Sudan University of Science and Technology

College of Engineering

Electrical Engineering

Optimized PV-Generator Hybrid System with the Local Grid

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A project Submitted In Partial Fulfillment for Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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October 2017

الايـة

قال تعالـي:

(قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ)

سورة البقرة (32)

DEDIECATION

We dedicate this research to our parents and our teachers, who taught us to think, understand and express. We earnestly feel that without their inspiration, able guidance and dedication, we would not be able to pass through the tiring process of this research, god bless them (Amen).

Also we dedicate to everyone who values and supports us physically and morally.

ACKNOWLEDGMENT

All praise is due to ALLAH Lord of all the worlds, the one god to whom praise is due forever.

We place on record and warmly acknowledge the continuous encouragement, invaluable supervision, timely suggestions and inspirited guidance offered by our guide Dr. Najm Eldeen.

We would also like to acknowledge with much appreciate the crucial role of the Energy Researches Center.

We are also thankful to whole electrical department for providing us the technical support to carry out the project work, to let us utilize all the necessary facilities of university and guidance at each & every step during the project work.

ABSTRACT

The development of any country or society depends on how sufficient electrical energy it has. Most of the energy needs of the world are being fulfilled by non-renewable sources of energy which it is in short supply and suffer from unreliability. Currently, the country is facing serious energy crisis with daily load shedding. This current scenario of load shedding affects the daily activities. Hence it is necessary to manage alternative way to fulfill electricity need.

This research focuses on improving the current system by implementing a hybrid system consisting of a combination of Photo Voltaic (PV) solar System, Fuel generator and the national grid for the power sources, and an energy management system for the control using the Arduino controller. The administration building in Sudan University of science and technology has been selected as a case study for this research. Before designing the system, it is necessary to create a load profile for the electrical devices and then size of the PV solar panels, the capacity of storage system, inverter type/size, and the suitable generator. Also the overall system will be simulated using Proteus simulator to show the different cases of the system.

The results show that the proposed hybrid power system can effectively ensure the reliability and Continuity of supply for the priority loads, reduce the monthly bills and consume less power from the utility grid.

المستخلص

تطور الدول والمجتمعات يعتمد على ما إذا كانت تمتلك القدر الكافي من الطاقة الكهربائية. ونجد أن مصادر الطاقة الرئيسية هي مصادر غير متجددة تفتقر للموثوقية. اذ انه في الوقت الحالي البلاد تعاني من ازمة طاقه تتمثل في القطوعات اليوميه المجدولة،هذه القطوعات المجدولة تؤثر علي الأنشطة اليومية.لذلك يجب التخطيط لطريقة بديله لتغطية احتياج الطاقة.

هذا البحث يركز علي تطوير النظام الحالي لتزويد الطاقة و ذلك بتمثيل نظام هجيني متكون من نظام الالواح الشمسة, ومولد يعمل بالوقود بالإضافة الى الشبكة القومية للكهرباء ،و نظام تحكم في الطاقه باستخدام المتحكمة أردوينو. تم اختيار مبني الاداراة في جامعة السودان للعلوم و التكنولوجيا كنموذج للدراسة في هذا البحث و لكن قبل تصميم النظام من الضروري معرفة إستهلاك الأجهزة الكهربائية في مبنى الادارة ثم تحديد سعة ألواح الطاقة الشمسية المناسبة و سعة نظام التخزين و نوع و حجم العاكس (للتحويل من تيار مستمر لتيار متردد) و تحديد سعة المولد المناسب.ايضا النظام كامل ستتم محاكاته باستخدام برنامج المحاكاة بروتوز لعرض حالات النظام المختلفة.

النتائح توضح ان النظام الهجيني يحقق الموثوقية و الاستمرارية في تغذية الاحمال المهمة في المبني ، و يقلل الاستهلاك من الشبكه القومية و بالتالي سيضمن تقليل فواتير الاستهلاك المدفوعة شهريا.

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LIST OF ABBREVIATIONS

SUST	Sudan University of Science and Technology
PV	Photovoltaic
AC	Alternating Current
DC	Direct Current
STC	Standard Test Condition
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
SCRs	Silicon Controlled Rectifier
IGBTs	Insulated-Gate Bipolar Transistor
PWM	Pulse Width Modulation
KW	Kilo Watt
MDOD	Maximum depth of Discharge
EMS	Energy Management System
VSC	Voltage Sensing circuit

LIST OF SYMBOLS

Ipv	Photocurrent delivered by the constant current source.
Rs	Series resistor in the actual PV cell circuit
Rsh	Shunt resistor that in the actual PV cell circuit.
I_{SC}	Short-circuit current
V_{OC}	Open-circuit voltage
Vmp	Voltage at maximum power point
Imp	Current at maximum power point
lm	lumen
Lux	one lumen per square meter (1 lux = 1 lm/m2)
LED	Light emitting diode
T_{min}	average sun hour per day
E_r	product of efficiencies of all components in the system to get the required energy
$\eta_{overall}$	The efficiencies of the system components
$\eta_{inverter}$	The efficiency of the inverter
Pp	the peak power
V_{dc}	DC- voltage of the system
I_{dc}	The total current of the module
Np	number of parallel modules
Ns	number of series modules
Ir	rated current of one module
V_r	rated voltage of each module
Erough	amount of rough energy storage required
H	number of hours per day
E	total power demand
C	capacity of the battery bank in ampere-hours

E_{safe}	the safe energy storage required
Vb	Voltage of one battery
F_{safe}	safety factor
Np	number of parallel units
Ns	number of series units
$N_{batteries}$	Number of batteries
$N_{controller}$	Number of voltage controllers
R1	Relay one
R2	Relay two
R3	Relay three
R4	Relay four

CHAPTER ONE

INTRODUCTION

1.1 Overview

Electricity has become a part of the modern life and one cannot think of a world without it. Sufficient and reliable source of electricity are the major conditions for a sustained and successful economic development. The rising rate of consumption, the price of fuels and the environmental problems causes by the conventional power generation draw worldwide attention to renewable energy technologies. In fact, renewable energy systems are pollution free, take low cost and social friendly. However, renewable power unit based on single source (wind or solar source) may not be effective in terms of cost, efficiency and reliability.

Researches on hybrid power systems combining renewable and fossil derived electricity started several years ago, but few have written papers about system implementation and experimental data collection. The first papers describing renewable energy hybrid systems appeared in the mid-eighties [1]. As both wind turbine and PV cells use renewable energy resources to generate electricity, the benefit of combining them into a single system can be significant. The combined system of many sources referred to as a hybrid system. In addition, the battery system, diesel engine can also work in parallel with such hybrid system to meet the load requirements. Initially, this expansion in hybrid literature was driven by the need to increase grid stability and reliability. Researchers then used optimization techniques to model how hybrid systems can reduce electricity generation costs over conventional fossil fuel systems [2].

The photovoltaic effect was first observed in 1839 by a French physicist, Edmund Becquerel. The history of photovoltaic energy (aka. solar cells) started back in 1876. In 1976, David Carlson and Christopher Wronski manufactured the first amorphous solar panel. And approximately 1.2 billion homes were using Solar by the 1990s; it was becoming more and more popular. In 2005, Professor Vivian Albert of South Africa invented thin film solar modules [3].

The diesel generator owes its roots to mainly two inventors, Michael Faraday the creator of first generator and Rudolph Diesel the creator of the diesel engine. Diesel generators of today are the better and improved versions of what was created. Rudolf Diesel was a German mechanical engineer and renowned inventor who revolutionized the engines of his day. In 1893 Rudolf Diesel created the internal combustion engine that worked by heated fuels. Michael Faraday was an English scientist who contributed immensely to the field of electromagnetism & electrochemistry. Faraday did not invent Diesel Generator or the diesel engine, however it was his invention of electromagnetic rotary devices formed the basis of electric motor technology which would later be the beginning of the generator. He built the first electromagnetic generator called the “Faraday Disc”, proving that rotary mechanical power can be converted into electric power .It used the electromagnetic principle discovered by Faraday to convert mechanical rotation into direct electric current [4].

1.2 Problem Identification

Electricity is the most necessary element for the educational institutes, but the educational institutes are facing a major problem of energy crisis due to load shedding and unreliable national grid, and it is not a very smart decision to mainly depend on the utility grid. So any important institutes have to depend on alternative sources of energy.

So in this research hybrid system will be represented in details for the administration building in Sudan University of science and technology

(SUST) to reduce the effects of load shedding and to reduce the dependency on the utility grid.

1.3 Objectives

The main objectives of the research is to improve and control a hybrid system for electricity generation instead of the conventional unreliable power generation in Sudan University of science and technologies. However, this objectives can be divided into other main sub-objectives:

- Reduce the monthly bills and consume less power from the utility grid.
- Using renewable energy (solar) as a first choice source for the priority loads.
- Minimize the effects of load shedding as low as possible.
- Ensure the reliability and Continuity of supply for the priority loads.
- Decrease the amount of fuel consumed by fuel generators and the number of hours that the generator will operate.

1.4 Methodology

The problem has been solved using Arduino to control the overall system. The simulation software Proteus was used to simulate the several possible cases of the case under study.

1.5 Project Layout

This research is organized in five chapters, chapter one (Introduction) gives General introduction about the research, besides problem statement, objectives of the study and methodology of the research. In chapter two (Literature Review), presents the review of solar system with a general view of the hybrid system and generators. Chapter three (system sizing) includes the suitable sizing of the solar system's components. Chapter four (design and simulation results) review the overall system and the connection between load and sources, also it includes the control system and the simulation of the overall system. Chapter five (conclusion) includes the conclusion and proposes recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Hybrid System

Combining several different types of power sources will form the system called "Hybrid Power system". Such system incorporates a combination of several renewable energy sources such as solar photovoltaic, wind energy and may be conventional generators for backup .A system using a combination of these different sources has the advantages of balance and stability that offers the strengths of each type of source that complement one another beside the power sources. In general, a hybrid system might contain AC diesel generators, DC diesel generators, an AC distribution systems, a DC distribution system, loads, renewable power sources (wind turbines, or photovoltaic power sources), energy storages, power convertors or load management control system [5].

There are two types of hybrid system, one is called a stand-alone system and the other is a grid connected system. Stand-alone systems are isolated from the electric distribution grid. It can be a PV or, wind turbine system or a combination of both the systems. The stand-alone power system is used primarily in remote areas where utility lines are uneconomical to install due to terrain, other difficulties, or environmental concerns. The figure 2.1 shows the stand alone or grid-off systems [6].

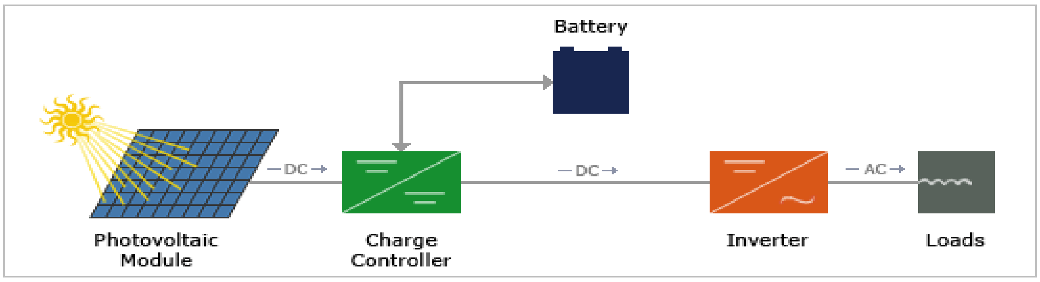

Figure 2.1: The stand alone or grid-off system

Grid-Tied or grid connected systems are directly coupled to the electric distribution network. Figure 2.2 describes the basic system configuration. Electric energy is either sold or bought from the local electric utility depending on the local energy load patterns and the solar resource variation during the day, this operation mode requires an inverter to convert DC current to AC current. [7]

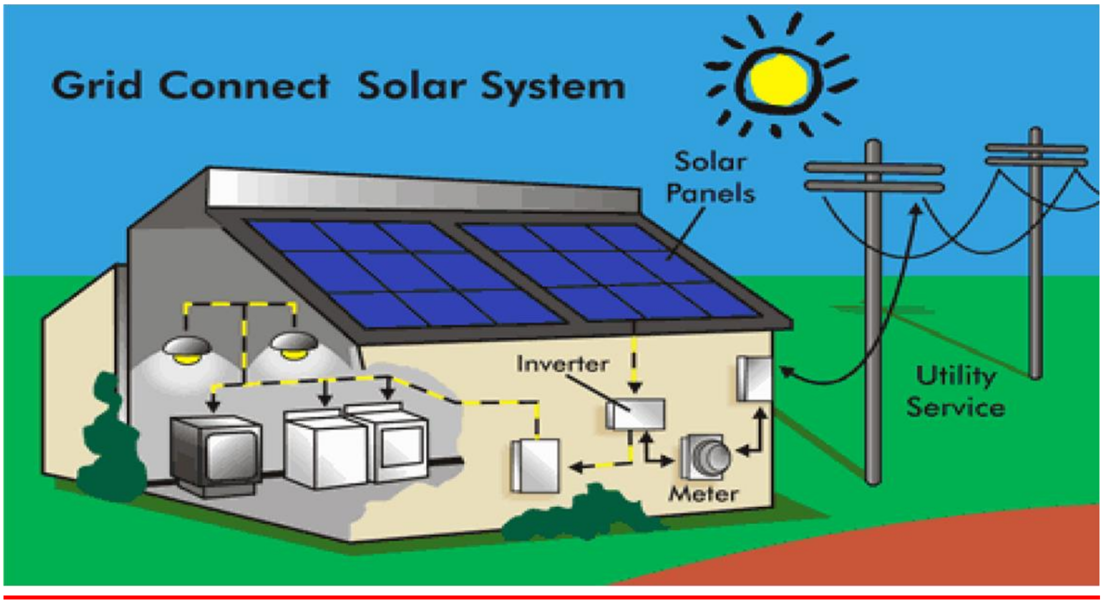

Figure 2.2: Grid tie or Grid connected system configuration.

2.2 Photovoltaic Energy

The term "photo" comes from the Greek word meaning "light" and the word "voltaic" was named after the Italian physicist Count Alessandro Volta, which means "electric". Hence, Photovoltaic describes the flow or generation of electric current from light [6].

Photovoltaic or PV system is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors materials like silicon [8]. Figure 2.3 shows a silicon arrangement.

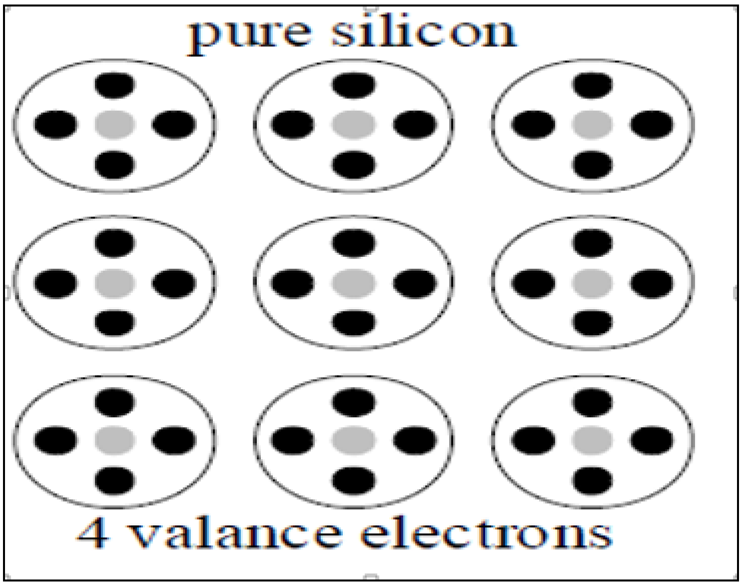

Figure 2.3: Representation of the silicon arrangement.

Described simply, the PV effect is as follows: Light, which is pure energy, enters a PV cell and imparts enough energy to some electrons (negatively charged atomic particles) to free them, a built-in-potential barrier in the cell acts on these electrons to produce a voltage (the so-called photo voltage), which can be used to drive a current through the circuit [9].

PV cells have one or more electric fields that act to force electron that are freed by light absorption to flow in a certain direction. This flowing of electron is a direct current (DC) and by placing metal contacts on the top and bottom of the PV cell, it can draw that current off to be used to supply the load [10]. Figure 2.4 shows the construction of a single photovoltaic cell.

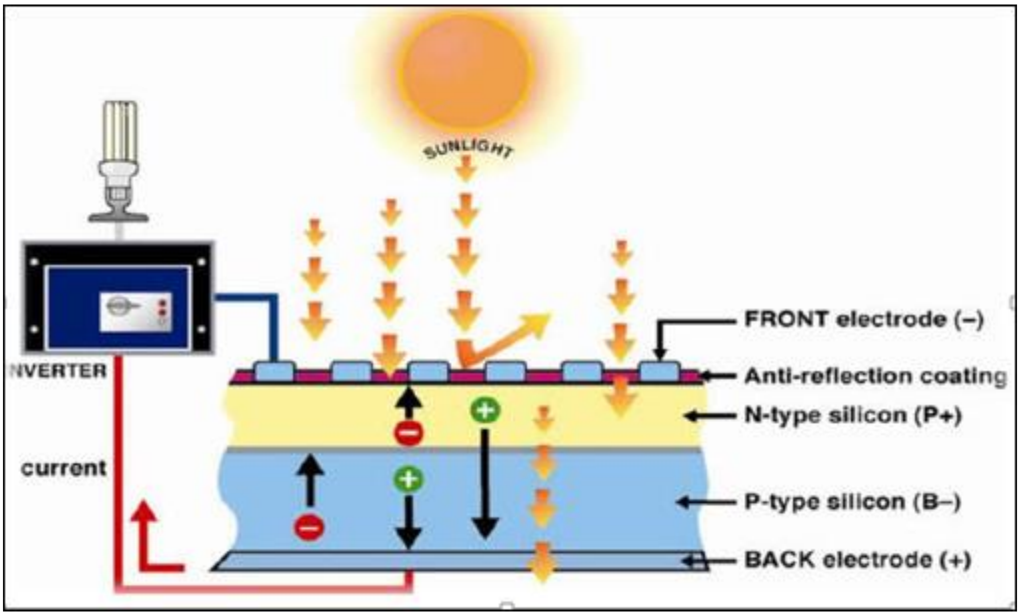

Figure 2.4: The Mechanism of a single Photovoltaic cell.

2.3 How PV Cell Produces Electricity

As in the figure 2.4, the generation of electric current happens inside the depletion zone of the p-n junction. The area around the p-n junction is called the depletion zone where the electrons from the "n-type" silicon, have diffused into the holes of the "p-type" material. Whenever a photon of light hits the surface and is absorbed by one of these atoms in the "n-type" silicon it will dislodge an electron, thus creating a free electron and a hole. The free electron and hole produced have sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (n-type silicon) to the anode (p-type silicon) electrons will flow (current) through the wire. The electron is attracted to the positive charge of the "p-type" material and travels through the external load creating a flow of electric current. The hole which is created by the freed electron is attracted to the negative charge of "n-type" material and drifts to the back electrical contact [11].

The amount of power produced by photovoltaic cells varies significantly on an hourly, daily and seasonal basis due to the variation in the availability of sun light and the temperature. This variation means that sometimes power is not available when it is required, and on other occasions there is excess power, so as long as light is shining on the solar cells, it generates electric power. When the light stops, the electricity stops. The electricity generated can be either stored or used directly, fed back into grid line or combined with one or more other electricity generators or more renewable energy source [12].

Some of the sunlight that strikes a solar cell is reflected. Normally, untreated silicon reflects 36% (or more) of the sunlight that strikes it. This would be a horrendous loss in terms of efficiency. Fortunately, there are several ways of treating cell surfaces to cut reflection drastically. Among them are chemically coating [13].

The PV cell has the following advantages for the generation of electricity:

- Very reliable and available almost everywhere in the world
- It emits no harmful gases and has no moving parts and hence there is no production of pollution or noise only electricity as its output.
- Unlike conventional power plants using coal, nuclear, oil and gas; solar PV has no fuel costs and relatively low operation and maintenance costs.
- Can suit a wide range of applications such as residence, industry, agriculture, etc.
- In terms of maintenance they require very less maintenance.

2.4 Photovoltaic Module and Array

The solar cell is rarely used individually because it is not able to supply an electronic device with enough voltage and power, it produces approximately 0.5 volt DC, and so it can supply small loads like calculators or watches. For this reason, a number of solar cells are electrically connected in parallel or in series in order to achieve as higher voltage and power output as possible, which called a photovoltaic module, figure 2.5 shows the formation of the solar cell from cell to array. The current produced is directly dependent on how much light hits the module .Cells connected in series increase the output voltage , while cells that connected in parallel increase the amount of the current .The solar array or panel is a group of several modules electrically connected in series-parallel combination to generate required current and voltage and hence the power [10,14].

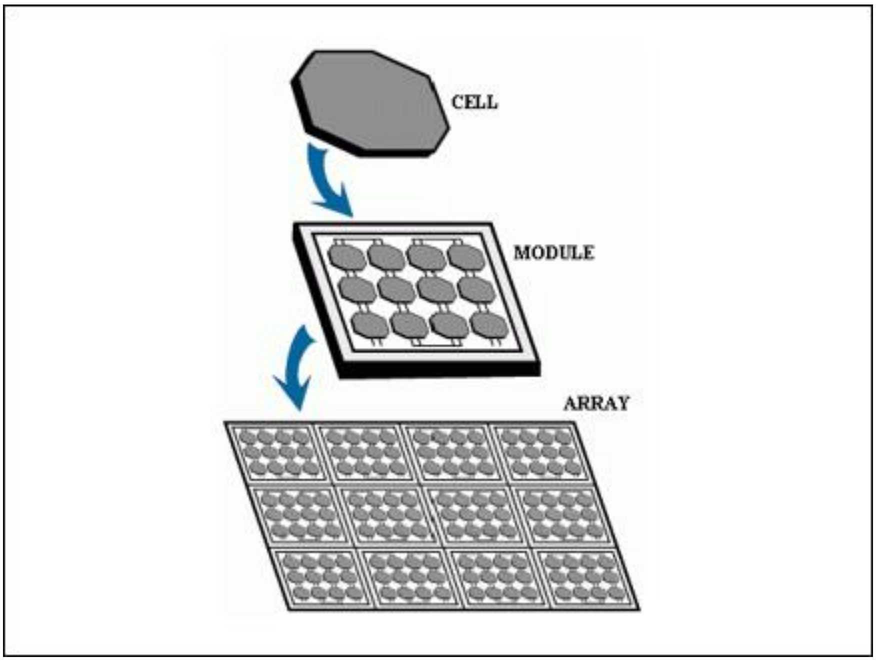

Figure 2.5: The formation of a PV array from cell to array.

2.5 Types of Photovoltaic Module

The type of module is determined by the cells that compose the module itself. There are three common cell technologies.

2.5.1 Mon-crystalline

As the name implies, these are cells that are grown from a single crystal. The production methods are difficult and expensive. These tend to be more efficient (more power in less area) and more expensive [15, 16].

2.5.2 Multi-crystalline

The production process allows multiple crystalline structures to develop within the cell. It is easier to implement in a production line. It is relatively cheaper than mono-crystalline at the expense of lower efficiency [15, 16].

2.5.3 Thin-film

Uses less silicon to develop the cell (hence the name thin film) allowing for cheaper production costs .But it has also lower efficiency [15, 16].

2.6 Standard Test Conditions of PV Modules

The term Irradiance is defined as the measure of power density of sunlight received at a location on the earth and is measured in watt per meter square [17].

PV modules are rated on the basis of the power delivered under Standard Testing Conditions (STC). The Standard Testing Conditions defined as a total irradiance of 1000W/m^2 and an ambient temperature of 25 ^{o}C, which is used to define modules rating [18]. Their output measured under (STC) is expressed in terms of “peak Watt” or WP nominal capacity [9].

2.7 Efficiency of PV Modules

The overall efficiency of the module will depend on the cell efficiency and placement within the module, and on the laminating materials used. Typical module efficiencies range between 11% and 17% for crystalline technologies at STC, most of the commercially available modules are in the lower bound of this range. Thin-film module efficiencies range between 6% and 12% [18].

2.8 Solar Cell Equivalent Circuit

The characteristics of a PV cell can be explained by creating an equivalent circuit for the solar cell. An ideal solar cell may be modelled by a current source in parallel with a diode. The diode represents the p-n layer and the current source represents the current which is generated by the photons, and its output is constant under constant temperature and constant incident radiation of light. Figure 2.6 shows the ideal circuit of the PV cell [11, 19].

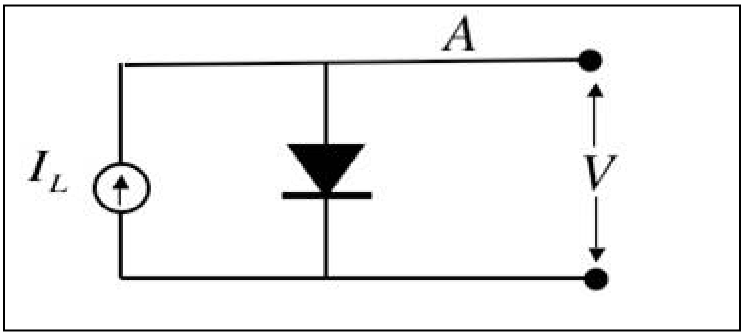

Figure 2.6: The Ideal circuit of the PV cell

In practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model as shown in figure 2.7, to create the equivalent circuit.

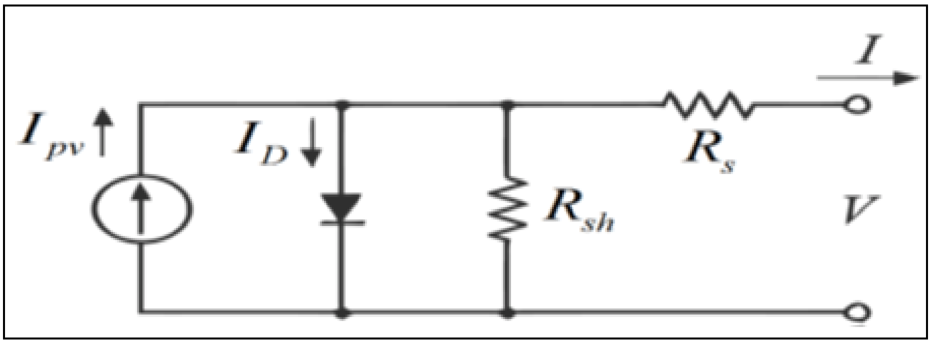

Figure 2.7: The Actual circuit of the PV cell.

2.9 I-V and P-V Curves of the PV module

Current-voltage (I-V) curve is obtained by exposing the cell to a constant level of light, while maintaining a constant cell temperature, varying the resistance of the load, and measuring the produced current. When an I-V curve is drawn it normally passes through two points

2.9.1 Short circuit current (I_{SC})

This is the current produced when the positive and negative terminals of the cell are short-circuited, and the voltage between the terminals is zero, which corresponds to zero load resistance.

2.9.2 Open circuit voltage (V_{OC})

This is the voltage across the positive and negative terminals under open-circuit conditions, when the current is zero, which corresponds to infinite load resistance. Figure 2.8 shows a typical I-V curve and the P-V curve. When the voltage and the current characteristics are multiplied, the P-V characteristic is produced. The point indicated as MPP is the point at which the panel power output is max [11].

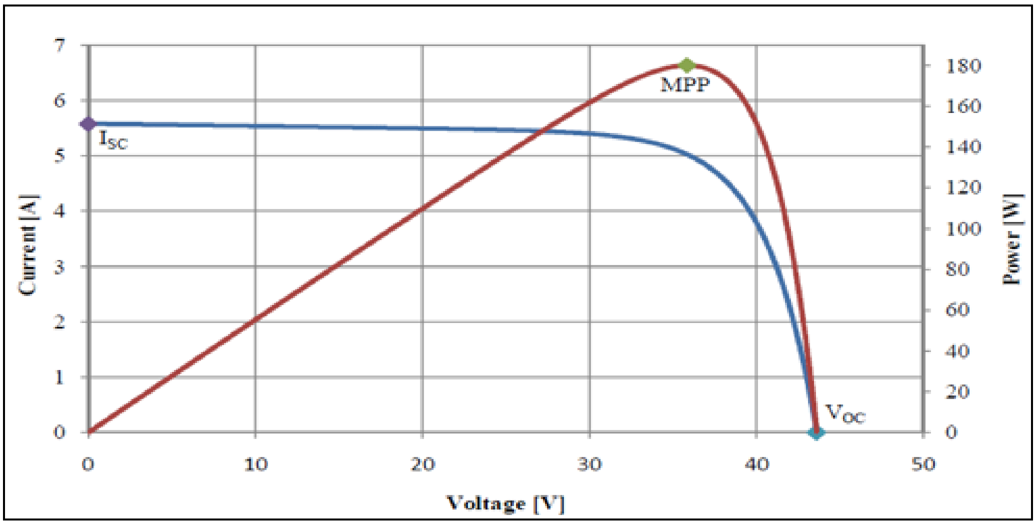

Figure 2.8: The I-V and P-V curves of a photovoltaic device at a constant temperature and irradiance.

Referring to figure 2.8, the span of the I-V curve ranges from the short circuit current (Isc) at zero volts, to zero current at the open circuit voltage (Voc). At the 'knee' of a normal I-V curve is the maximum power point (Imp, Vmp), the point at which the array generates maximum electrical power. The voltage and current corresponding to this point are peak point voltage and peak point current. There is one point on the curve that will produce maximum electrical power under incident illumination level. Operating at any other point other than maximum power point will mean that cell will produce less electrical power [17].

2.10 Effect of Irradiance and Temperature

Two important factors that have to be taken into account are the irradiation and the temperature. As the solar isolation keeps on changing throughout the day similarly I-V and P-V characteristics varies. As a result, the maximum power point (MPP) varies during the day, and that is the main reason why the MPP must constantly be tracked and ensure that the maximum available power is obtained from the panel [16].

The photo-generated current is directly proportional to the irradiance level like as shown in figure 2.9, so an increase in the irradiation leads to a higher photo-generated current [17, 16].

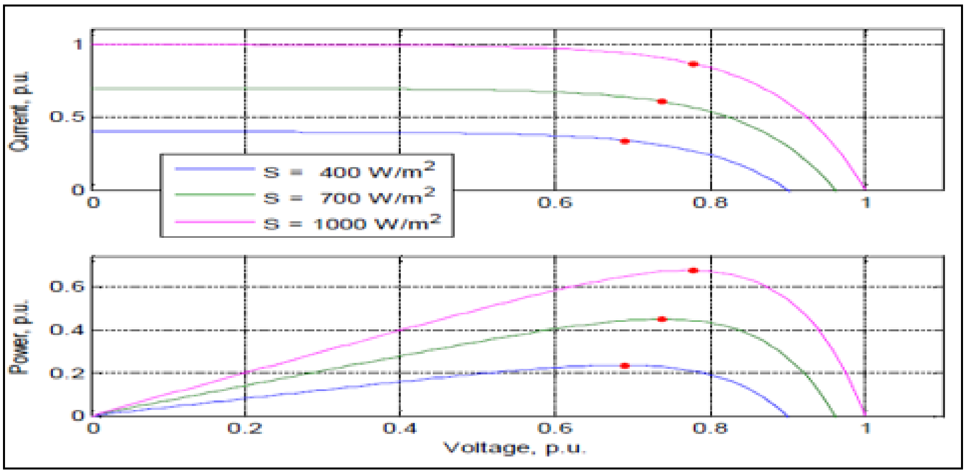

Figure 2.9: The IV and PV curves for different irradiation levels.

With the increase in solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies, but the increase in the voltage is marginal not like the increase in current. The temperature, on the other hand, affects mostly the voltage. So it leads to marginal changes in current but major changes in voltage. Temperature acts like a negative factor affecting solar cell performance. As in figure 2.10 below, the effect of the temperature on VOC is negative. When the temperature rises, the voltage decreases and the current increases with the temperature, but very little and it does not compensate the decrease in the voltage caused by a given temperature rise. That is why the power also decreases. Therefore solar cells give their full performance on cold and sunny days rather on hot and sunny weather. PV panel manufacturers provide in their data sheets the temperature coefficients, which are the parameters that specify how the open circuit voltage, the short circuit current and the maximum power vary when the temperature changes. As the effect of the temperature on the current is really small, it is usually neglected. Figure 2.10 shows the effect of temperature on the PV panel at constant irradiance, the curves are again in per unit [17, 16].

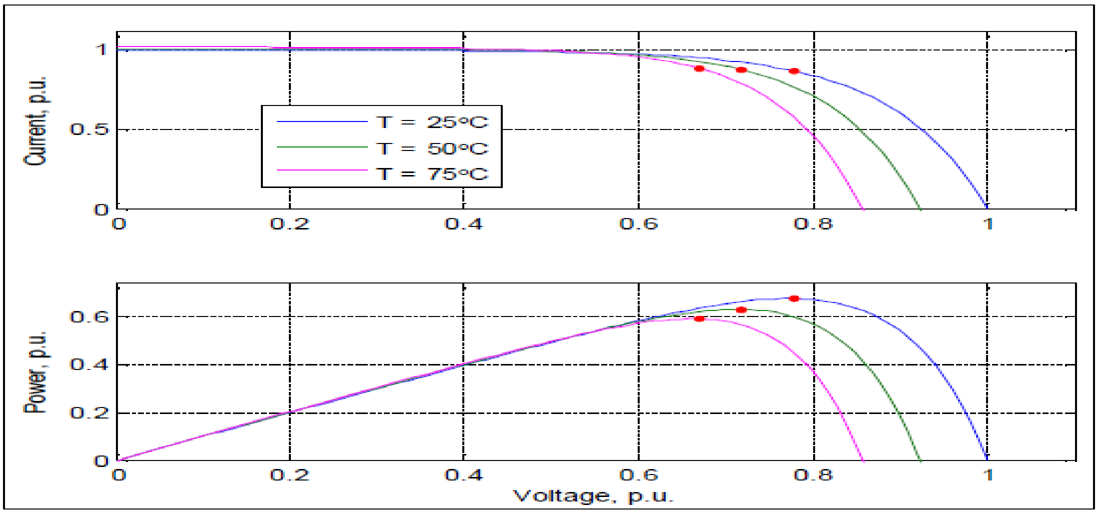

Figure 2.10: The IV and PV curves for different temperature levels at constant irradiation level.

2.11 Maximum Power Point Tracker (MPPT)

As was previously explained, the MPP of a solar panel varies with the irradiation as in figure 2.9 and temperature as in figure 2.10. And in order to continuously harvest maximum power from the solar panels, they have to operate at their MPP independently of changes in the environment. So the use of Maximum power point tracker algorithms is required in order to obtain the maximum power from a solar array. Different algorithms have been developed to achieve MPPT control ,some achieve more than 98% of the PV array output capacity .Nominal voltage and current conditions will not be available from the PV array at all times due to constant changes in solar irradiance . With this in mind, many maximum power point tracking algorithms have been developed, and much research has been carried out to optimize the various techniques [20].

In a PV system, many PV modules are often connected in series and/or parallel to provide a system with the required voltage and feeding current capacity. As a result, partial shading is typically inescapable because some parts of the array or the PV system receive low solar irradiance because of shadows of clouds, trees, buildings, and other neighboring items. Partial shading significantly influences the efficiency of the output of PV systems depending on the system architecture and shading scheme. Under these conditions, a PV module that belongs to the same string receives different insolation. The output P–V characteristic curve becomes complicated and consequently yields a multiple-peak curve. The emergence of multiple peaks in the output characteristics of PV systems reduces the efficiency of ordinary MPPT methods, assuming that an individual maximum power point (MPP) exists on the P–V characteristic. These techniques are based on “hill-climbing” theory to shift the following operating point in the direction where the output power is optimized. These strategies obtain only a local MPP because the P–V curve is multimodal [21].

2.12 Solar Inverter

Inverters are electronic solid-state devices used to transform electric energy from DC to AC [10]. A solar inverter or PV inverter converts the variable direct current (DC) output of a battery or a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can supply individual AC loads. The primary switching elements of the inverter are either silicon controlled rectifiers (SCRs) or power transistors (IGBTs). They are arranged in a bridge circuit and switched on (and off, in the case of transistors) in such a way that an oscillating waveform results [22].

There are different typs of inverters that can be divided depending on how the PV modules are connected to the inverter and according to the type of the system. The decision on what configuration should be used has to be made for each case depending on the environmental and financial requirements [23].The classification of the inverters according to the type of the system as flow.

2.12.1 Stand alone inverters

These inverters are meant to operate isolated from the electrical distribution network and require batteries for proper operation. The batteries provide a constant voltage source at the DC input of the inverter.

2.12.2 Grid Tied inverters

These inverters operate coupled to the electric distribution network and therefore must be able to produce almost perfect sinusoidal voltages and currents. The operating requirements for these types of inverters are in most cases determined by the local utilities.

Some stand-alone inverters can also be operated as grid-tied inverters or in combination with other renewable energy sources as part of hybrid power systems. Modern inverters can achieve efficiencies higher than 95% (especially grid-tied inverters) and are warranted for 5 to 10 years in most cases. Most inverters have efficiencies above 85% [24].

2.13 Batteries

Energy storage has been the most challenging and complex issue of the industry whether it is in electric utilities or for industrial applications. The new and evolving applications are seen in hybrid vehicles, electric utility storage, portable electronics and storage of electric energy produced by renewables like solar or wind generators. The constant need for efficient energy storage has seen the emerging new technologies which promise reliability, productivity and the use of renewables. Energy storage can balance the fluctuations in supply and meet the ever growing demand of electricity. For short duration requirements battery storage can bring stability and for longer duration requirements they can bring about energy management. Storage also can be used to complement primary generation as they can be used to produce energy during off peak periods and this energy produced can be stored as reserve power [25].

2.14 Solar charger controller

A solar charger controller is a device needed for monitoring and controlling the charging of battery bank connected to the PV modules. Charge controllers are part of the electrical equipment costs. These control the current flow from the PV array to the battery in order to ensure proper charging. These controllers disconnect the PV array from the battery whenever produced energy exceeds battery storage capacity or the load whenever charge levels are dangerously low or reach a certain threshold. It is common for charge controllers to monitor battery voltage, temperature, or a combination of both to determine depth of discharge. The controllers extend battery life and are a safety requirement of the National Electrical Code (NEC) for residential and commercial installations. It is important to select a proper charge controller and controller settings for the battery type selected for the system. Some controllers can be adjusted to accommodate different battery types; some are built for specific battery technologies [26].

A solar charge controller is available in two different technologies, PWM and MPPT. How they perform in a system is very different from each other. An MPPT charge controller is more expensive than a PWM charge controller, and it is often worth it to pay the extra money.

2.14.1 PWM Solar charge controller

A PWM Solar charge controller stands for “Pulse Width Modulation”. When a solar array is connected to the battery through a PWM charge controller, its voltage will be pulled down to near that of the battery. This leads to a suboptimal power output wattage (Watt = Amp x Volt) at low and at very high solar cell temperatures. In times of rainy or heavily clouded days or during heavy intermittent loads a situation may occur where the battery voltage becomes lower than is normal. This would further pull down the panel voltage; thus degrading the output even further. At very high cell temperatures the voltage drop off point may decrease below the voltage needed. The PWM charge controller is therefore a good low cost solution for small systems only, when cell temperature is moderate too high (between 45° C and 75° C) [20].

2.14.2 MPPT solar charger controller

A MPPT solar charger controller stands for “Maximum Power Point Tracking”. It will measure the Vmp voltage of the panel, and down-converts the PV voltage to the battery voltage using DC to DC converter. Because power into the charge controller equals power out of the charge controller, when the voltage is dropped to match the battery bank, the current is raised [21].

2.15 Fuel Generator

The diesel generator for example consist of three main functional units: a diesel engine, a synchronous generator with voltage regulator, and a governor (device which automatically regulates speed). The diesel engine is normally connected directly to a synchronous generator. A voltage regulator ensures the proper voltage is produced. The frequency of the AC power is directly proportional to the engine speed, which in turn is controlled by the governor [22].

Diesel generating sets are used in places without connection to a power grid, or as emergency power-supply if the grid fails, as well as for more complex applications such as grid support [4].

CHAPTER THREE

SYSTEM SIZING

3.1 Introduction

The system that will be implemented has the advantages of the two types of hybrid systems (stand alone and grid tie system). The system behaves like grid tie system when the grid is available, and it takes some of the load from the utility grid. However, it behaves like a standalone system when the utility grid is off. The system will be consisting of three power sources, which are: the unreliable utility grid, photovoltaic system, and an AC backup generator. The loads that the sources of the system are willing to serve are classified into two types depending on the importance of the loads, that is to ensure that the work and the worker at the chosen institute will not be affect by the loss of one source or in some cases loss of two sources of the mentioned supply sources. The administration building in Sudan University of science and technology (SUST) is used as a case study of this research, this building has been selected according to its importance and it sensitivity to the cutout of the electricity

The proper sizing of the system is made based on load profile and according to the maximum capacity. The electrical devices available in administration building are itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt hour per day .The total average energy consumption is used to determine the required equipment sizes and ratings starting with the solar array and ending with the sizing of the proper generator. Also the energy consumption will be improved by replacing the present lighting system by more efficient one which will fulfill the world standard, and hence the overall system will be improved.

3.2 The Total Loads of the Present System

The administration building has the electrical devices shown in table 3.1.

Table 3.1: Loads of the administration building

Loads	**Number**
Computers and their LCD screens	33
Lighting(4feet)	150
Fans	22
Lighting(2feet)	34
HP LaserJet 1012 printer	6
Microphone SSB-60 EM	1
Air condition	14
Large Printer	1
Sockets	35
Television	1
Heater	1
Coolers	1
Refrigerator	1

As shown in table 3.1, the present system uses different types of lamps and each one has low quality with low light intensity and short lifetime .Also it was found that more lamps are installed in a small space, so they consume more power due to their excessive number. Therefore, before starting the sizing of the system, the lighting system must be improved based on the international standard.

3.3 The Loads of the Improved System

Utilities bill their customers in a variety of ways, including an energy use charge, demand charge, power factor charge and other charges. But the focus in this section on reducing energy consumption.

Energy Consumption (kWh) = Input Watts (kW) x Time (hours operated in a given year)

To reduce energy consumption, therefore, we can either reduce the input wattage or reduce the hours of operation. Input wattage can be reduced by replacing lamps with more energy efficient, more quality and longer life time counterparts. A lighting upgrade is any strategy that reduces the system's energy use. Also the Energy savings are realized over time.

3.3.1 Light intensity

A lumen (symbol lm) is a standardized unit of measurement of the total amount of light that is produced by a light source, such as a lamp or tube (or LED).

Lux is a standardized unit of measurement of light level intensity (which can also be called "luminance" or "illumination"), which basically means it's a measurement of how much light there is over a given surface area. One Lux is equal to one lumen per square meter (1 lux = 1 lm/m2). The difference between the unit’s lumen and lux is that the lux takes into account the area over which the luminous flux is spread. So lux = lumens/m2, and 1000 Lumens, spread out over ten square meters, produces an luminance of only 100 Lux.

The certain amount of brightness needed for any place depends on the type of activity in that place, indoor or outdoor and the area of the place, so in this research both the offices and the meeting room of the administration building needs different amount of brightness (lux), and the right amount of lux will be chosen according to the Egyptian standard, which equal 300 lm/m^2 for the meeting room and between 300 to 500 lm/m^2 for the offices.

3.3.2 The software programs Dialux and Philips catalogue

Dialux is a software program which can be used to design, calculate and visualize light professionally for single room, whole floors, buildings and outdoor scenes. Dialux is used as a planning tool which meets the requirements of modern lighting design and lighting calculation. To obtain the best results Dialux is used with some of the light manufacturer's catalogue like Philips catalogue. So the present lighting system will be improved with the help of Dialux and Philips catalogue, where a suitable type and number of lamps and their specifications will be determined for each room (office room and the conference room), but first the area and the suitable amount of lux (according to the Egyptian standard) will be entered to the program and the following results were obtained.

3.3.3 Specifications of the right lamps

The length of the small offices is taken 5m and the width is 4m. The suitable amount of lux 300 lm/m^2, and according to the programs it needs 4 lamps for each office, type: PHILIPS SP533P L1450 1 xLED33S/830, where it consumes 32 watt and gives 3300 lm.

The length of the larger offices is taken 6m and the width is 5m. The suitable amount of lux 450 lm/m^2, and according to the programs it needs 9 lamps for each office, type: PHILIPS SP533P L1450 1 xLED33S/830, where it consumes 32 watt and gives 3300 lm.

The length of the meeting room is taken 8m and the width is 4m. The suitable amount of lux 300 lm/m^2, and according to the programs it needs 4 lamps for each office, type PHILIPS SP533P L1450 1 xLED33S/830, where it consumes 32 watt and gives 3300 lm.

Table 3.2 shows the total load after improving the lighting system, which will be used to design the hybrid system.

Table 3.2: Loads after improving the lighting system

Loads	**Number**
lighting	100
Computers and their LCD screens	33
Fans	18
HP LaserJet 1012 printer	6
Microphone SSB-60 EM	1
Air condition	14
Large Printer	1
Sockets	35
Television	1
Heater	1
Coolers	1
Refrigerator	1

3.4 Classification of Loads

As shown in table 3.2, there are different types of electrical devices, and some of them are more important than the others when the electricity is not available, hence the loads are divided into two types according to their importance in the building as flow.

3.4.1 Important loads

These loads should not be turned off in any case .the solar system is designed to serve these loads as its primary load, also the other sources can serve them when the solar system is not available. The important loads are connected to an individual bus-bar named important bus-bar. Lights and computers are examples of the important loads. Table 3.3 shows the important loads in the administration building.

Table 3.3: Important loads in the administration building

Loads	Total number	Watt per device	Hours	KWh
Computers and their LCD screens	33	115	9	34.12
Lighting	100	32	9	28.8
HP LaserJet 1012 Printers	6	250	3	4.5
Microphone SSB-60 EM	1	160	3	0.48
Summation		8655		67.9

3.4.2 Less important loads

these loads are bigger than the important loads and they are served only be the grid .they are less important and the work at the institute will not be affected if the loads are turned off. The Unimportant loads are connected to an indivitual bus-bar named less important bus-bar.Air conditions is an example of the less important loads. Table 3.4 shows the less important loads in the building.

Table 3.4: Less important loads in the building

Load	**Total number**
Air conditions	14
Large Printer	1
Fans	18
Sockets	35
Television	1
Heater	1
Coolers	1
Refrigerator	1

3.5 Sizing of Solar System

As the system that will be designed must ensures that the work is not going to be affected by the cutout of the utility grid, so the solar system will be sized to handle the important loads only, Also one of the roles of the solar system when the utility grid is available is to supply the important loads from the utility grid to reduce the monthly bills.

3.5.1 Sizing of the Solar Arrays

Before sizing the array, the total daily energy in Watt-hours (E), the average sun hours per day (T_{min}), and the DC-voltage of the system (VDC) must be determined. To avoid under sizing, losses must be considered by dividing the total power demand in WH-day by the product of efficiencies of all components in the system to get the required energy (E_r). So many assumption has been made before the sizing of the suitable solar arrays.

3.5.1.1 Assumption taken for designing the solar system

- The system will be 48 volt to reduce the amount of current flow.
- Inverter converts DC into AC power with efficiency of about 90%.
- The combined efficiency of the system will be 80%
- Sunlight available 11 hours/day (equivalent of peak radiation),but the average sun hours per day is 6 hours/day (equivalent of minimum radiation)
- Operation hours of the important loads (it is a day time loads) equal 9 hours/day (assumed equal to the working hours in SUST from 7 am to 4 pm).

3.5.1.2 Sizing process

According to the selected panel, the calculations of the required number of panels will be done, Firstly the average energy demand per day will be divided by the efficiencies of the system components to obtain the daily energy requirement from the solar array.

$$E_r = \frac{E}{\eta_{overall}} \quad (3.1)$$

$$E_r = \frac{67.9}{0.8} = 84.88\ kwh$$

To obtain the peak power, the previous result is divided by the average sun hours per day for the geographical location T_{min}.

$$\text{Pp} = \frac{\text{E}_\text{r}}{\text{T}_\text{min}} \quad (3.2)$$

$$\text{Pp} = 14.15\ kw$$

The total current needed can be calculated by dividing the peak power by the DC- voltage of the system.

$$I_{dc} = \frac{P_P}{V_{dc}} \quad (3.3)$$

I_{dc}=294.7 Amp

Modules must be connected in series and parallel according to the need to meet the desired voltage and current, Firstly the number of parallel modules which equals the whole modules current divided by the rated current of one module Ir.

$$Np= \frac{I_{dc}}{I_r} \tag{3.4}$$

$$Np = \frac{294.7}{7.45} = 40$$

Second, the number of series modules which equals the DC voltage of the system divided by the rated voltage of each module V_r

$$Ns= \frac{V_{dc}}{V_r} \tag{3.5}$$

$$Ns = \frac{48}{24} = 2$$

Finally, the total number of modules Nm equals the series modules multiplied by the parallel ones:

$$Nm=Ns*Np \tag{3.6}$$

$$Nm = 80$$

3.5.2 Sizing of the Battery Bank

When there is a shortage in generation of the panels during the day due to atmospheric conditions, Batteries will cover this shortage in supply by discharging the power stored in it. But batteries have high capital cost and require maintenance and its life time is short. So in this research the main role of the batteries is to give steady generation and as the load is a day time load (no need for batteries for the night), the batteries will be sized to handle the load for two hours, if the batteries couldn’t overcome the shortage in generation then the important loads will be transferred to other available source.

The calculations of the required number of batteries will be done. The amount of rough energy storage required is equal to the multiplication of the total power demand and the number of hours per day.

$$\text{Erough}=\frac{\text{E}\times\text{H}}{\eta_{overall}} \tag{3.7}$$

$$\text{Erough} =\frac{8.655\times 2}{0.8}=21.64 \text{ KWh}$$

For safety and According to the selected battery the maximum allowable level of discharge (MDOD).

$$E_{safe}=\frac{\text{E}_{\text{rough}}}{MDOD} \tag{3.8}$$

$$E_{safe}= \frac{24}{0.75}=28.85 \text{ KWh}$$

The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected.

$$\text{C} = \frac{E_{safe}}{\text{Vb}} \tag{3.9}$$

$$\text{C} = \frac{28.85}{48}= 601.04 \text{ Ah}$$

The number of batteries in series equals the DC voltage of the system divided by the voltage rating of one of the batteries selected.

$$N_S = \frac{V_{DC}}{V_b} \tag{3.10}$$

$$N_S= \frac{48}{12} =4 \text{ batteries}$$

Then number of parallel paths Np is obtained by dividing the capacity of the batteries needed by the capacity of one.

$$N_P = \frac{N_{batteries}}{N_S} \quad (3.11)$$

$N_P = \frac{601.04}{250}$ =3 batteries

The total number of modules Nm equals the series modules multiplied by the parallel ones.

Nm =12 batteries

3.5.3 Sizing of the charge Controller

Voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. According to the selected charge controller; Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor Fsafe. The result gives the rate current of the voltage regulator.

$$\mathrm{I} = I_{SC} \times N_P \times F_{safe} \quad (3.12)$$

I = 8.03 × 40× 1.25=401.5 Amp

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array, and to handle a load current more than that planned due to addition of equipment. In other words, this safety factor allows the system to expand slightly.

$$N_{controller} = \frac{I}{Amps\ each\ controller} \quad (3.13)$$

$N_{controller} = \frac{401.5}{140} = 3$

3.5.4 Sizing of the inverter

The used inverter must fulfil the following:

- The input rating of the inverter should never be lower than the total watt of appliances.
- For stand-alone systems, the inverter must be large enough to handle the total amount of Watts, so in this research the inverters must handle important loads.
- The inverter size should be 25-30% bigger than total Watts of appliances (in this case the total watts of the important loads).
- The inverter must have the same nominal voltage as the battery.
- As the solar system is not connected to the utility grid (not grid tie system), the suitable type of the inverters used in the three individual buildings are standalone inverters.

The inverter needed must be able to handle about 8.66 KW at 220-VAC and by adding 25% future consideration and 0.9 inverter efficiency, the total watt is

$$\text{Inverter rating} = \frac{E\times1.25}{\eta_{inverter}} = \frac{8.66\times1.25}{0.9} = 12 \text{ kW}$$

So the suitable inverter for the administration Building must have the following: standalone power inverter, 12KW, 48 VDC, 220 VAC

3.6 Sizing of the Generator

The generator used in this system is a backup generator to supply the important loads when both the grid and the solar system are not available, so the generator must be sized according to the important loads. Total important loads equal 8.66 kW, and by taking 25% future considerations the total watt will be 1.25*8.66=11kW, so the suitable backup generator must huddle about 11 kW.

3.7 Grid as a Power Source

The grid has the ability to supply all the connected loads (important, and less important), but as the country's grid is suffering from unreliability and has problems of frequent load shedding, unstable voltage and in sometimes a fault problems. So the system is designed to provide more reliability to the important loads and ensures the continuity of supply to them, even when the grid is off for short period of time. So the utility grid represents the main supply source beside the PV system. Even though the grid is unreliable but a combination of multi unreliable systems create an overall reliable system, because it increases the chances of at least one system to be available.

CHAPTER FOUR
SYSTEM IMPLEMENTATION AND SIMULATION RESULTS

4.1 Introduction

This chapter discusses the Hardware and the Software parts of this system, the hardware part explain the real circuits in the system, the used component like the Arduino and the relays, also the connection diagram between the three sources and the control system will also be shown. All the possible cases that can happen during the variation of the sources will be explained by flowchart diagram. In the other hand, the software part consists the Arduino's code and the simulation will be done by using Proteus software to ensure that the control system and the Arduino's code is working properly to achieve all the cases that will be explained.

4.2 Energy Management System (EMS)

The energy management system (EMS) switches the mode of power sources, and controls the flow of power to the important loads according to the availability of solar system, availability of the grid and load requirement. The energy management system (EMS) keeps tracking and checking the status of the sources to give the best possible Decisions. In this research, the hybrid system will be controlled using an Arduino with the preferred program to execute the desired algorithm. The overall block diagram in figure below 4.1 shows the power sources, the EMS and the loads.

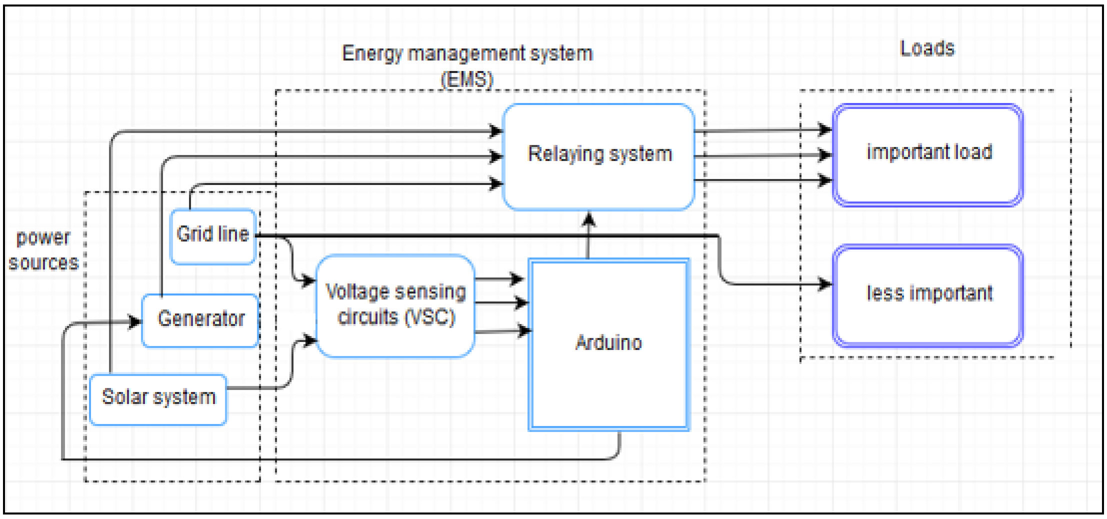

Figure 4.1: Connection of the power source with loads through EMS.

There are three main input sources: grid line, solar system and generator. Each source is connected with relay as shown in figure 4.2. The Relays are used to control the on and off of input sources' power lines and switching for loads.

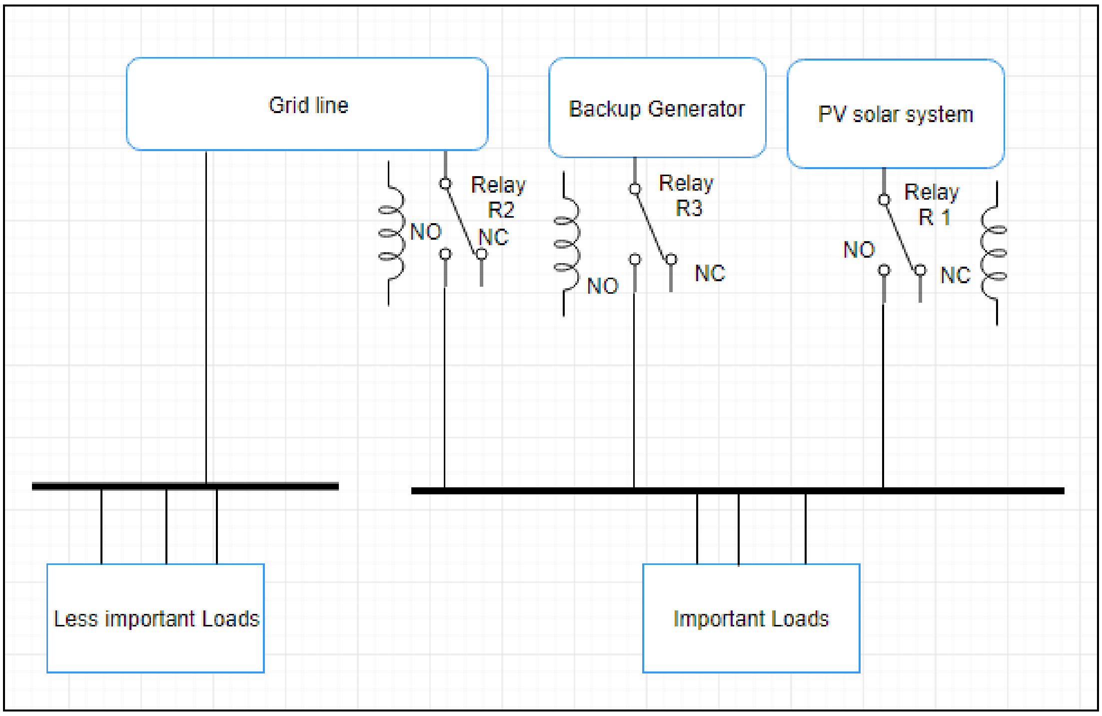

Figure 4.2: Connection of the power source and the load.

As in figure 4.2, the system consist of four relays used to control the flow of electricity from the sources to the important loads. one to control the folw of power from the generator (R3) ,other one is used to supply the important loads from the solar system (R1) and the other one to control the flow from the grid (R2).Last relay (not shown in figure 4.2) is used to turn on the generator by sending a signal from the arduino to operate the relay.

The power from the sources are sensed by Voltage Sensing Circuit to know which power lines are active. The Arduino in the EMS used to decide which source will open and which relays will be loaded. Moreover, the procedure for turning on/off of the generator is also done according to the requirement of the system.

So the Energy management system EMS consist of three parts: Arduino, voltage sensor (VSC) and the Relaying circuit .each one of them will be discussed in the following.

4.2.1 Arduino as microcontroller

Arduino is a microcontroller which can be defined as the heart of this project. Arduino is a combination of both programmable circuit board and software. There are many benefits can be achieved for choosing Arduino as a control device like it has many analog and digital pins, low cost, wide availability, and it can be programmed easily. The voltage sensor senses the voltage and they fed the result into Arduino and therefore Arduino compares them with the preset instruction to extract the result. It needs 5 volts to get powered up but also it can be supplied by the 12v battery. To convert the voltage from 12v to 5v a LM7805 voltage regulator was used in the voltage sensing circuit.

4.2.2 Voltage Sensing circuit (VSC)

The Voltage Sensor is used to sense voltage from input sources to decide which sources are active and which one are not. As all the three sources provide a 220 volt AC and the Arduino receives only a 5v DC signal, so it requires to design a circuit that can sense the voltage from the input sources and turn it to voltage suitable for Arduino. The digital input signal to the Arduino must be either zero or 5v DC, when it is zero means the source is not active and when it is 5v means the source is active and available to supply the loads. The VSC consist of the following components.

4.2.2.1 Step down transformer

The input transformer is used to convert the incoming AC line voltage down to the required level of power. It also isolates the output circuit from the line supply. Here it must be using a step-down transformer, so 220V AC is converted into 12V AC using the step-down transformer. 12V output of step-down transformer is an RMS value and its peak value is given by the product of square root of two with RMS value, which is approximately 17V.

4.2.2.2 Rectifier

As the secondary voltage of the transformer is 12V (RMS value wherein the peak value is around 17V), but the required power is 5V DC; for this purpose, 17V AC power must be primarily converted into DC power then it can be stepped down to the 5V DC. Thus Full wave bridge rectifier is used to convert the incoming signal from an AC format into DC. Here the obtained is not a pure DC as it consists of pulses which it is called a pulsating DC power. But voltage drop across the diodes is (2*0.7V) 1.4V; therefore, the peak voltage at the output of this rectifier circuit is approximately 15V (17-1.4).

4.2.2.3 Smoothing capacitors

The 15v Dc output of the diode bridge is a DC consisting of ripples also called as pulsating DC. This pulsating DC can be filtered using a capacitor filter for removing the ripples.

4.2.2.4 Voltage regulator

Under practical situations, there are a lot of variations in the AC line voltage that are not in our control. This causes the DC output voltage to fluctuate. And the Arduino wouldn't work properly on such output voltage fluctuations. Hence it requires a regulated dc power. A regulator is a device that will convert the unregulated DC voltage to a stable 5 volts that we need. This can be done by using LM7805 (voltage regulator IC), and then the 15v DC voltage can be stepped down to 5v DC. The input voltage to the 7805 IC should be at least 2v greater than the required 5v output (due to the voltage drop), therefore it requires an input voltage at least close to 7v. So The IC LM805 gives a steady 5v dc output when the input is higher than 7v, the LM805 IC voltage regulator is shown in figure 4.3.

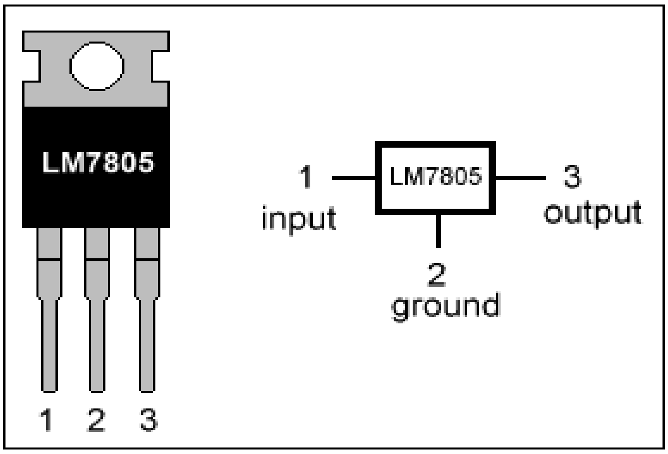

Figure 4.3: LM805 IC voltage regulator

The overall circuit diagram of voltage sensing circuit (VSC) is shown in figure 4.4.

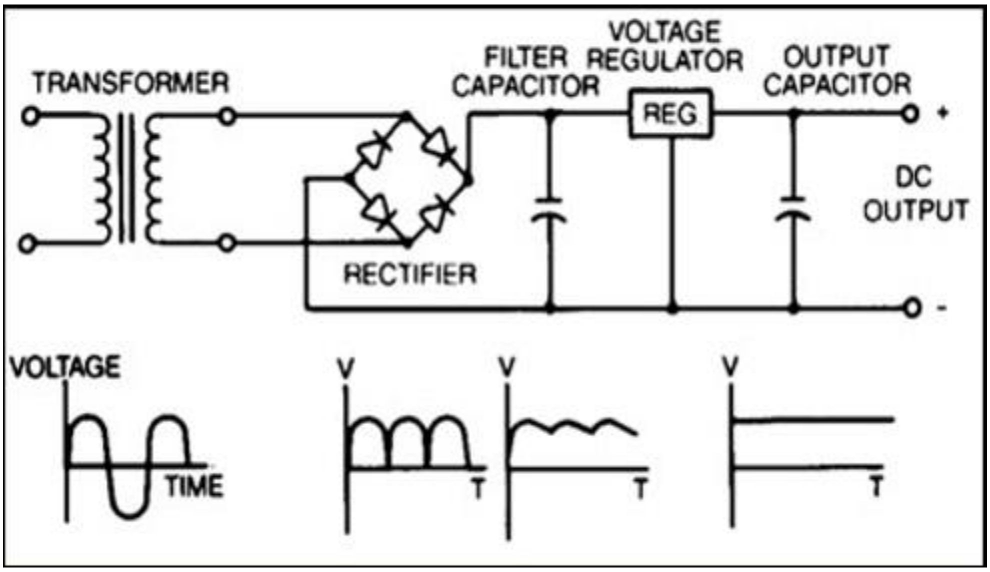

Figure 4.4: Voltage sensing circuit.

4.2.3 Relaying circuit

According to the available sources, Arduino makes a necessary decision and switch on/off of the relays that connected with the important loads. A relay can be used to switch higher power devices such as motors, and the relay can be powered by a separate power supply. In this system, relays are used to control the loads as switches .The diode across the relay contacts is used to prevent damage to the transistor because relay creates a back-EMF when power is switched off. And npn transistors, can be used as switching and amplification for general purpose. And in this case, it is used as switch to control 12v relay on/off.

When the base of transistor receive the signal from the Arduino, it is completely on and the relay also on. If the signal absence in the base of transistor, it is fully off and the relay also off. The relaying circuit construction is shown in figure 4.5.

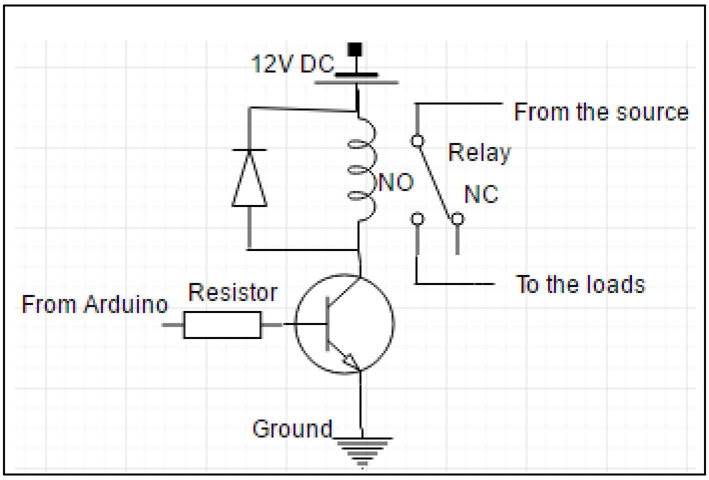

Figure 4.5: The construction of Relay circuit.

4.3 Simulation and Results

ISIS provides the development environment for Proteus. Proteus is a simulation software program which provides the designer with the tools they need to construct, simulate and check their circuits before designing it in the real life later one. So in this research the Proteus, Arduino library and the Arduino programing tool (to write the Arduino's code) will be used to simulate the system.

4.3.1 Overall circuit in Proteus

As in figure 4.6, the voltage sensing circuits in the simulation gives an input digital signal (high or low) to the Arduino's pins 8 and 9. When the switch is pushed, that's mean there is a signal from one of the sources and the source is available and ready to supply the loads. And according to the programed conditions it gives an output signals to the pins 1, 2, 3 and 4, where each one represents the relays shown in figure 4.2 except relay 4 (not shown in figure 4.2, which represents the signal required to operate the generator. The two loads (important and less important) is represented in the simulation by two lamps to give an indication when they turned on under certain conditions. Figure 4.6 shows the overall system in Proteus, where it consists of the three power sources, the relaying circuit, voltage sensing circuit and the loads.

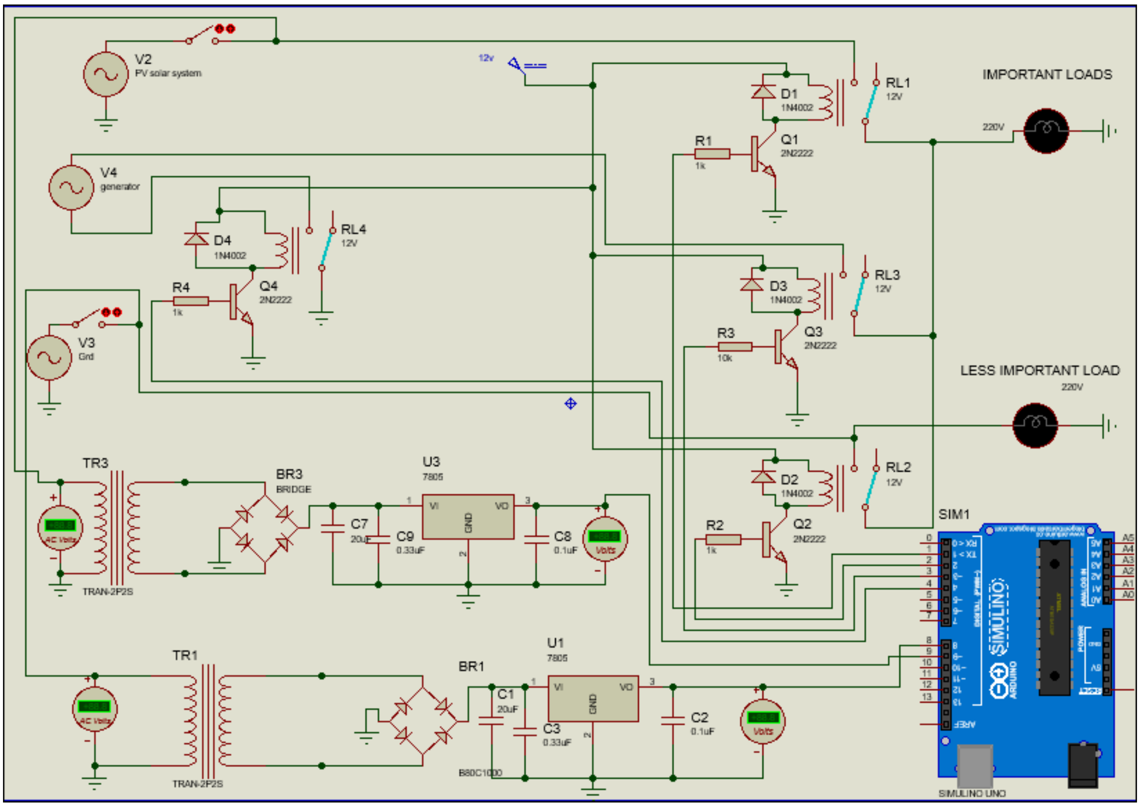

Figure 4.6: Overall system in Proteus.

4.3.2 Availability cases of the sources in a flow chart

The several cases are checked as in the flow chart in figure 4.7. When the system is started, the Arduino receives the signals from the voltage sensors (VSC of the grid and the solar), then it checks if the grid is available and if the power is enough from the solar system, then it operates relay 1 (R1=1=HIGH) to supply the important loads from the solar system (case A). But if the solar is not available or suffering from shortage of supply due to the atmospheric conditions or due to maintenance (case B) then relay 2 will be activated to supply the important loads from the grid (R2=1=HIGH).Case C is when only the grid not available, then the priority of supply is to the important loads, and as the solar was sized to supply the important loads ,so relay 1 is active (R1=1=HIGH) and the solar system is supplying the important loads. When both the grid and the solar are not available to supply the loads then the generator will be operated (relay 4=R4=HIGH) and also relay 3 is activated to supply the important loads from the generator (case D).

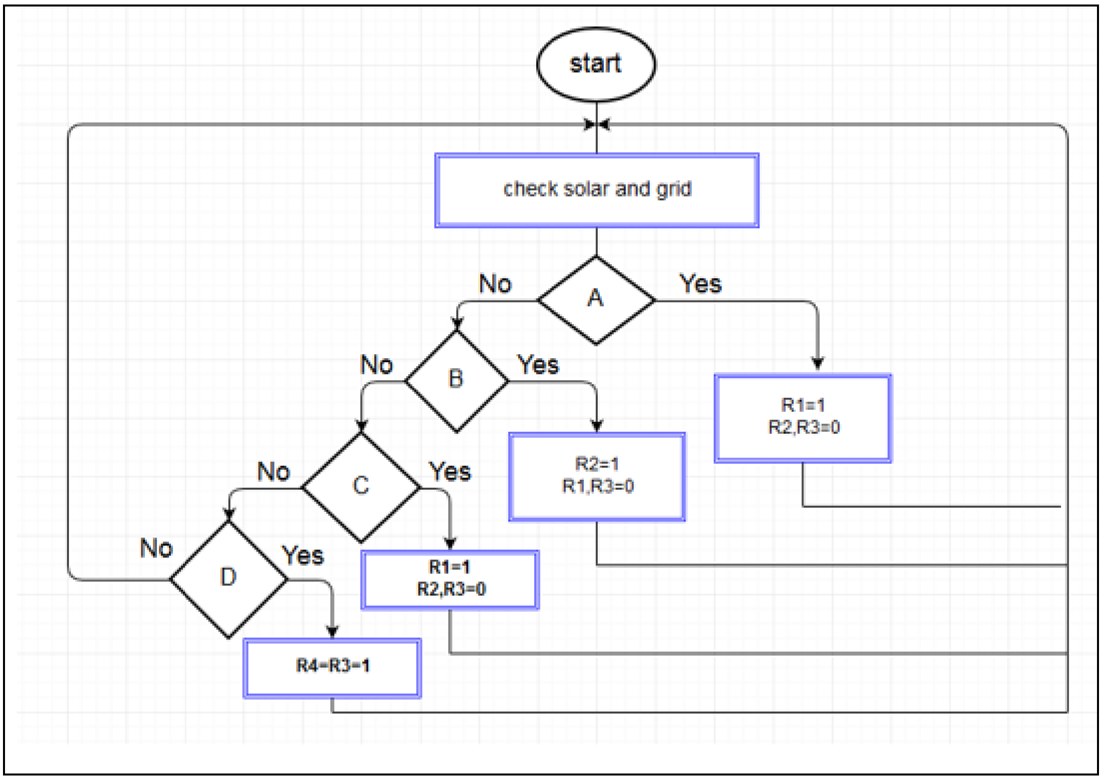

Figure 4.7: Flow chart of the system cases.

4.3.3 Availability cases of the Sources in Proteus

With the help of the flow chart diagram in figure 4.7, which they illustrate all the possible conditions of the system, the Arduino's code was written, verified and uploaded to Arduino. Then the results of the cases was given as flow.

4.3.3.1 Case A

When both the grid and the solar are available, the Arduino sends high signal to R1 and low signal to R2, R3 and R4 as shown in figure 4.8.

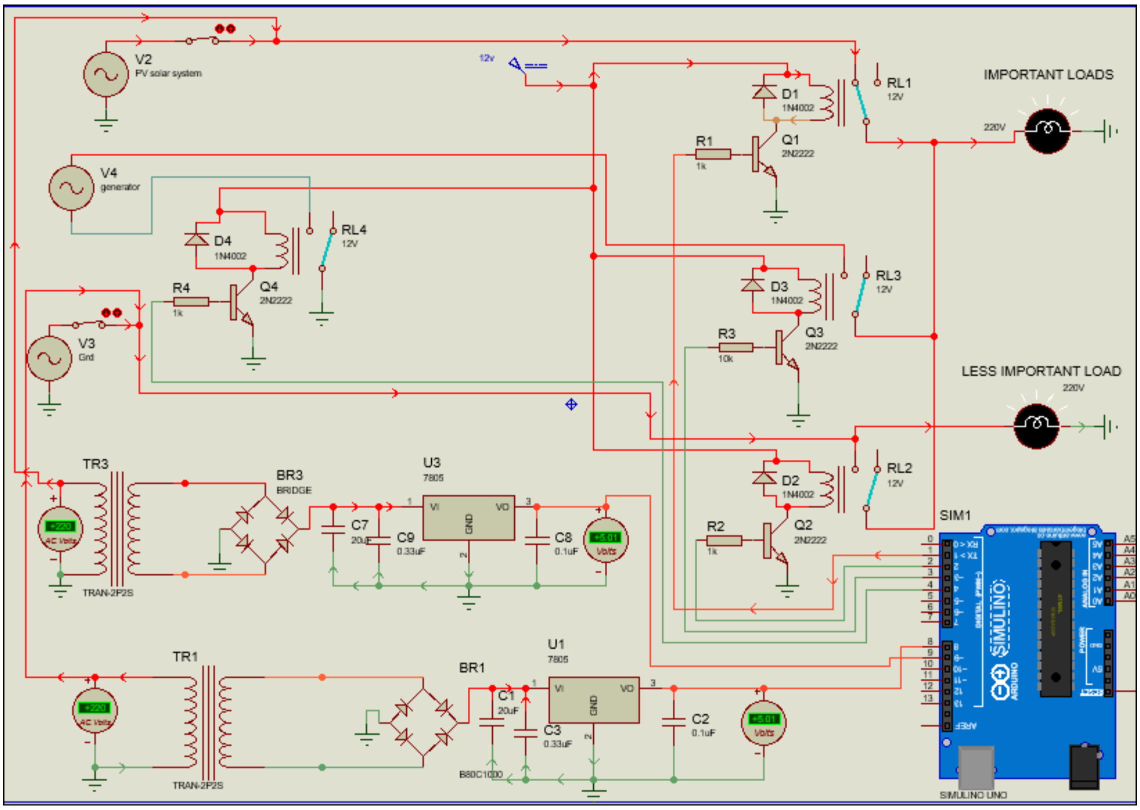

Figure 4.8: Case A, both grid and solar are available.

4.3.3.2 Case B

When the grid is available but the solar is not available the Arduino will send a high signal to R2 only and turn off the other relays, and the important loads will be supplied by the grid as shown in figure 4.9.

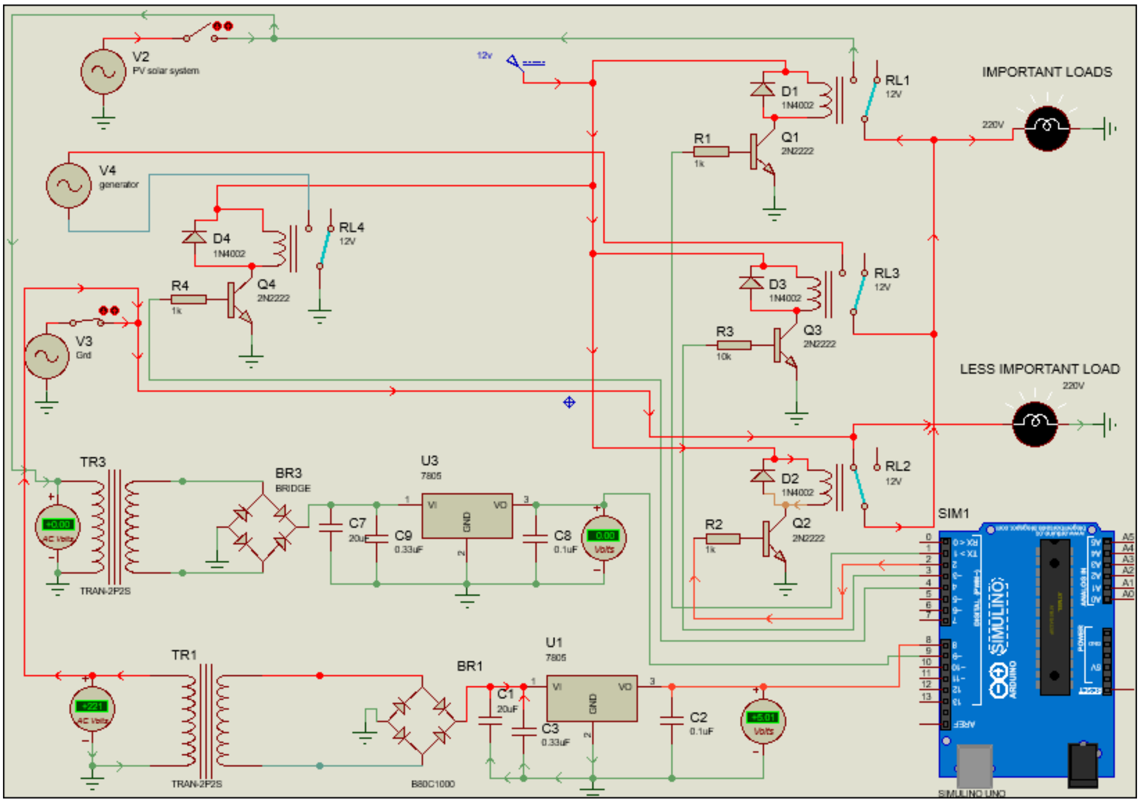

Figure 4.9: Case B, grid is available, solar is not available.

4.3.3.3 Case C

Grid is not available and the solar is available, as shown in figure 4.10, in this case the unimportant load is off (not been supplied) and only R1 will be high.

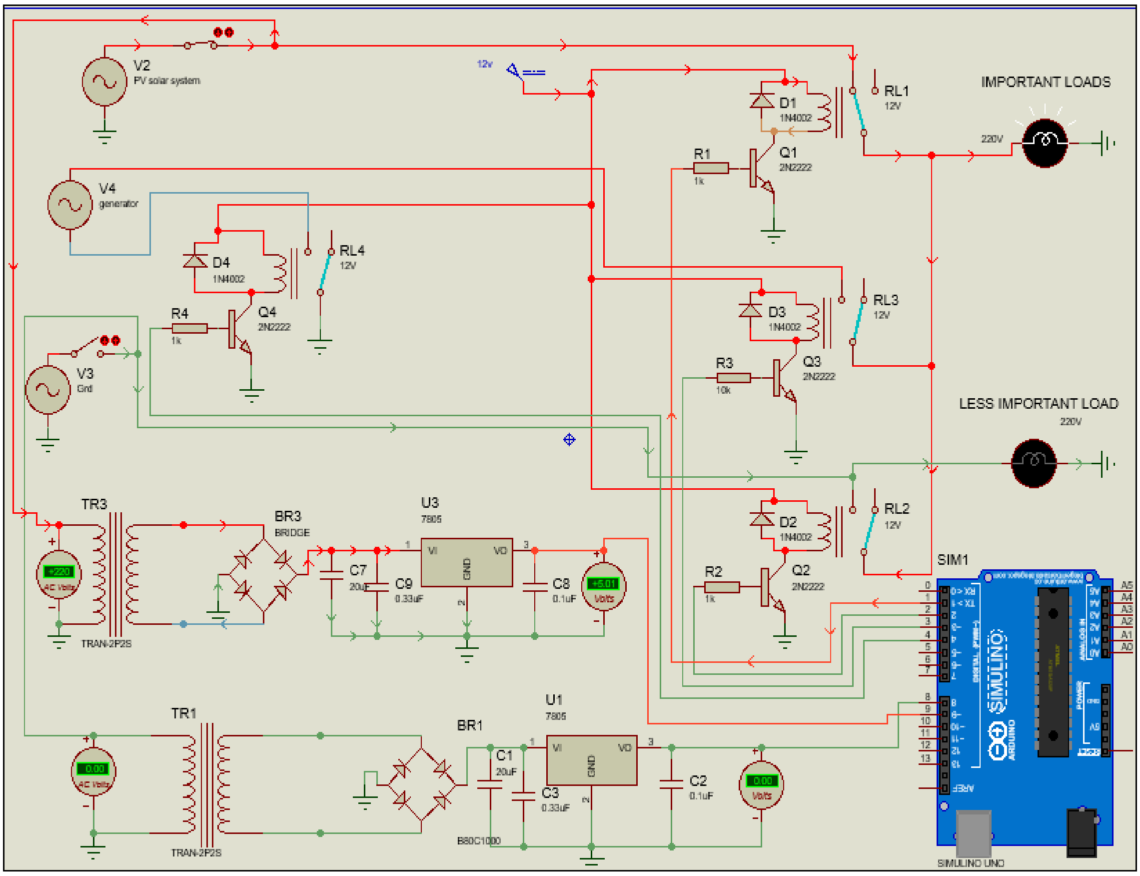

Figure 4.10: Case C, grid is out, solar is available.

4.3.3.4 Case D

In this case both grid and solar are not available, then Arduino sends a signal to turns on the generator (R4), and the relay (R3) is activated to supply the important loads (The unimportant load is turned off in this case too). Figure 4.11 shows this case.

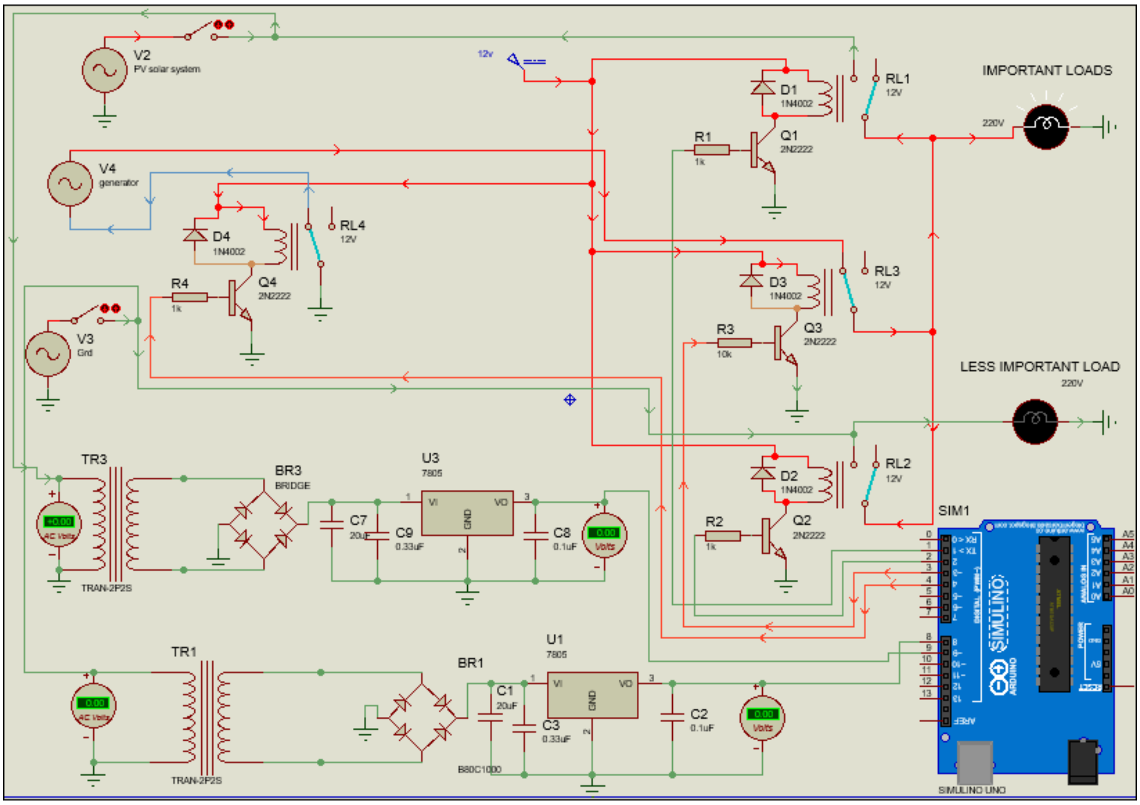

Figure 4.11: Case D, grid and solar are not available.

4.3.4 Discussion

As the generator is a third choice source, the amount of fuel consumed is lesser than the present system (grid and generator only).also the working hours of the generator is lesser than the present system.

As the solar system will supply the important loads most of the time, the power consumed from the grid is lesser and therefore the monthly bills will reduce.

As shown in the simulation, this system can ensures that there is a supply for the priority loads (important loads) almost in any case, and the work is not going to be affected by the outage of one source or in some case the outage of two sources. This system can be constructed in any other institutes or homes as well to gain its advantages.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This hybrid system helps Sudan University of Science and Technology solving the grid utility instability and unreliability issues due to load shedding, the present system has been improved by using the solar energy as a renewable source. Loads of the administration building were calculated and divided according to their priorities into important, and less important loads. At the sizing process the lighting system was found has low quality with low light intensity and short lifetime, so firstly the lighting system was improved by the help of the software programs DIALUX and Philips catalogue.

The system was controlled using Arduino where the voltage of the input sources is sensed by voltage sensing circuit, then the program active or inactive the relays According to the availability of the sources to ensure the continuity of supply to the priority loads.

Using the solar energy gave the advantages of reducing the monthly bills, consume less power from the utility grid, and as the generator used as a third choice source the amount of fuel consumed and the number of hours that the generator will operate is reduced.

The overall system which consisting of the energy management system, the load and the sources is represented and simulated by using Proteus to show the several cases of the system.

5.2 Recommendations

- The control of the system can be achieved by other tools such as PLC.

- Using DC lamps and DC fans to reduce the size of the inverter and to avoid the losses which occur when converting to AC.
- Adding other power source like wind power energy.
- Replace the generator by higher rating one.

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APPENDIX A

Arduino's Code

```
int vs_grid=8; /*to store the status of voltage sensor of the grid */

int vs_solar=9; /*to store the status of voltage sensor of the solar */


void setup() {

 pinMode(1,OUTPUT); /*to give a signal to operate relay 1 */

 pinMode(2,OUTPUT); /*to give a signal to operate relay 2 */

 pinMode(3,OUTPUT); /*to give a signal to operate relay 3 */

 pinMode(4,OUTPUT); /*to give a signal to operate relay 4 (to
operate the generator) */

 pinMode(8,INPUT); /*to to recive a signal form the voltage sensor of
the grid */

 pinMode(9,INPUT); /*to to recive a signal form the voltage sensor of
the solar */

}


void loop() {

  vs_grid=digitalRead(8);/*to know the status of the grid*/

  vs_solar=digitalRead(9);/*to know the status of the solar */
```

```
/* condition A: grid is avilable & solar is avilable */
if(vs_grid ==HIGH && vs_solar ==HIGH)
{
  digitalWrite(2,LOW);
  digitalWrite(3,LOW);
  digitalWrite(4,LOW);
  digitalWrite(1,HIGH);
  }

  /* condition B: grid avilable & solar not avilable */
 if(vs_grid ==HIGH && vs_solar ==LOW)
   {
  digitalWrite(1,LOW);
  digitalWrite(3,LOW);
  digitalWrite(4,LOW);
  digitalWrite(2,HIGH);
 }

 /* condition C: grid not avilable & solar avilable */
 if(vs_grid ==LOW && vs_solar ==HIGH)
 {
```

```
  digitalWrite(2,LOW);

  digitalWrite(3,LOW);

  digitalWrite(4,LOW);

  digitalWrite(1,HIGH);

 }


 /*condition D: grid not avilable & solar not avilable */

   if(vs_grid ==LOW && vs_solar ==LOW)

   {

   digitalWrite(1,LOW);

   digitalWrite(2,LOW);

   digitalWrite(3,HIGH);

   digitalWrite(4,HIGH);

 }

}
```

APPENDIX B

Egyptian's lux standard

ملحق رقم (م1) :معايير شدة الإضاءة

جدول رقم (م1): مستوى شدة الإضاءة فى الفراغات المختلفة للمبانى

شدة الإضاءة (لوكس)	المكان	
120	ســــلالم	المبانى السكنية
60	ممرات	المبانى السكنية
	<u>غرفة معيشة</u> :	المبانى السكنية
150	عـــام	المبانى السكنية
300	قراءة	المبانى السكنية
120	غرفة طعام	المبانى السكنية
120	غرفة نوم	المبانى السكنية
	<u>مطبـــخ</u> :	المبانى السكنية
120	عام	المبانى السكنية
500	أسطح العمل	المبانى السكنية
300	حمام	المبانى السكنية
	<u>حجرة مكتب</u> :	المبانى السكنية
300	- عام	المبانى السكنية
500	- سطح المكتب	المبانى السكنية
120	إستقبال، قاعات إستراحة	المكاتب
300	صالات إجتماعات	المكاتب
300	حجرة تصوير وطباعة	المكاتب
500	حجرة الرسم التخطيطى	المكاتب
1000	حجرة الرسم المعمارى الهندسى	المكاتب

APPENDIX C

PHILIPS SP533P L1450 1 xLED33S/830

Large Office 6m*5m:

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	9	PHILIPS SP533P L1450 1 xLED33S/830 NOC (1.000)	3300	3300	32.0
			Total: 29700	Total: 29700	288.0

Small Office 5m*4m:

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	PHILIPS SP533P L1450 1 xLED33S/830 NOC (1.000)	3300	3300	32.0
			Total: 13200	Total: 13200	128.0

Meeting Room 8m*4m:

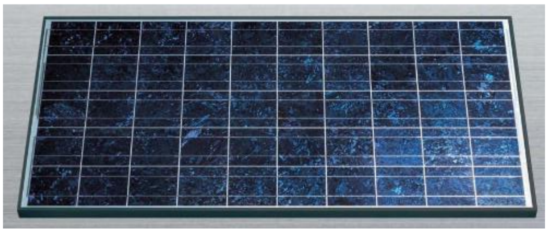
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	PHILIPS SP533P L1450 1 xLED33S/830 NOC (1.000)	3300	3300	32.0
			Total: 19800	Total: 19800	192.0

APPENDIX D

Mitsubishi Electric Photovolatic Module

SPECIFICATIONS

Manufacturer	MITSUBISHI ELECTRIC			
Model name	PV-MF185UD4	PV-MF180UD4	PV-MF175UD4	PV-MF170UD4
Cell type	Polycristaline silicon, 156 x 156 mm square, Solder-coatingless			
Number of cells	50 cells in a series			
Maximum power rating(Pmax)	185W	180W	175W	170W
Warranted minimum Pmax	175.8W	171.0W	166.3W	161.5W
Open circuit voltage (Voc)	30.6V	30.4V	30.2V	29.9V
Short circuit current (Isc)	8.13A	8.03A	7.93A	7.83A
Maximum power voltage (Vmp)	24.4V	24.2V	23.9V	23.7V
Maximum power current (Imp)	7.58A	7.45A	7.32A	7.19A
Tolerance at Pmax	Nominal value +10%, -5%			
Maximum system voltage	DC 600V			
Fuse rating	15A			
Output terminal	(+) 31.5 inch (800mm) / (-) 49.21 inch (1250mm) with MC connector			
Dimensions	65.3x32.6x1.81 inch (1658x834x46mm)			
Weight	43.0 lbs. (19.5 kg)			
Module efficiency	13.4%	13.0%	12.7%	12.3%
Package Contents	2 pcs - 1 carton			
Certifications	IEC 61215, UL1703			

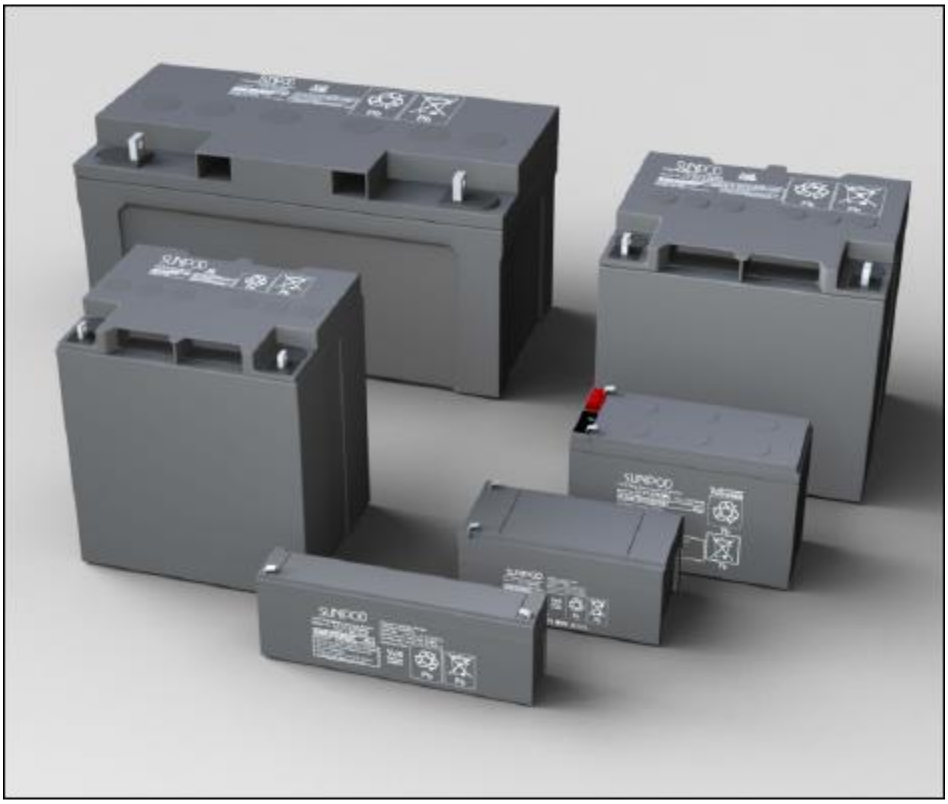


APPENDIX E

Solar Batteries Sunipod

SPECIFICATIONS

Nominal Voltage		12V
Capacity (10 hr, 25˚C)		250Ah
Dimension	Length	520 mm
	Width	268 mm
	Height	220 mm
	Total Height	243 mm
Approx. Weight		73 Kg



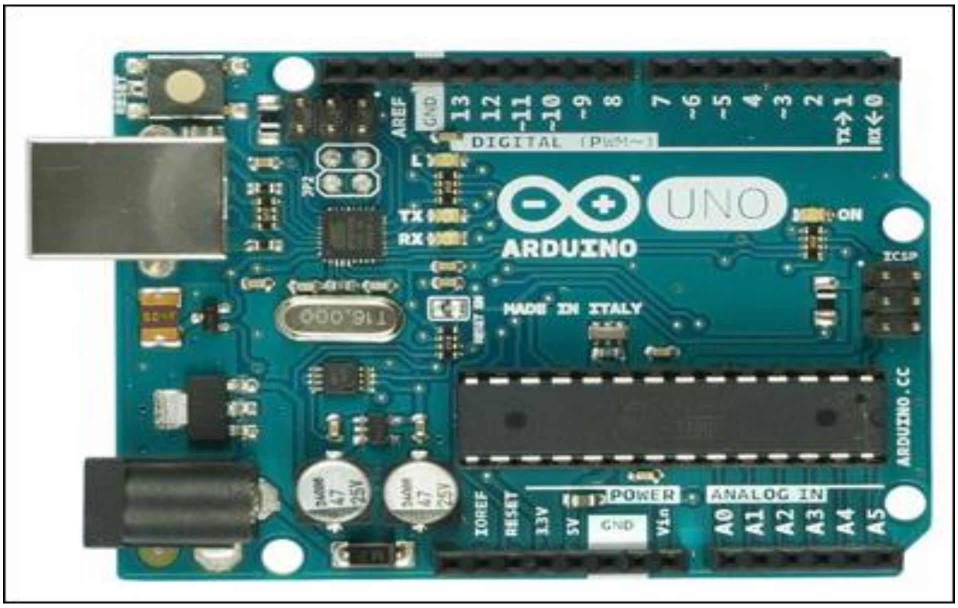
APPENDIX F

Steca Charge Controller

	2070	2140	4055	4110	4140
Characterisation of the operating performance					
System voltage	12 V (24 V)	12 V (24 V)	48 V	48 V	48 V
Own consumption	14 mA				
DC input side					
Open circuit voltage solar module (at minimum operating temperature)	< 50 V	< 50 V	< 100 V	< 100 V	< 100 V
Module current	70 A	140 A	55 A	110 A	140 A
DC output side					
Load current	70 A	70 A	55 A	55 A	70 A
Reconnection voltage (SOC / LVR)	> 50 % / 12.6 V (25.2 V)	> 50 % / 12.6 V (25.2 V)	> 50 % / 50.4 V	> 50 % / 50.4 V	> 50 % / 50.4 V
Deep discharge protection < 30 % (SOC / LVD)	< 30 % / 11.1 V (22.2 V)	< 30 % / 11.1 V (22.2 V)	< 30 % / 44.4 V	< 30 % / 44.4 V	< 30 % / 44.4 V
Battery side					
End-of-charge voltage	13.7 V (27.4 V)	13.7 V (27.4 V)	54.8 V	54.8 V	54.8 V
Boost charge voltage	14.4 V (28.8 V)	14.4 V (28.8 V)	57.6 V	57.6 V	57.6 V
Equalisation charge	14.7 V (29.4 V)	14.7 V (29.4 V)	58.8 V	58.8 V	58.8 V
Set battery type	liquid (adjustable via menu)				
Operating conditions					
Ambient temperature	-10 °C … +60 °C				
Fitting and construction					
Terminal (fine / single wire)	50 mm² - AWG 1	95 mm² - AWG 000	50 mm² - AWG 1	70 mm² - AWG 00	95 mm² - AWG 000
Degree of protection	IP 65				

APPENDIX G

Arduino Uno



Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

APPENDIX H

LM78XX Regulator

FAIRCHILD
SEMICONDUCTOR®

March 2008

LM78XX/LM78XXA
3-Terminal 1A Positive Voltage Regulator

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

General Description

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

Recommended connection: