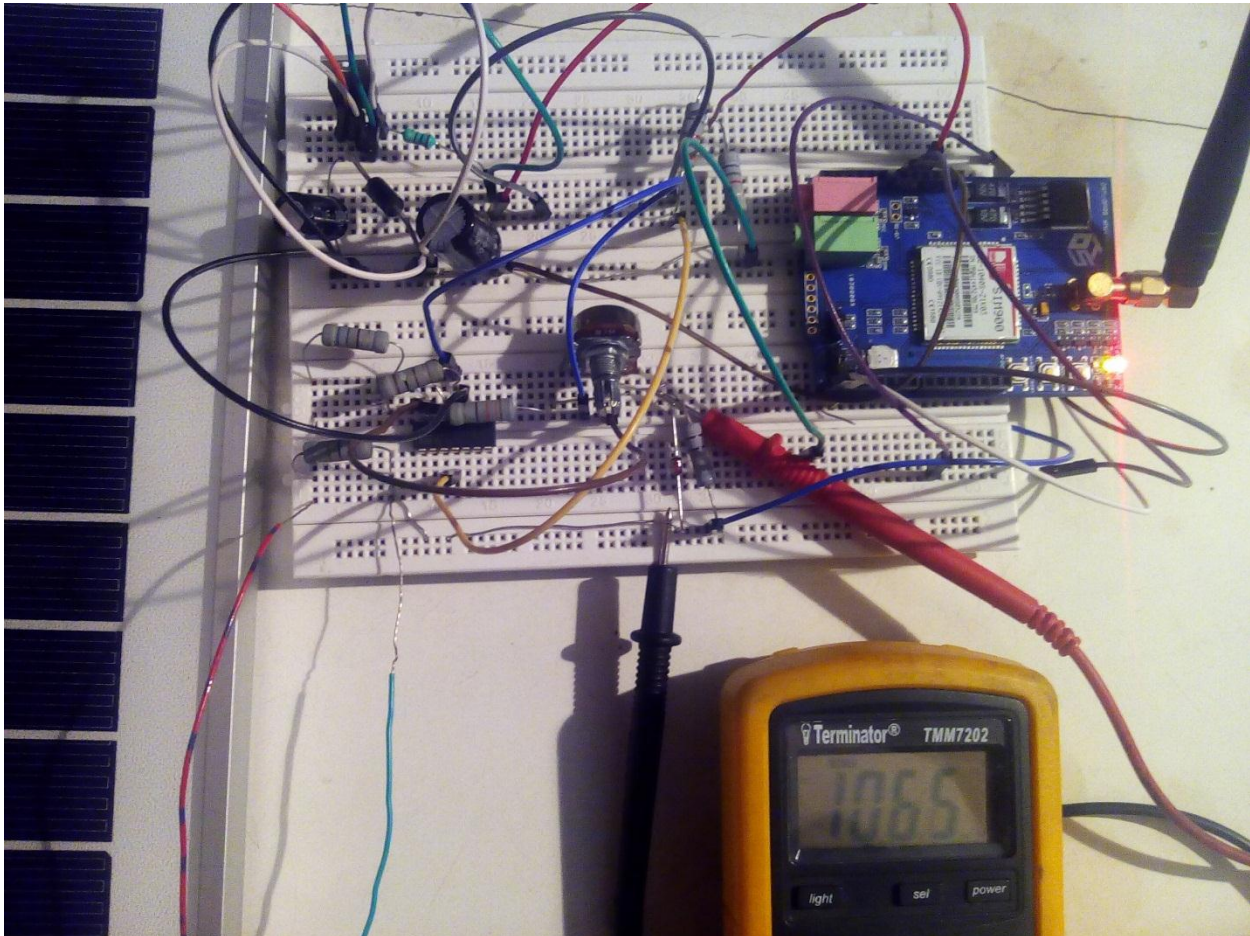


Fig 4.3: Setup on the breadboard

The multimeter in the figure above displayed a value of 106.5mV, which translated to 0.858Volts from the solar panel, after it was connected to the analogue output values from the signal conditioning circuit. This confirmed that the signal was attenuated by a factor of 0.124.

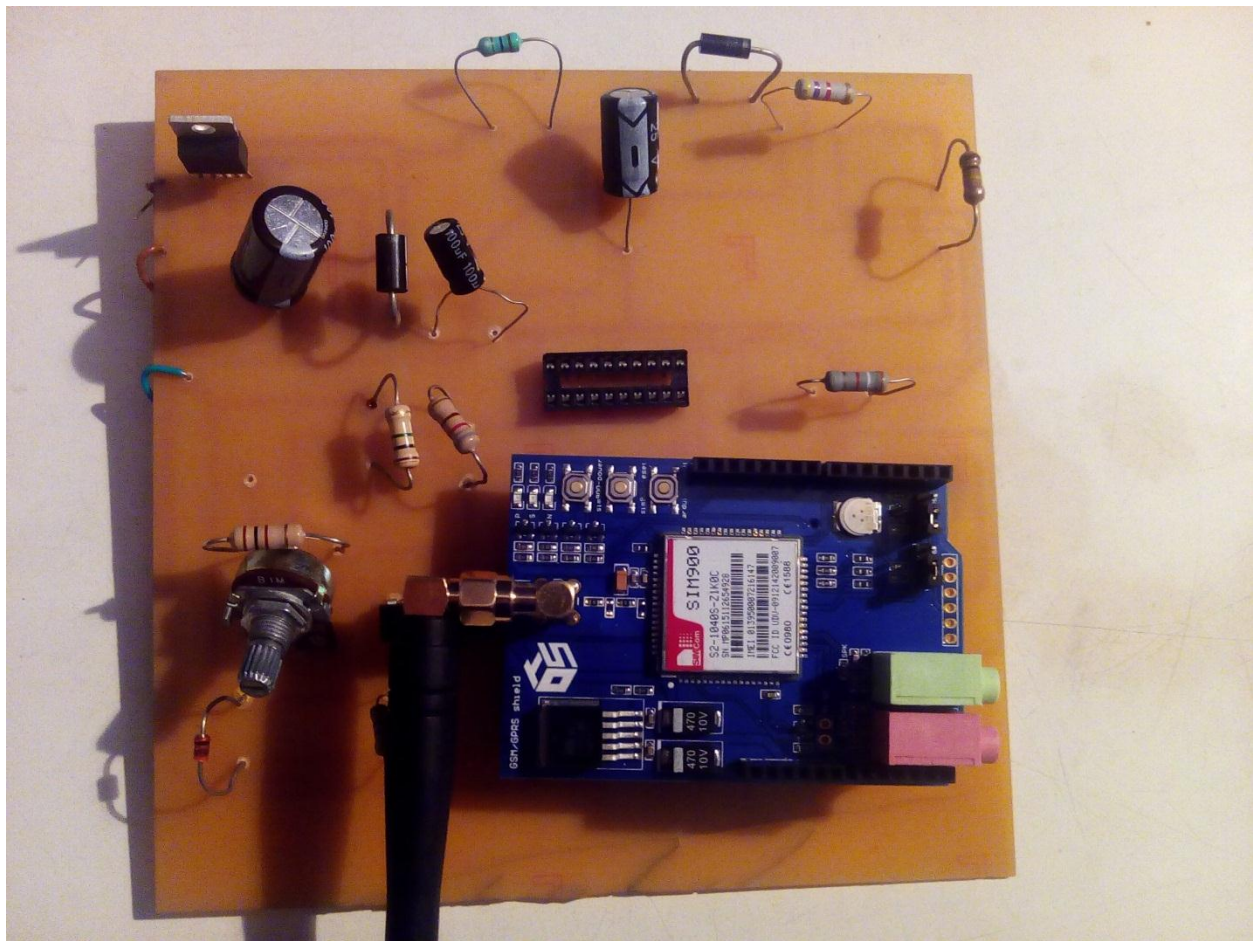


Fig 4.4: PCB diagram

The figure above shows the circuit soldered to the PCB.



Fig 4.5: Screenshot 1 of the Solar PV Monitor Database

The solar panel was producing an almost constant voltage of about 7 Volts under low light conditions. The current produced under these conditions was around 0.07Volts and power was around 0.54Watts. This showed that the solar panel was very effective even in low light conditions.

A clearer image of the same was downloaded from the website as shown below.

Voltage vs. Current vs. Power

Voltage in Volts, Current in Amps, Power in Watts



Fig 4.6: A graph of voltage vs current vs power outputs from a 20Watt solar panel under low light conditions.

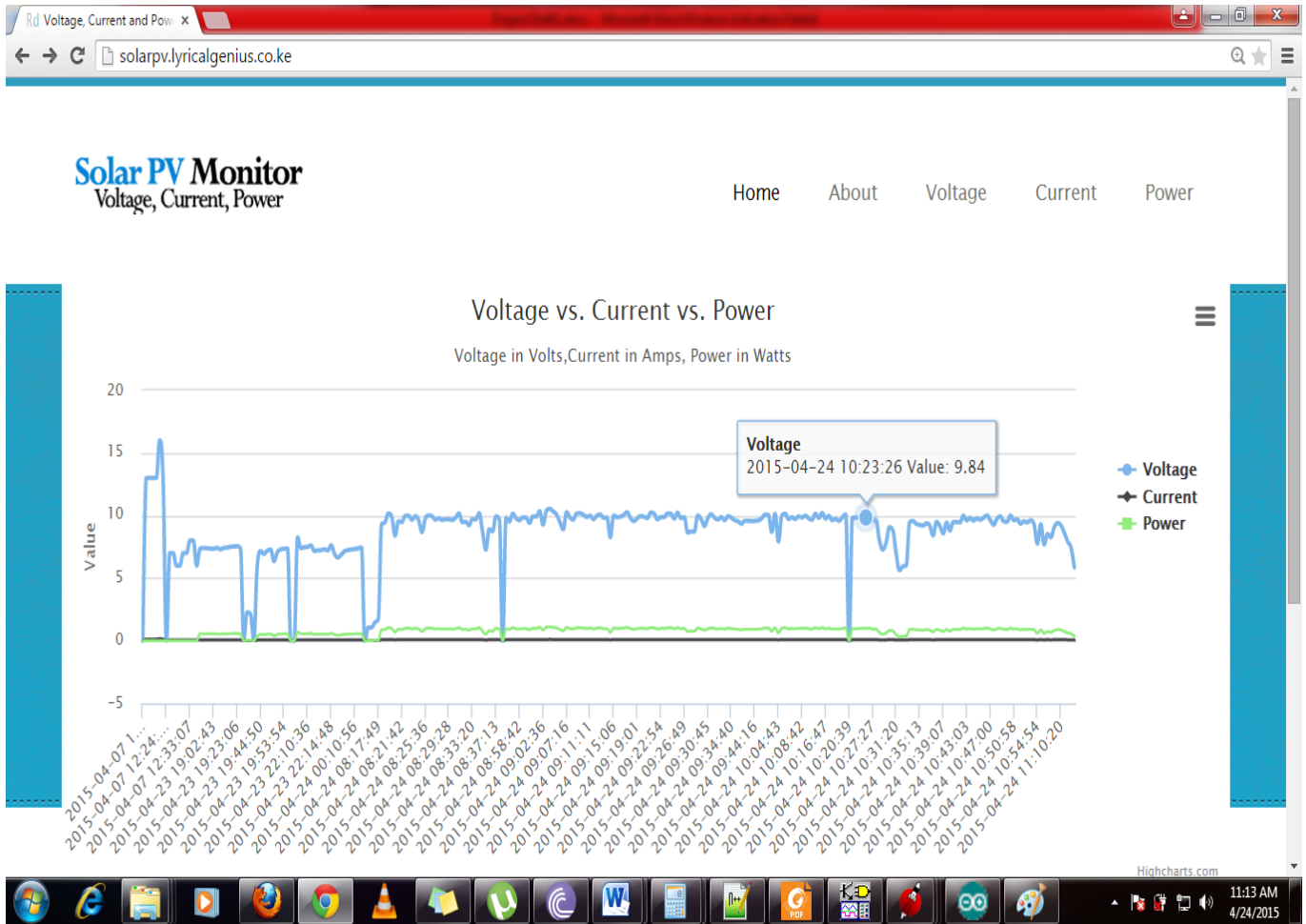


Fig 4.7: Screenshot 2 of Solar PV monitor database

The fig above shows data collected during the morning hours in a partly cloudy day. The output voltage from the solar panel was about 10Volts even in cloudy weather. The power output increased to about 1 Watt and current was about 0.1 Amps.

This showed that the output voltage from the solar panel increases with an increase in light intensity.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

A microcontroller based Solar PV Monitor was successfully implemented and was able to record the voltage from the solar panel and perform calculations to determine the values of current and power and store the results in a database.

It was observed that the solar panel used was able to produce a substantial amount of voltage under low light conditions and was thus very effective. It also produced an almost constant voltage when illuminated.

This system can be used in solar farms to monitor the output and with additional information of feed-in tariffs, can be used to calculate returns for the investor and predict future solar power outputs based on the trends recorded in the database.

5.2. RECOMMENDATIONS

- i. The system can be improved to do maximum power point tracking and record the data
- ii. The system can also be improved to give actual values of the returns per day by multiplying the daily yields by the feed-in tariffs.
- iii. The system can also alert the investor of the daily yields via a mobile phone application.

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APPENDIX A

This section includes the code that was used. The microcontroller code was written with Energia software from Texas Instruments for the MSP430.

Microcontroller Code

```
#include <stdio.h> //include the standard c library

#include <SoftwareSerial.h> //include the software serial library

SoftwareSerial sim900(P1_4, P1_3); //P1_4, P1_3 are the RX, TX software serial ports

float AnalogueSensorvalue=0; //Analogue Voltage value

int analogInPin2 = A7; // Analog sensor input is on pin A7

int trials; //set a counter trials

void setup()

{

    analogReference (INTERNAL2V5); //Set reference voltage as the internal reference 2.5V.

    Serial.begin(9600); // initialize serial communication at 9600 bits per second:

    sim900.begin(9600); // initialize the software serial port for sim900 at 9600 bits per second:

    //Check whether the GPRS module is powered on and responsive

    while(sendATcommand("ATE0", "OK", 2000)==0);

    while(sendATcommand("AT", "OK", 2000)==0);

    // Configuring gprs data bearer settings for the safaricom network

    while( sendATcommand("AT+SAPBR=3,1,\"Contype\", \"GPRS\", \"OK\", 2000)==0);
```

```
while( sendATcommand("AT+SAPBR=3,1, \APN\", \safaricom\", \"OK\", 2000)==0);
```

```
while(sendATcommand("AT+SAPBR=3,1, \USER\", \saf\", \"OK\", 2000)==0);
```

```
while( sendATcommand("AT+SAPBR=3,1, \PWD\", \data\", \"OK\", 2000)==0);
```

```
while (sendATcommand("AT+SAPBR=1,1", \"OK\", 20000) == 0);
```

```
}
```

```
void loop()
```

```
{
```

```
// Initializes HTTP service
```

```
int8_t answer;
```

```
answer = sendATcommand("AT+HTTPIPINIT", \"OK\", 10000);
```

```
if (answer == 1)
```

```
{
```

```
answer = sendATcommand("AT+HTTTPARA=\CID\",1\", \"OK\", 5000);
```

```
if (answer == 1)
```

```
{
```

```
sim900.print("AT+HTTTPARA=\URL\", \http://www.solarpv.lyricalgenius.co.ke/insert.php?");
```

```
Serial.println("Uploading data to server");
```

```

float AnalogueSensor=analogRead(A7);
float AnalogueSensor2=(AnalogueSensor*0.00244140625);
AnalogueSensorvalue=(AnalogueSensor2/0.124);
sim900.print("AnalogueSensorvalue="); //DATA feed name
sim900.print(AnalogueSensorvalue);

Serial.print(AnalogueSensorvalue);
Serial.print("\r\n");

delay(30000);

answer = sendATcommand("\", "OK", 5000);
if (answer == 1)
{

// Starts GET action
answer = sendATcommand("AT+HTTPACTION=0", "+HTTPACTION:0,200", 30000);
if (answer == 1)
{
Serial.println(F("Done!"));
}
else
{
Serial.println(F("Error getting url"));
}
}

```

```
}  
}  
else  
{  
Serial.println(F("Error setting the url"));  
}  
}  
else  
{  
Serial.println(F("Error setting the CID"));  
}  
}  
else  
{  
Serial.println(F("Error initializing"));  
}  
sendATcommand("AT+HTTPTERM", "OK", 5000);  
}
```

```
void send_HTTP();
```

```
int8_t sendATcommand(char* ATcommand, char* expected_answer1, unsigned int  
timeout)
```

```
{
```

```

uint8_t x=0, answer=0;

char response[100];

unsigned long previous;

memset(response, '\0', 100); // Initialize the string

delay(100);

while( sim900.available() > 0) sim900.read(); // Clean the input buffer

sim900.println(ATcommand); // Send the AT command

Serial.println(ATcommand); // Send the AT command

x = 0;

previous = millis();

// this loop waits for the answer
do
{
if(sim900.available() != 0){
response[x] = sim900.read();
x++;

// check if the desired answer is in the response of the module
if (strstr(response, expected_answer1) != NULL)
{
answer = 1;
}
}
}

```



```

}

// Waits for the answer with time out
}

while((answer == 0) && ((millis() - previous) < timeout));

Serial.println(response); // Send the AT command

return answer;

}

//

```

Server Software

This includes the server files used.

Db_connect.php – This code was used to connect to the database

```

<?php
session_start();

date_default_timezone_set('Africa/Nairobi');

$link = mysql_connect('localhost', 'lyricalg_solar', 'solarpv2015')
or die('Could not connect: ' . mysql_error());

//echo 'Connected successfully';

mysql_select_db('lyricalg_solarpv');

?>

```

Insert.php – This code was used to insert the analogue voltage and current value into the database

```

<?php

```

```

require('db_connect.php');

$voltage_value=$_GET['AnalogueSensorvalue'];
$current_value=($voltage_value/100);
$power_value=($voltage_value*$current_value);

$sql = 'INSERT into `sensor_values` (`voltage_value`, `current_value`, `power_value`)

VALUES (\'.$_GET['AnalogueSensorvalue'].'\', \'.$current_value.','\'. $power_value.\')';

echo $sql;

$result = mysql_query($sql);

?>

```

Index.php – This code was used to display the data on the website

```

<html lang="en-US" xmlns="http://www.w3.org/1999/xhtml" dir="ltr">
<head>
    <title>Voltage, Current and Power Monitor</title>
    <meta http-equiv="Content-type" content="text/html; charset=utf-8" />
    <link rel="shortcut icon" href="css/images/favicon.ico" />
    <link rel="stylesheet" href="css/style.css" type="text/css" media="all" />
    <!--[if IE 6]>
        <link rel="stylesheet" href="css/ie6.css" type="text/css" media="all" />
        <script src="js/png-fix.js" type="text/javascript"></script>
    <![endif]-->

```

```

<script src="js/jquery.jcarousel.js" type="text/javascript"></script>
<script src="js/js-func.js" type="text/javascript"></script>
    <script type="text/javascript" src="js/jquery-1.9.1.min.js"></script>
    <style type="text/css">
    ${demo.css}
    </style>
<script type="text/javascript">
$(document).ready(function() {
var options = {
    chart: {
        renderTo: 'container',
        type: 'spline',
        marginRight: 130,
        // marginBottom: 25
    },
    title: {
        text: 'Voltage vs. Current vs. Power',
        x: -20 //center
    },
    subtitle: {
        text: 'Voltage in Volts,Current in Amps, Power in Watts ',
        x: -20
    },
    xAxis: {

```

```
    categories: []
  },
  yAxis: {
    title: {
      text: 'Value'
    },
    plotLines: [{
      value: 0,
      width: 1,
      color: '#808080'
    }]
  },
  tooltip: {
    formatter: function() {
      return '<b>'+ this.series.name +'</b><br/>'+
        this.x +' Value: '+ this.y;
    }
  },
  legend: {
    layout: 'vertical',
    align: 'right',
    verticalAlign: 'top',
    x: -10,
    y: 100,
```

```
        borderWidth: 0
    },
    series: []
}
```

```
$.getJSON("data.php", function(json) {
    options.xAxis.categories = json[0]['data'];
    options.series[0] = json[1];
    options.series[1] = json[2];
        options.series[2] = json[3];
    chart = new Highcharts.Chart(options);
    //setTimeout("function(json)",5000);
});
});
</script>
```

```
</head>
```

```
<body>
```

```
<script src="js/highcharts.js"></script>
```

```
<script src="js/modules/exporting.js"></script>
```

```
<!-- Header -->
```

```
<div id="header">
```

```
    <div class="shell">
```

```
        <h1 id="logo" class="notext"><a href="#">Solar PV Monitor</a></h1>
```

```
        <div id="navigation">
```

```

        <ul>
            <li><a href="index.php" class="active"><span>Home</span></a></li>
            <li><a href="about.html"><span>About</span></a></li>
            <li><a href="voltage.html"><span>Voltage</span></a></li>
            <li><a href="current.html"><span>Current</span></a></li>
            <li><a href="power.html"><span>Power</span></a></li>
        </ul>
    </div>
</div>
</div>
<!-- End Header -->
<!-- Slider -->
<div id="slider" style="margin-bottom: 30px;">
    <div class="shell">
        <div id="container" style="min-width: 310px; height: 400px; margin: 0
auto"></div>
    </div>
</div>
<!-- End Slider -->
<!-- Main -->
<div id="main">
    <div class="shell">
        <div class="col">
            <h2>About this Project</h2>

```

```
<p>The project is generally about sending a Solar PV power, current and voltage parameters in real-time through a GSM to a web portal that plots the variations on a graph and stores the values in a database for reference</p>
```

```
<a href="about.html" class="find-more">find out more</a>
```

```
</div>
```

```
<div class="col">
```

```
<h2>The Team</h2>
```

```
<p>Vist the About Us page to find out more about me and the project
```

```
</p>
```

```
<div class="cl">&nbsp;</div>
```

```
<a href="about.html" class="find-more">find out more</a>
```

```
</div>
```

```
<div class="col last">
```

```
<h2>Contact Me </h2>
```

```

```

```
<p>To get in touch with me about this project visit the about me page
```

```
</p>
```

```
<div class="cl">&nbsp;</div>
```

```
<a href="about.html" class="find-more">find out more</a>
```

```
</div>
```

```
<div class="cl">&nbsp;</div>
```

```
</div>
```

```
</div>
```

```
<!-- End Main -->
```

```
<!-- Footer -->
```

```
<div id="footer">
```

```

<div class="shell">
    <p class="left">Copyright &copy; 2015 Solar PV Monitor</p>
    <p class="right">
        <a href="index.php">Home</a>
        <span>|</span>
        <a href="about.html">About</a>
    </p>
    <div class="cl">&nbsp;</div>
</div>
</div>
<!-- Footer -->
</body>
</html>

```

Data.php – This code was used to get the values from the database and display them on a graph using High Charts.

```

/**
 * Data feed from mysql table
 */
?>
<?php
require('db_connect.php');

mysql_select_db("lyricalg_solarpv", $con);

```



```
$sth = mysql_query("SELECT added_at FROM sensor_values");  
$rows3 = array();  
$rows3['name'] = 'Time';  
while($rrrr = mysql_fetch_array($sth)) {  
    $rows3['data'][] = $rrrr['added_at'];  
}
```

```
$sth = mysql_query("SELECT voltage_value FROM sensor_values");  
$rows = array();  
$rows['name'] = 'Voltage';  
while($r = mysql_fetch_array($sth)) {  
    $rows['data'][] = $r['voltage_value'];  
}
```

```
$sth = mysql_query("SELECT current_value FROM sensor_values");  
$rows1 = array();  
$rows1['name'] = 'Current';  
while($rr = mysql_fetch_assoc($sth)) {  
    $rows1['data'][] = $rr['current_value'];  
}
```

```
$sth2 = mysql_query("SELECT power_value FROM sensor_values");  
$rows2 = array();
```

```
$rows2['name'] = 'Power';  
while($rrr = mysql_fetch_array($sth2)) {  
    $rows2['data'][] = $rrr['power_value'];  
}  
  
$result = array();  
array_push($result,$rows3);  
array_push($result,$rows);  
array_push($result,$rows1);  
array_push($result,$rows2);  
  
print json_encode($result, JSON_NUMERIC_CHECK);  
  
mysql_close($con);  
?>
```

APPENDIX B

Bill of Quantities

| COMPONENTS | Cost(KSH.) |
|-----------------------------|------------------------|
| MSP430G2 Microcontroller | 4000 |
| GSM SIM900 Modem | 5000 |
| Solar Panel 20Watts | 3000 |
| Breadboard * 2 | 550 |
| PCB board (15cm*13cm) | Provided by Department |
| Resistors * 6 | 120 |
| Op-Amp, LM324 | 50 |
| Voltage Regulator, LM 2576T | 120 |
| 1 MEG Potentiometer | 50 |
| Diodes * 3 | 15 |
| Capacitors * 2 | 50 |
| Battery 12V | 1000 |
| Total | 14,125 |