TITLE PAGE

DESIGN, CONSTRUCTION AND IMPLEMENTATION OF A 2KVA SMART HYBRID UNINTERUPTIBLE POWER SUPPLY

APPROVAL PAGE

This work has been reviewed and approved by Engr Nnamani Christantus Obinna and Engr Olisa Samuel

DEDICATION

We love to dedicate this work to God and to every power engineer.

ACKNOWLEDGEMENT

We love to acknowledge the effort of all the engineers we consulted and whose works were referenced for this project to come to success. Thank you.

ABSTRACT

Poor economy and under Industrialization of Nigeria is largely contributed by energy crisis and poor management. Small and Medium Enterprises (SME) are yet to see their full potentiality in a developing country such as Nigeria due to energy challenges. This project deals with an innovative system achieving an auxiliary source of energy supply from solar system, power inverters. These operate in case of blackouts by providing a set of loads determined by the continuity of service during the absence of power supply by the network. The system is designed for use in the field of home appliances, offices, schools. It also finds additional possible uses in medical and in industries where the continuity of service plays a fundamental role for safety. The proposed solution is based on a photovoltaic system (i.e. method of converting solar energy into direct current electricity) for stand-alone coupled with a conventional 2KVA SHUPS (Smart Hybrid Uninterruptible Power Supply). A key role is played by an intelligent control that handles both the charge of a suitable stack of batteries, and the electrical loads connected to the SHUPS. SHUPS enables loads to be supplied by assigning them an index of priority established by the operator depending on its importance or safety.

TABLE OF CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

An uninterruptible power supply (UPS) is an electrical system capable of supplying high quality electrical power without interruptions. The mains electrical supply is connected to the input of the UPS and the output is connected to the customer electrical load. Within the UPS system there are power supply storage systems such as batteries and flywheels which can provide a high quality electrical supply. A Smart Hybrid Uninterruptible Power Supply (SHUPS) is basically a device that maintains the correct power to your equipment in the event of mains failure or poor quality mains supply. An Uninterruptible Power Supply (UPS) uses backup batteries and has an automatic controller that ensures continuous supply when the mains power feed is interrupted. A UPS uses batteries to provide power to a connected appliance in the event of a blackout.

A UPS is typically used to protect hardware such as computers, datacenters, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss [1]. The UPS keeps a computer safe and running whatever happens to the power supply (be it lightning, voltage drop, current surge, fuse blow or power cut). UPS is a back-up power system used to prevent power loss or damage to a computer or other critical piece of electrical equipment and electronic appliances. To reduce the risk of losing data to power failure, it is necessary to protect your ongoing works with uninterruptible power supply [2]. A UPS is often operated in parallel to give extra security of electrical supply to the equipment connected to them. This is known as operating in 'redundant configuration' which means that if one module fails or is removed for maintenance, the other connected modules can support the critical load. Under these circumstances, each UPS operates at a reduced power level and shares the supply. It is important that UPS systems not only avoid reducing the quality of the electrical supply, but also smooth out any peaks or spikes in the power supply which could damage the equipment. A UPS not only provides protection against all types of power supply failure, but can also filter a vast range of disturbances found in the mains supply, thus providing more sensitive loads with a clean power supply. A UPS can provide power to a critical load while an alternative supply, such as a stand-by generator, is brought on-line [3].

In this case, the UPS may only need to support the critical load for a short period, perhaps five to 10 minutes. However, a UPS can also be designed to support the critical load for much longer. Uninterruptible Power Supplies (UPS) provides clean and uninterruptible power to the sensitive loads in all supply conditions. "Dirty power" is the industry term for changes, variances, and disturbances that occur during normal usage of utility provided power. This dirty power without notice can cause extreme damage to data and computers alike, but UPS system helps by providing regulated sinusoidal output voltage, with low total harmonics distortion, and high input power factor irrespective of the changes in the supply voltage say from PHCN. Other equipment nearby can produce "noise on the line" that can wreak havoc with a computing environment. These problems can be caused externally by brownouts or load switches or grid problems at the utility or caused internally by subtle disturbances from sources such as fluorescent lights, faxes or even vending machines. Spikes, surges, sags, gaps, as well as electrostatic and electromagnetic interference attack your delicate electrical environment daily. UPS provide reliable continuous computer-grade AC power regardless of what happens to our primary power sources [4].
This project provides comprehensive work on design, construction and implementation of a 2KVA Smart Hybrid UPS system with details such as performance, size and cost of the system at heart. The different hybrid energy sources of our UPS system will include solar, mains and battery.

In fact, there are many different types of UPS systems which are implemented in different ways depending on the requirements of the devices that they power. Hence choosing a UPS needs careful consideration if it is to safely fulfill the function required of it. There are various implementations of UPS units; some being more efficient than others, but for the non-technical user the types can broadly be split into three main groups: Off-line UPS, On-line UPS and Line interactive UPS. Our work will be based on an Off-line UPS. Off-line UPS systems are so-called because the load is fed directly from the raw mains during normal operation, rather than from the inverter output. To that extent, the energy storage components – charger, battery and inverter – are off-line as far as the load is concerned, although the charger and battery remain connected to the mains to ensure the battery is always fully charged. If the mains voltage fails, or exceeds acceptable limits, the static switch immediately connects the inverter output to the critical load. A more serious objection to off-line systems is that the load is continuously exposed to spikes, transients and any other aberrations coming down the power line, creating a risk of loss or damage to sensitive equipment which led to incorporation of an automatic voltage regulator (AVR) to stabilize the voltage [5].

1.2 Aims and Objectives

- To build a system that can make use of three sources of power.
- To design a smart UPS system to make sure that the UPS provides a stable and steady 2KVA output power.
- To build a smart system that can monitor overload, low battery level, low/over charge monitor, auto change over.

1.3 Problem Statement

Ideally, we desire a constant power supply source, with a balanced supply voltage. Companies and offices need a reliable power source to avoid hiccups at work, homes and businesses entreat for a fit power source to run their electrical and electronic appliances. Unfortunately, one of the greatest challenges we have in Nigeria and other developing countries is that of enatic power supply and shabby quality of electricity. Frequent power failures and poor electricity quality caused by voltage surges, instability of voltage, sustained under voltage and power blackouts currently experienced in both rural and urban areas in Nigeria cause considerable difficulties in day-to-day operations in offices, hospitals, homes and industries. With regards to that this work proffer a solution with a 2KVA smart hybrid uninterruptible power supply that can be used in homes/offices. This provides constant power to appliances when a power fluctuation or power loss occurs. It has built-in electronics which constantly monitors line voltages: if the line voltage fluctuates above or below predefined limits, or fails entirely, the UPS supplies power to the system from built-in batteries. The UPS converts the direct current (DC) battery voltage into the alternating current (AC) voltage required by our appliances. The change to batteries must take place very rapidly to prevent data loss.

1.4 Scope of Work

The scope of our project is to the design, construction and implementation of a 2KVA Smart Hybrid Uninterruptible Power Supply (SHUPS).

1.5 Organization of Work

This write up consists of 5 chapters. Chapter one introduces the topic and highlights on the background, problem statement, aims and objectives, scope and organization of our entire work. Chapter 2 talks about Literature review. Here, we discussed basically on other works by people that are related to ours. Chapter 3 emphasizes on the design methodology where various block diagrams of some units are discussed. Also, the components that make up this work is also discussed. Chapter 4 shows the main design, implementation and testing. Here, all our circuits like the oscillation circuit, pre-amplifier unit, driver unit, transformation unit, monitor circuit, control unit and display unit is being designed, implemented and the transformer, over load, battery charger, charge controller, stabilizer, driver unit, solar power cell and system reliability is tested.

CHAPTER TWO

LITERATURE REVIEW

2.1 SOLAR POWER SYSTEM

Solar Photo Voltaic (Solar PV) is a broad field with many different technologies and applications. Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air. In this section the sustainability, economy, development and technology of common types of solar PV are discussed.

2.1.1 Solar Energy Conversion

Solar Energy Conversion deals with converting energy from the sun into electrical energy. Solar energy is promoted as a sustainable energy supply technology because of the renewable nature of solar radiation and the ability of solar energy conversion systems to generate greenhouse gas-free electricity during their lifetime. However, the energy requirement and the environmental impact of PV module manufacture can be further reduced, even though recent analysis of the energy and carbon cycles for PV technologies recognized that strong improvements were made both in terms of energy and carbon paybacks. The most common type of solar electricity generation is through the use of the photovoltaic effect. Solar PV applications range from pocket calculators to solar power plants with several megawatts of power. The first solar PV cells were produced in the 1950s by Bell Labs, but the low efficiency and high production cost rendered it too expensive for almost any application except in space [6]. However, during the last decades, the interest in electricity generation from solar PV has increased sharply, taking the solar technology to commercial applications used worldwide [7]. Solar PV is considered a low-emission energy source with virtually no emission during operations requiring no fuel except the incoming light from the sun.

When comparing the lifetime Green House Gas (GHG) emissions from different energy sources such as fossil fuels, coal, hydro, solar PV technologies have significantly lower emissions [7].

2.1.2 Solar Cells Technology

All Photovoltaic (PV) electricity generation can be summarized in 4 basic steps [8].

- The energy from sunlight is absorbed by the absorber material in the solar cell, causing a transition in the material from a ground state to an excited state.
- The excited state causes the generation of a negatively charged and a positively charged carrier.
- The free positive and negative carriers are separated by either an electric or effective field which causes the negative carriers to travel towards the front contact of the solar cell and the positive carriers to travel towards the opposite (back) contact.
- Arriving at the front contact, the negative carriers release electrons into an external circuit between the front and back contact of the solar cell where the electric current powers a load before returning to the back contact. Here, the electrons recombine with the positive charge carriers, returning to the original ground state.

While these basic steps are common for all solar PV systems, the materials, chemical reactions, type of charge carriers, separation mechanism and overall design differs significantly between different types of solar cells [9]. Solar PV is classified into first, second and third generation solar cells, based on the different technologies used to generate electricity. The materials used in the semiconductor can also be used to classify solar cells, with silicon-based PV being the dominating technology.

The solar cells classified as belonging to the first generation is of the same general type as the original ones developed by Bell Labs 55 years ago, and are based on crystalline silicon (c-Si). These solar cells are utilizing a thick silicon wafer as semiconductor and can generally be divided into either monocrystalline or polycrystalline cells, with the macro structures of the silicon crystals being the difference between the two cell types [8].

The mono-crystalline cell consists of a single silicon crystal grain, with a fixed atom structure covering the entire wafer, resulting in higher conversion efficiency due to the lower amounts of impurities in the crystal. A typical efficiency for monocrystalline silicon solar modules in mass production is around 18% [10]. The high performance of monocrystalline silicon cells however comes at the price of higher manufacturing costs, which is the reason why polycrystalline silicon is another common semiconductor material. Polycrystalline Silicon has a crystal lattice consisting of smaller crystal grains that are joined together. In the boundaries between the crystal grains there is an area without a higher-level atom structure. These impurities in the crystals results in areas where the free carriers driving the photovoltaic current can recombine, lowering the overall efficiency of the cell [8]. The size of the crystal grains has a major impact on the efficiency of the cell, but smaller grain size allows for simpler manufacturing processes and thus lower overall costs. The grain size in different types of polycrystalline silicon ranges from 1 μm to 10 cm [11].

The dominating technology used in field applications is still crystalline silicon (c-Si), both for utility scale and small scale systems. The internal distribution of market share of c-Si solar cells is approximately 60% polycrystalline Si and 40% monocrystalline Si. During the last couple of years however, c-Si has started to be challenged by other types of solar cells referred to as second generation solar cells.

The second generation of solar cells is generally referred to as thin film solar cells and the main types are Copper-Indium-Gallium-Selenide (CIGS), Cadmium-Telluride (CdTe) and amorphous silicon (a-Si). The aim of thin film solar cells is to reduce manufacturing costs by using a much thinner layer of the semiconductor material compared to traditional silicon wafers, resulting in both lower material costs and simpler manufacturing processes**.** The most common type of thin film technology in mass production is a Si, but both CIGS and CdTe have been used a lot also in the last few years [12]. The crystals used in the semiconductor in a Si solar cells have very small grains, so that almost no macrostructure exist. This makes the manufacturing cheaper and lowers the module efficiency. The availability of materials for CIGS and CdTe solar cells is largely determined by the mining of copper and zinc, since the materials used are by-products of copper and zinc mining. As the demand for CIGS and CdTe solar cells rise, more of these by-products are being recovered during copper and zinc mining. This has had the result that the potential shortage that previously capped the production of these types of solar cells now has disappeared. The increased production has led to both lower prices and higher efficiencies due to increased research and development. As of 2013 thin film solar cells in mass production have a typical efficiency of around 11.5–13.5%, with the best lab produced cells achieving above 18.8% efficiency [13].

Third generation technologies aim to enhance poor electrical performance of second generation (thin-film technologies) while maintaining very low production costs. Generally, third generation cells include solar cells that do not need the p-n junction necessary in traditional semiconductor, silicon-based cells. Third generation contains a wide range of potential solar innovations including polymer solar cells, Nano crystalline cells, and dye-sensitized solar cells [14].

2.1.3 Solar Charge Controllers

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or control circuitry integrated within a battery pack, battery-powered device, or battery charger.

2.1.4 Applications of Solar Power System

- **Concentrating Solar Power (CSP):** Concentrating solar power (CSP) plants are utility-scale generators that produce electricity using mirrors or lenses to efficiently concentrate the sun’s energy. The four principal CSP technologies are parabolic troughs, dish-Stirling engine systems, central receivers, and concentrating photovoltaic systems (CPV).
- **Solar Thermal Electric Power Plants:** Solar thermal energy involves harnessing solar power for practical applications from solar heating to electrical power generation. Solar thermal collectors, such as solar hot water panels, are commonly used to generate solar hot water for domestic and light industrial applications. This energy system is also used in architecture and building design to control heating and ventilation in both active solar and passive solar designs.
- **Photovoltaics:** Photovoltaic or PV technology employs solar cells or solar photovoltaic arrays to convert energy from the sun into electricity. Solar cells produce direct current electricity from the sun’s rays, which can be used to power equipment or to recharge

batteries. Many pocket calculators incorporate a single solar cell, but for larger applications, cells are generally grouped together to form PV modules that are in turn arranged in solar arrays. Solar arrays can be used to power orbiting satellites and other spacecraft, and in remote areas as a source of power for roadside emergency telephones, remote sensing, and solar street lights.

- **Solar Heating Systems:** Solar hot water systems use sunlight to heat water. The systems are composed of solar thermal collectors and a storage tank, and they may be active, passive or batch systems.
- **Passive Solar Energy:** It concerns building a design to maintain its environment at a comfortable temperature through the sun's daily and annual cycles. It can be done by: Direct gain or the positioning of windows, skylights, and shutters to control the amount of direct solar radiation reaching the interior and warming the air and surfaces within a building, indirect gain in which solar radiation is captured by a part of the building envelope and then transmitted indirectly to the building through conduction and convection; and isolated gain which involves passively capturing solar heat and then moving it passively into or out of the building via a liquid or air directly or using a thermal store. Sunspaces, greenhouses, and solar closets are alternative ways of capturing isolated heat gain from which warmed air can be taken.
- **Solar Lighting:** Also, known as daylighting, this is the use of natural light to provide illumination to offset energy use in electric lighting systems and reduce the cooling load on HVAC systems. Daylighting features include building orientation, window orientation, exterior shading, saw tooth roofs, clerestory windows, light shelves, skylights, and light tubes. Architectural trends increasingly recognize daylighting as a cornerstone of sustainable design.
- **Solar Cars:** A solar car is an electric vehicle powered by energy obtained from solar panels on the surface of the car which convert the sun's energy directly into electrical energy. Solar cars are not currently a practical form of transportation. Although they can operate for limited distances without sun, the solar cells are generally very fragile. Development teams have focused their efforts on optimizing the efficiency of the vehicle, but many have only enough room for one or two people.

- **Solar Power Satellite:** A solar power satellite (SPS) is a proposed satellite built in high Earth orbit that uses microwave power transmission to beam solar power to a very large antenna on Earth where it can be used in place of conventional power sources. The advantage of placing the solar collectors in space is the unobstructed view of the sun, unaffected by the day/night cycle, weather, or seasons. However, the costs of construction are very high, and SPSs will not be able to compete with conventional sources unless low launch costs can be achieved or unless a space-based manufacturing industry develops and they can be built in orbit from off-earth materials.
- **Solar Updraft Tower:** A solar updraft tower is a proposed type of renewable-energy power plant. Air is heated in a very large circular greenhouse-like structure, and the resulting convection causes the air to rise and escape through a tall tower. The moving air drives turbines, which produce electricity. There are no solar updraft towers in operation at present. A research prototype operated in Spain in the 1980s, and Enviro Mission is proposing to construct a full-scale power station using this technology in Australia [15].

2.1.5 Economic Importance of Solar Power System

Solar energy is abundant. It's a totally renewable source of energy. The power comes from the sun. The sun is free and inexhaustible. The supply will last as long the sun lasts. Using the sun helps us to be in tune with nature and the cycles of our planet. Humans need to strive to work with the environment- not against it. When we use roof-top panels our supply grows in line with the demand. The most important aspect of solar energy is the positive effect on the environment. There is no noise, very little pollution, and no GHG. Again, the sun is a renewable source of energy so there is no strain on the environment. The surface of our planet absorbs the energy equivalent of a barrel of oil for every square meter from our sun. Solar energy emits no carbon dioxide or GHG. There is no damage to our ecosystem the way oil drilling does. The only pollution is from the manufacturing of the equipment and is nothing compared to current pollution output from fossil fuels.

Solar energy is very cost effective. The sun is free. There is no charge for sunshine. For those who cannot afford traditional energy an investment in solar equipment provides long lasting energy for generations to come. Solar panels require almost no maintenance after installation and have a long working life. Wind turbines are noisy and may breakdown. Even though the initial price of installation can be high, money is saved in the long run on electric bills. Energy can be stored for use on dark hours and inclement weather. The cost of the equipment is also declining due to advances in technology. The prices of fossil fuels are on the rise and will only continue to grow. The actual cost of running the solar energy in the home is low. Most governments give out grants, rebates, and tax credits for those using solar power. Power bills can also be reduced by selling energy back into power grid [16].

2.2 Power Electronics

Power Electronics is the study of switching electronic circuits in order to control the flow of electrical energy. Power Electronics is the technology behind switching power supplies, power converters, power inverters, motor drives, and motor soft starters.

2.2.1 Uninterruptible Power Supply (UPS)

A UPS system is used to protect sensitive electric loads in a wide variety of applications. The UPS is situated upstream from the load it is designed to protect, and is tailored to fit the requirements of the individual load that it is being used to power. Generally, an UPS system consists of electronic components to rectify and invert electricity, an energy storage medium (typically a battery), filters to suppress distortions in the power output and switches that detects power failures and switches the system into the inbuilt energy storage (battery) which powers the load [17].

For many companies relying on computerized systems, the costs for system downtime due to power failures are much higher than the cost of the UPS system, making UPS a core technology when building computerized systems. The development towards more computerized systems is continuing and consequently also the increase in demand for UPS systems.

2.2.1 Functionality and applications

The UPS system can serve several functions related to power quality and power reliability. The main functionality of UPS systems is to provide back-up electric power for a specified time if the main power supply is cut off or in any other way is unable to deliver satisfying power for a specific application. The typical time range can be anything between a few seconds up to several hours depending on application [18]. For large-scale applications such as computer halls, UPS systems typically only serve as an intermediate power source before reserve generators can be started. In less critical systems, for example household applications, a UPS commonly constitutes the sole reserve power system. For more advanced types of UPS systems, the sensitive load protected by the UPS is also isolated from the power grid, and thus protected from sags and surges in the grid. In these applications, the power quality of the electricity provided from the UPS to the load is much higher than that of the power grid. At the same time the UPS also protects other devices from the harmonics caused by the sensitive equipment powered by the UPS. When the UPS is converting the incoming power from the grid during normal operation it is also possible for the UPS to adjust the voltage and frequency to user-defined levels. This can be used when the load uses another voltage or frequency compared to the power grid.Typical large-scale systems that need to be protected by UPS systems are data centers, airport lighting, medical systems and industrial processing plants [19]. These applications typically use more advanced UPS systems that not only serve as back-up power but also use the power quality protection that certain UPS systems provide.

2.2.2 Types of UPS

Since UPS systems are used in a wide variety of applications, ranging from safe shutdown of individual computers to back-up systems for entire server halls with a total power of several MW, the types, sizes and functionalities of UPS systems differ significantly. One general categorization used is to classify the UPS based on the energy storage system used. With this classification method, the UPS systems are either stationary, utilizing a battery for energy storage or rotary, relying on flywheels to store energy as mechanical energy [20]. Most UPS systems are stationary, and flywheel technology is mainly used in applications with high power where back-up power is only needed for a few seconds. Using batteries, the back-up time for the UPS is determined by the dimensioning of the battery bank, which can be adjusted to the demands of the load. Hybrids of the two technologies are also possible, but due to the increased costs they are only used in large scale systems powering critical loads. Stationary UPS systems are divided into four main categories based on their functionality and basic working principle. Sorted by increasing complexity the categories are:

- Off-line UPS
- On-line UPS
- Line-interactive UPS
- True (delta conversion) UPS.

An off-line UPS is mainly used in smaller applications, for example in back-up systems for individual computers or other similar household applications. The off-line UPS only serves as a second source of power in case of loss of the normal power supply [21]. During normal operation, a small current is used to charge the battery and then keep it fully charged. Since an off-line UPS does not isolate the load from the power grid the load is not protected from sags and surges in the grid. In case of a power failure, or when the quality of the incoming power is decreased below a pre-set threshold, the switch turns off the power grid and instead connects the battery to the load. Since the switch must detect a power failure and then make a switching before the battery back-up can be used to power the load there is a delay between the two power sources. This delay is in the order of a quarter of a cycle and less sensitive equipment like personal computers are unaffected by this transition time. An off-line UPS cannot be used to power highly sensitive loads however, as the transition time could damage such equipment.

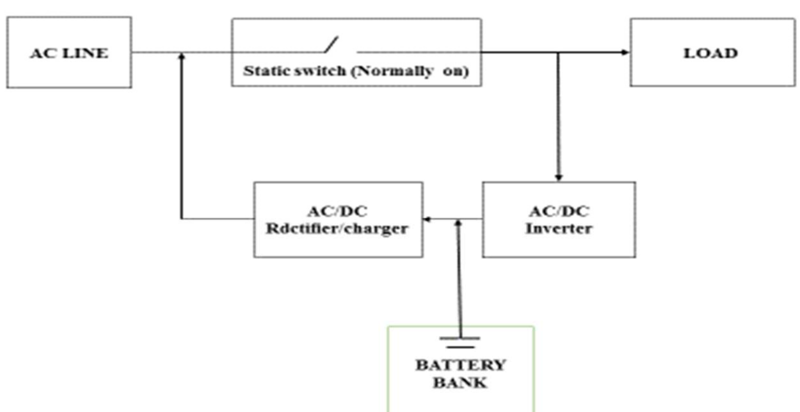


Figure 2.1: Block Diagram of an Off-line UPS

On-line UPS system are typically used for applications where the power quality of the normal power grid could be a problem. In an on-line UPS system, the load is completely isolated from the power grid and all electricity flow through the UPS. The UPS uses double conversion where the incoming electricity during normal operation is rectified into DC and a minor current is used to charge the battery. The remaining power is converted back to AC through an inverter and used to power the critical load. This design has the advantages that the load is protected from all types of power contamination that was initially sent by the power grid, this means that the voltage and frequency of the AC can be adjusted in the UPS and that in the case of power failure there is no transition time before the battery start to power the load [19]. The multi-functionality provided by on-line UPS is the reason why this type of UPS is most common for digital offices and data centers. However, the double conversion also results in a lower efficiency due to conversion losses in the power electronic components. Since the power is continuously fed through both a rectifier and an inverter the power losses makes the operation of an on-line UPS more expensive than an off-line UPS. Efficient components are thus of critical importance in an on-line UPS.

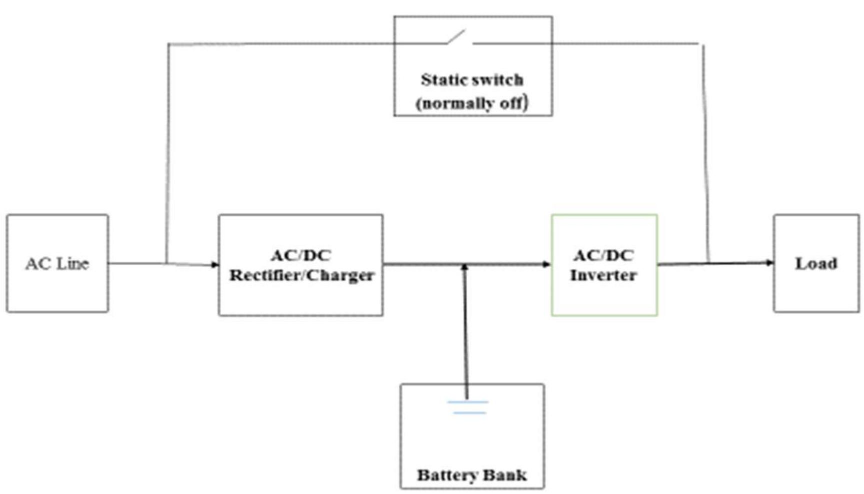


Figure 2.2: Block Diagram of an Online UPS

The line-interactive UPS is shown in the figure below and can function as both an off-line and on-line UPS. The bi-directional AC–DC converter can both rectify power to charge the battery and invert the power from the battery to power the load. During normal operations, the line-interactive UPS can go into on-line mode to either adjust the voltage (but not frequency) or improve the power factor of the load. If this is not required, the UPS works as an off-line UPS with the electricity from the power grid going directly into the load. In the case of a power failure the static switch disconnects the grid and the system powers the load with the battery.

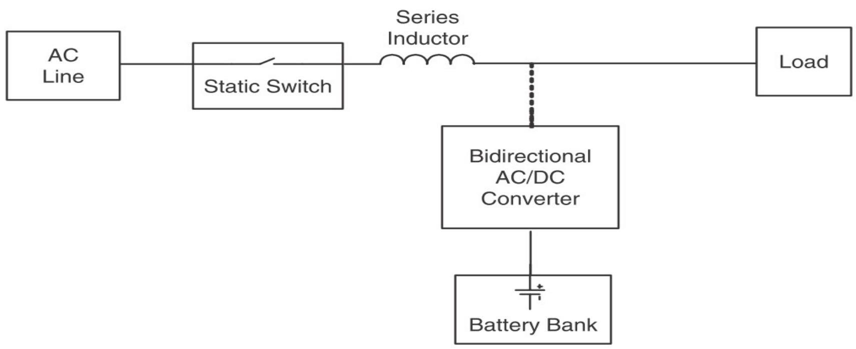


Figure 2.3: Block Diagram of a Line-interactive UPS [20]

The advantage of the line-interactive UPS is that it can provide some power factor correction and voltage adjustment without the increased complexity and losses of double conversion in on-line UPS. However, the load is not isolated from the power grid and is thus still subjected to some power contaminations from the power grid. The line-interactive UPS can thus be considered as an intermediate between off-line and on-line UPS. Large data centers use large amounts of energy, and in such applications the high losses connected to the double conversion of the on-line UPS can result in high costs. For such applications, an advanced version of UPS called true (or delta conversion) UPS can be used. The principle outline of a true UPS (consists of two bi-directional converters – one in series and one in parallel with the main power line. Both converters can be used to charge the battery but only the parallel converter can be used to supply the load.

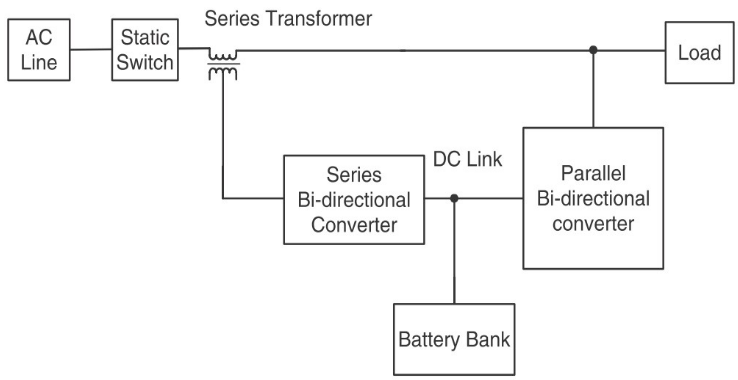


Figure 2.4: Block Diagram of a True UPS

During normal operation, the parallel converter is used to absorb power irregularities related to harmonic distortion and current distortions. At the same time the series converter mitigates surges and sags in the voltage, while charging the battery. The main advantage of this system is that most of the power goes directly from the grid into the load, with the battery and converters only providing power to even out all irregularities. By avoiding the double conversion of all power – as in the on-line UPS – the efficiency is increased.

2.2.2 Inverters

The objective of an inverter (also called DC–AC converter) is to convert direct current to alternating current, and in some cases to also adjust the voltage level. Inverters are common in both solar power systems and required UPS systems with batteries as energy storage. Inverters can be classified into three different categories regarding the output; pure sine wave, modified sine wave and square wave. Ideally, a pure sine wave inverter produces an output voltage that is a perfect sine wave regardless of load. A modified sine wave inverter on the other hand is designed to produce a waveform that is similar but not identical to a sine wave. Square wave inverters produce a square wave output and are the simplest in design. Modified sine wave and square wave inverters are typically cheaper than pure sine wave inverters, but in many applications (such as UPS) pure sine wave inverters are preferable. Both modified and square wave inverters introduce harmonics that can be harmful to sensitive equipment.

2.2.3 DC–DC converters

A DC–DC converter converts direct current from one voltage/current level to another. There are three types of DC–DC converters considering voltage characteristics: the buck converter can only convert the voltage down; the boost converter can only convert the voltage to a higher level while the buck-boost converter is a combination of the two and can thus convert an input voltage to both a higher or lower output voltage [22].

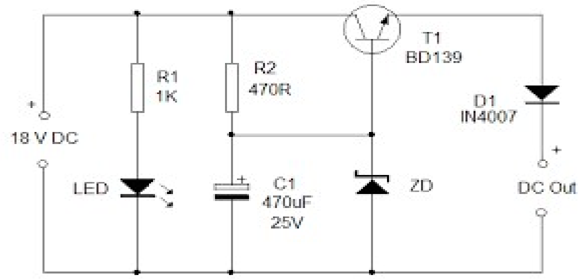


Figure 2.5: Circuit Diagram of DC-DC Converter

2.2.3 AC–DC converters

To convert power from alternating current to direct current, an AC–DC converter, also called rectifier, can be used. The simplest form of rectification for a single-phase circuit which is called the half-wave rectification is achieved by one diode in series with the load as shown in the figure below. However, the waveform produced is far from an ideal DC voltage which is why this arrangement is seldom used in practice. The circuit simply removes the negative part of the AC current which means that there will be no current flowing in the circuit 50% of the time, considering a pure resistive load.

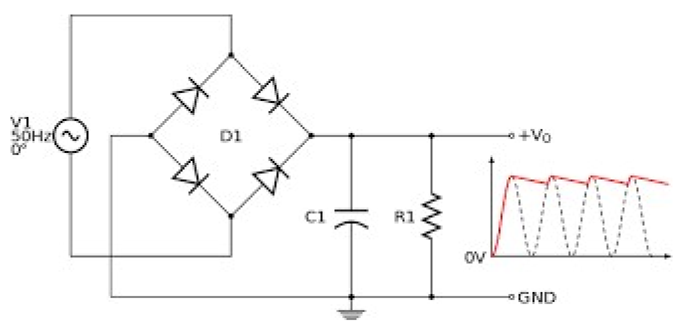


Figure 2.6: Circuit Diagram of AC-DC Converter [22]

An improvement of the single-diode rectifier is the full-wave rectifier seen in the figure below consisting of four diodes instead of one. The load is shown as a resistance R in the diagram. A full-wave diode rectifier is designed to convert both the positive and negative parts of the AC current into positive current. The resulting waveform is still far from ideal DC current, but it is possible to smooth the current with the use of filters. Particularly, a high inductance in series with the load will try to preserve the current through the load which results in a waveform that is closer to ideal DC.

2.2.5 Power Electronics in Solar Power System

The major roles of Power Electronics in Solar Cells are:

- To interconnect the individual solar panels in series and parallel according to requirement. A dc-dc converter interfacing the two solar panels that cannot be identical will help to maintain the required current and voltage, and with regulation improve the overall efficiency. Several non-isolated dc-dc converters have been employed. Buck, buck-boost, boost and Cuk topologies with suitable modifications can be employed for this purpose.
- Interfacing the dc output of the PV system to the grid or the load, this includes dc-dc-ac and dc-ac-ac conversion. Where the grid is not present and the use of batteries to store energy is required, off-grid PV systems are used, in order to cover the demand during the night or whenever energy is needed. To prevent the batteries to discharge on the modules

during the night, blocking diodes are used which also protect the batteries from short circuit. They also provide over-current protection of the strings in case of short circuits, if more than one string is used. Charge regulators control the charging of the batteries. There is the need to use dc voltage and current with stable characteristics, independent from irradiance fluctuations, in off-grid systems. Hence, a DC-DC conversion topology is used. Switch mode DC-DC converters are used to match the dc output of a PV generator to a variable load [23].

2.3 Power Transformer

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. The electrical energy is always transferred without a change in frequency, but may involve changes in magnitudes of voltage and current. Here we consider the two kinds transformer used in the UPS system:

- High frequency transformer
- Low frequency transformer

The high frequency transformer usually made with a Ferrite core material is used in the transformer-less UPS. This approach helps to create higher power AC voltage from a low DC voltage. High frequency transformers are cheaper and smaller, but the downside of it is that its fragile, less reliable and has low peak power capacity.

The Low frequency transformer is produced using a laminated magnetic core (usually thin iron sheets) which gives it high permeability. This type of transformer is used in designing the transformer based UPS system. Low frequency transformer is more reliable and robust but has low efficiency and high cost of material.

2.4 Review of Related works

The aim of this work is to explore the possibilities to combine UPS and solar PV systems. For instance, in a prototype for a utility interactive solar power system which is combined with a battery used as energy storage, this have a heavy focus on the electrical behavior of the components used [22]. The circuit which was built consists of a solar PV panel used to charge a battery with the DC current from the solar panels. To power a load, the DC current of the battery and PV panels is inverted in a bi-directional inverter. The load can also be served directly by the mains utility supply, and this supply can also be used to charge the battery with the inverter acting as a rectifier. In the case of a power failure the battery can serve the load, and thus the system performs one of the critical tasks of an UPS system providing back up energy. Considering that the design of the system does not provide any possibility to isolate the load from the main power grid and thus cannot improve power quality makes it unfit for the type of loads normally served by on-line UPS. Similarly, the conversion methods and power flow design indicate significant conversion losses, making the system uneconomical. The system is however a good reference regarding the electrical behavior of power electronic systems. A more recent work also shows the possible combinations of UPS and solar power systems [24]. They did not build a prototype but instead uses computer simulations in MATLAB and Simulink to model a set of solar modules charging a battery bank which is used in an UPS system. The paper discusses the time required to charge a battery bank using only solar power in different weather conditions, and methods for intelligent battery charging and load management. In the work, the solar modules are only connected to the battery, thus the power from the solar system cannot power the load without going through the battery. Since the battery in a UPS system needs to be kept at full charge this means that the solar panels are only used to restore the battery pack to full charge after a power failure. If the battery is fully charged the solar panels is not used. Another system consists of solar panels connected to a DC–DC converter acting as the charge controller of the batteries [25]. The charge controller can also supply power to the load via an inverter, without the power passing through the batteries. There is a switch after the inverter which either uses power from the grid or the solar UPS to power the load. The UPS only serves as a backup power source, and have no impact on power quality or electrical isolation to protect the load. It is thus not suitable for sensitive equipment but rather as an alternative for household applications.

CHAPTER THREE

DESIGN METHODOLOGY

3.1 DESIGN APPROACH

This is the roadmap to achieve the design, construction and implementation of a smart hybrid uninterruptible power supply. It shows the block diagrams and its various units.

3.1.1 BLOCK DIAGRAM OF INVERTER

An inverter can be taken as a crude form of UPS. The main use of an inverter is for powering electrical and electronic appliances like lights, radios, televisions and fans during a power failure. As the name suggests, the basic function of an inverter is to invert an input Direct Current (DC) and Direct Voltage into a much larger magnitude of Alternating Current (AC) and Alternating Voltage. The block diagram of an inverter is shown in **Figure 3.1**

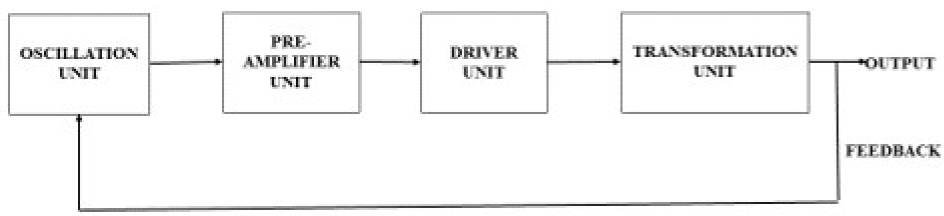


Figure 3.1: Block diagram of an inverter

3.1.1.1 OSCILLATION UNIT

This unit receives input from the feedback signal. The oscillator output is used to generate a clock pulse for the next stage, and is used to determine the frequency at which the system operates.

Refrence voltage of the SG3524, $\text{Vout} = (\frac{\mathbf{R1}}{\mathbf{R1+R2}})\,\text{Vin}$ (3.1)

Frequency of the output pulse, $f = \frac{\mathbf{1.18}}{\mathbf{TC}+\frac{\mathbf{TR}}{\mathbf{2}}}$ (3.2)

3.1.1.2 PRE-AMPLIFIER UNIT

This unit is made up of pre-amplifiers components. The pre-amplifier is a very low noise amplifier that takes a very small signal from the oscillator, and boosts it enough to be a sufficient input for a more powerful amplifier. Without the pre-amplifier, the final output signal will by noisy.

3.1.1.3 DRIVER UNIT

In this unit, the signal is amplified to a sufficient level. It efficiently provides high speed and high current switching required by the transformer. The driver section also helps to separate the signal into two different channels.

3.1.1.4 TRANSFORMATION UNIT

This unit gets a switched DC voltage input from the driver unit, and steps the voltage up to a higher AC value (depending on the calculation). This stepped-up voltage serves as the output to our various appliances as well as a feedback to our oscillation unit. The transformation section determines the load capacity of the UPS system.

Volume of Transformer Core = length * breadth *height (3.3)

Power, P = Current(I) * Voltage(V) (3.4)

3.1.2 THE CONTROL UNIT

Figure 3.2: Block Diagram of the Control Unit

3.1.2.1 MONITORED INPUT SIGNAL

This Unit is designed to keep check on overload, under-charge, over-charge and low battery conditions in the system. Once any of these occurs the microcontroller is signaled.

3.1.2.2 MICROCONTROLLER UNIT

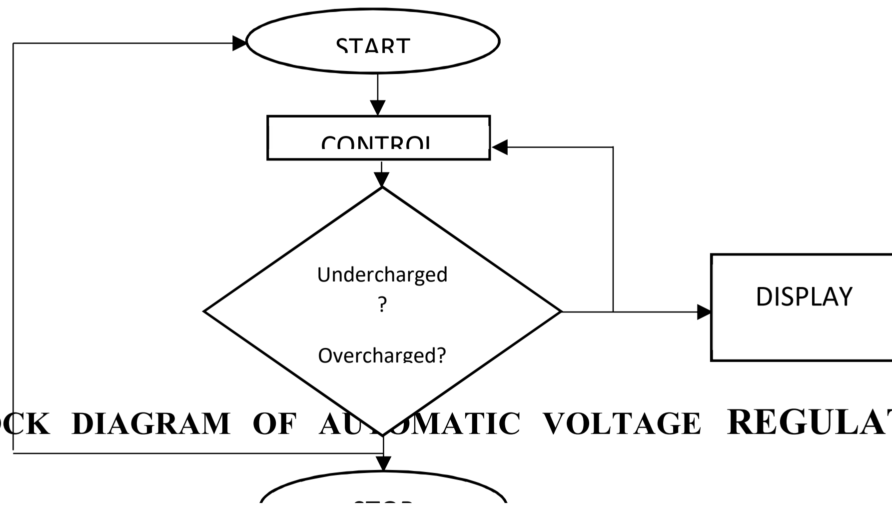
This unit works based on a series of instruction set. When the monitor unit detects any of these unfavorable conditions, the microcontroller unit sends the corresponding programmed output to the display unit.

3.1.2.3 DISPLAY UNIT

This unit displays the information sent by the microcontroller through the Liquid Crystal Display, so that user can read the cause of inverter shutdown.

3.1.2.4 FLOWCHART

The flowchart below shows the algorithm involved in the process;



3.1.3 BLOCK DIAGRAM OF AUTOMATIC VOLTAGE REGULATOR (AVR)

Figure 3.3: Block Diagram of A Control Unit

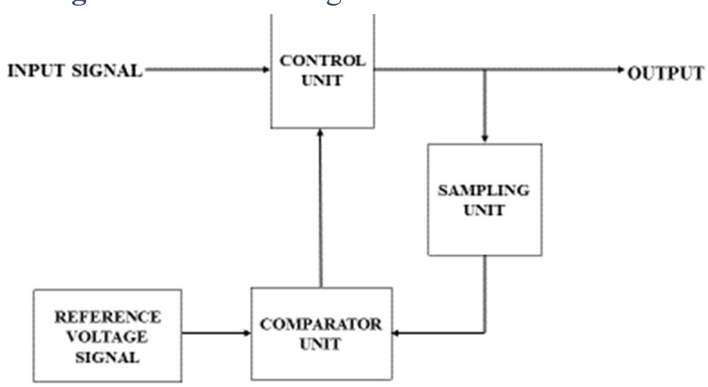


Figure 3.4 **BLOCK DIAGRAM OF AUTOMATIC VOLTAGE REGULATOR**

3.1.3.1 CONTROL UNIT

A control element is placed to collect the unregulated input, which controls the magnitude of the input voltage and passes it to the output.

3.1.3.2 SAMPLING UNIT

The initial output voltage sent by the control unit is fed back to the sampling circuit and then compared with a reference voltage before being sent back to the output.

3.1.3.3 COMPARATOR UNIT

In this unit if the output voltage tends to increase or decrease the comparator circuit provides a control signal to cause the control unit to reduce or raise the magnitude of the output voltage respectively thereby maintaining a constant and steady output voltage.

3.1.3.4 VOLTAGE REFERENCE SIGNAL

This unit provides the reference voltage that the comparator works with.

3.2 SYSTEM COMPONENTS

These are the various electronic components that make up the system.

3.2.1 RELAY

A relay is an electrically operated switch. When an electric current is passed through the coil it generates a magnetic field that energizes the armature, and the consequent movement of the movable contact either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. The relay is used in the changeover unit and automatic voltage regulator section of the system. There are various types of relays which are listed below;

- The Single Pole Single Throw Relay.
- The Single Pole Double Throw Relay
- The Double Pole Single Throw Relay.
- The Double Pole Double Throw Relay.

In this design, a Single Pole Double Throw was used. The Single Pole Double Throw SPDT relay is quite useful in certain applications because of its internal configuration. It has one common terminal and 2 contacts in 2 different configurations: one can be normally closed and the other one is opened or it can be normally open and the other one closed. So basically, you can see the SPDT relay as a way of switching between 2 circuits: when there is, no voltage applied to the coil one circuit “receives” current, the other one doesn’t and when the coil gets energized the opposite happens.

Figure 3.5 **RELAY**

3.2.2 BATTERY

It serves as a DC power source to electrical or electronic equipment that make use of it. Battery is made available as the direct source of energy when the mains fails. It is therefore necessary to select a reliable battery for optimum performance. The choice of battery depends on the load requirements. We have the lead-acid battery and the dry cell battery. But the dry cell battery is used for this design. This is because of its suitability for UPS systems since it requires less maintenance.

Figure 3.5 **BATTERY**

3.2.3 SOLAR PANEL

Solar panels absorb the sunlight as a source of energy to generate electricity. The absorption is done through the photo voltaic module. This device serves as the alternative source of power to the mains for charging the battery.

There are two types of solar panel; the monocrystalline and the polycrystalline solar panel. In this work, the monocrystalline solar panel is used due to its high efficiency.

$$\text{Total Watt-Hour} = \text{Total load} * \text{Period of operation} \quad (3.5)$$

$$\text{solar panel wattage} = \frac{\text{Total Watt−Hour}}{\text{period of the solar panel exposed to the sun}} \quad (3.6)$$

$$\text{Number of panel} = \frac{\text{Total solar panel wattage}}{Watta \quad eac \quad solar\ panel} \quad (3.7)$$

3.2.4 SOLAR CHARGE CONTROLLER

A solar charge controller is used to regulate the incoming from the sun for charging the batteries or for powering DC equipment with solar panels. The charge controller not only provides a regulated DC output and stores excess energy in a battery but also monitors the battery voltage to prevent under/overcharging. An inverter can also be connected to the output of a charge controller to drive AC loads. There are various types of solar charge controller;

- **Simple 1 or 2 Stage Controls:** It has shunt transistors to control the voltage in one or two steps. This controller basically just shunts the solar panel when a certain voltage is arrived at. Their main genuine fuel for keeping such a notorious reputation is their unwavering quality – they have so not many segments, there is very little to break.

- **PWM (Pulse Width Modulated):** This is the traditional type charge controller, for instance anthrax, Blue Sky and so on. These are essentially the industry standard now.

- **Maximum power point tracking (MPPT):** The MPPT solar charge controller is the best of all in solar system applications. These controllers are able to identify the best working voltage and amperage of the solar panel, exhibit and match that with the electric cell bank.

3.2.5 BATTERY CHARGER

This is a circuit used to store energy in the rechargeable battery. Slow battery chargers may take several hours to complete a charge; high-rate chargers may restore most capacity much faster, but high rate chargers can be more than some battery types can tolerate. The battery charger is required to generate at least one-tenth of the total battery current. The specification of the battery need to be considered in order to preserve the battery performance even with continuous charging process.

3.2.6 SWITCH

In electrical engineering, a switch is an electrical component that can "make" or "break" an electrical circuit interrupting the current or diverting it from one conductor to another. The switch is used to turn ON/OFF the system.

3.2.7 FUSE

A fuse is an electrical device used in electrical systems to protect against excessive current. It is a sacrificial device, its essential component is a metal wire or strip that melts when too much current flows through it, thereby interrupting the current to prevent any damages to the system. Today there are different fuse designs which have specific current and voltage ratings, depending on the application.

3.2.8 SOCKETS

Sockets are devices that allow electrically operated equipment to be connected to the primary alternating current (AC) power supply. Electrical sockets differ in voltage and current rating, shape, size and type of connectors.

3.2.9 LED INDICATOR

It radiates optical energy when forward biased. LED is classified based on the type of optical energy it radiates. The visible LED provides a useful means of indicating the state of a circuit and is therefore used as an indicator. To use visible LED as an indicator there is a need for the use of a protective resistor, which serves as a potential divider. The invisible/infrared LED radiates infrared light when forward biased. It is used in conjunction with the photodiode phototransistor to form a sensing system as in the remote-control circuit.

3.2.10 TRANSISTOR

A solid-state semiconductor device used to switch the DC current source into pulses of electricity and/or into an AC waveform. The Bipolar junction transistor is a solid-state device and in the BJTs the current flow in two terminals, they are emitter and collector and the amount of current controlled by the third terminal i.e. base terminal.

The Base-Emitter (BE) junction is a forward bias and the Collector-Base (CB) is a reverse bias junction. The width of the depletion region at the CB junction is higher than the BE junction. The forward bias at the BE junction decreases the barrier potential and produces electrons to flow from the emitter to the base. Electrons from the emitter recombine in the base region with holes and flows out from the base terminal. This initiate the base current flow due to combination of electrons and holes. The left over large number of electrons will pass the reverse bias collector junction to initiate the collector current.

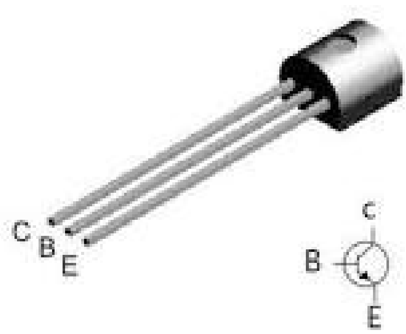
There are two types BJT transistor; the NPN and the PNP transistor.

- **PNP junction transistors**: Here, the collector terminal is connected to the positive terminal and the emitter to a negative supply with resistor either the emitter or collector circuit. To the base terminal, the voltage is applied and it operates transistor as an ON/OFF state. The transistor is in OFF state when the base voltage is same as the emitter voltage. The transistor mode is in ON state when the base voltage decreases with respect to the emitter.

- **NPN junction transistors**: In this type, positive supply is given to the collector terminal and the negative supply to the emitter terminal with a resistor either the emitter or collector or emitter circuit. To the base terminal, the voltage is applied and it operated as an ONN/OFF state of a transistor. The transistor is in OFF state when the base voltage is same as the emitter. If the base voltage is increased with respect to the emitter, then the transistor mode is in ON state.

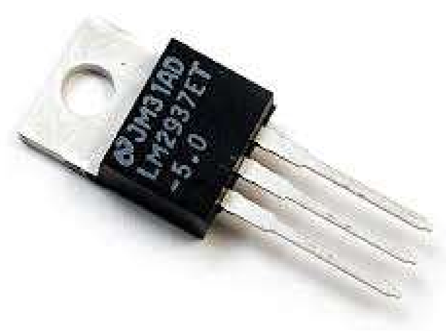
$$\text{DC Current Gain} = \frac{\textit{Output Current}}{\textit{Input Current}} = I_C \div I_B \tag{3.8}$$

$$\boldsymbol{\alpha} = I_C \div I_E$$



3.2.11 VOLTAGE REGULATOR

Voltage regulator is an electronic component designed to automatically maintain a constant voltage level. All voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. The incoming voltage must be greater than the reference voltage, so that this reference voltage will constantly be produced at the output.



3.2.12 SG3524 OSCILLATOR (IC)

It is a monolithic IC that contains all the control circuitry for a regulated power supply inverter or switching regulator. Included in a 16-pin package is the voltage reference, error amplifier, oscillator, pulse width modulator PWM, pulse steering flip-flop, dual alternating output switches, current limiting and shutdown circuitry. The oscillator in the SG3524 uses an external resistor (RT) to establish a constant charging current into an external capacitor (CT). While this uses more current than a series-connected RC, it provides a linear ramp voltage on the capacitor which is also used as a reference for the comparator. The range of values for C_T also has limits as the discharge time of C_T determines the pulse-width of the oscillator output pulse. This pulse is used as a blanking pulse to both outputs to ensure that there is no possibility of having both outputs on simultaneously during transition.

3.2.13 MOSFET

Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is a three-terminal device they can be used either as an amplifier or as a frequency switch. MOSFETs are the major components of the switching section.

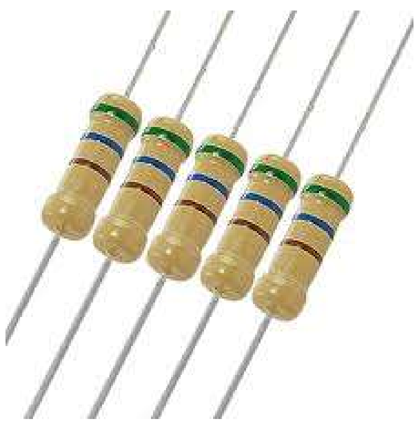
3.2.14 DIODE

A diode is a two-terminal electronic component that conducts primarily in one direction. It has low (ideally zero) resistance to the current in one direction, and high (ideally infinite) resistance in the other. A semiconductor diode, the most common type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals.

3.2.15 RESISTOR

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses.

$$\text{Voltage, } V = \text{Current}(I) * \text{Resistance}(R) \qquad (3.9)$$

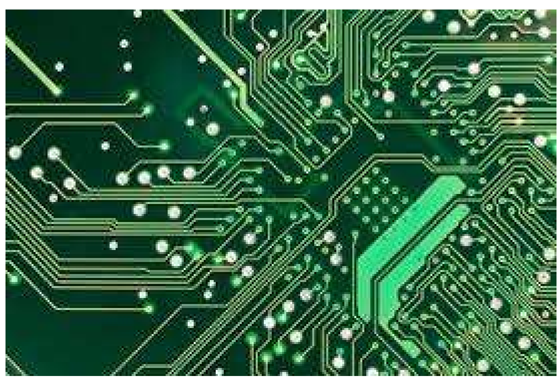


3.2.16 CAPACITOR

An electrochemical device that can temporarily store or provide very quick pulses of electricity in an AC or DC electrical system, capacitors are often used to smooth out variations in power. There are two kinds of capacitors used in this project the electrolytic and the non-electrolytic capacitor. The electrolytic capacitor is polarized while the non-electrolytic capacitor is non-polarized.

3.2.17 PRINTED CIRCUIT BOARD (PCB)

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. Electronic components (e.g. capacitors, resistors or active devices) used in the design of this system are soldered on the PCB.



3.2.18 TRANSFORMER

An electromagnetic device, typically made of two separate copper windings on an iron or steel core, that can step an AC voltage up or down. There are two kinds of transformer; the step-up and the step-down transformer.

The Step-up transformer increases the input AC voltage at the output while the Step-down transformer decreases the supplied input AC voltage. For this work we will make use of a step-up transformer since an inverter operates by increasing the pulsated input voltage from the battery from 24V to 240V AC voltage.

Also, the transformer can be according to its frequency of operation. The Low frequency transformer operates at a frequency of 50-60Hz while the High frequency transformer operates at about 37-60KHz. Low-frequency transformers tend to be large and very heavy, while high-frequency transformers can be small and light.

For this system, a low frequency transformer is used basically due to its suitability for high power operations (in this case 2KVA), ruggedness, and reliability.

3.2.19 MICROCONTROLLER

A microcontroller is a small and low-cost computer built for the purpose of dealing with specific tasks. Microcontroller has an input device in order to get the input and an output device (such as LED, LCD) to exhibit the final process. This component works based on a series of instruction set. On receiving an input, the microcontroller unit sends the corresponding programmed output to the display unit.

CHAPTER 4

DESIGN, IMPLEMENTATION AND TESTING

There are various available means for generating power like electric generator, Uninterruptible Power Supply (UPS) etc. When downtime is to be avoided, an UPS is the best option available so far.

To design an inverter the first thing to consider is the power requirements. This helps to determine the power capacity of the system, the kind of pulse to be generated by the inverter you are to be designed and the battery size (which depends also on how long the system is expected to last).

For this design of a 2KVA, to determine the battery capacity:

To convert VA(Volts-Ampere) to Watts:

Real Power (Volts-Ampere) * Power Factor = Apparent Power(watts)

2000 * 0.8 = 1600W

Battery Ampere-Hour = 100AH

Battery Voltage = 24V

Efficiency of battery is assumed to be 0.8

Back-up time = 9hrs

Number of Batteries = $\frac{Total\ power*Back-up\ time}{Battery\ Amp-hour*Battery\ Voltage*efficiency}$

Number of Batteries = $\frac{1600*9}{100*24*0.8}$ = 7.5 ≅ 8 Batteries

4.1 HARDWARE DESIGN AND CALCULATION

4.1.1 Inverter Design: This section shows the inverter design and the related calculations.

4.1.1.1 Circuit Diagram:

4.1.1.2 Oscillator Unit: The sg3524 IC is used in the oscillation section to generate the output pulse sent to the pre-amplifier. This IC has 16 pins;

Pin1 & 2: These are the two input pins to the internal error amplifier of the sg3524. Pin1 serves as the pin for the reference voltage, it receives a 2.5v input ($Vout$) from the pin9 through a voltage divider.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right)\boldsymbol{Vin}$$

$$\boldsymbol{Vout} = \left(\frac{\mathbf{4.7}}{\mathbf{4.7+4.7}}\right) 5$$

$$Vout = 2.5\text{v}$$

Pin3 & 4: These two pins are also error amplifiers. But were not used since we require just one error amplifier.

Pin5: A non-electrolytic capacitor is connected to this pin and this serves as a filter.

Pin6: A resistor of calculated value is connected to this pin and this is used to assign a 50Hz frequency of operation to the sg3524. A 20K variable resistor is also attached and this is used to tune the frequency.

Frequency, f = $\frac{\mathbf{1.18}}{\boldsymbol{TC}+\frac{\boldsymbol{TR}}{\mathbf{2}}}$

$$50 = \frac{\mathbf{1.18}}{\mathbf{1}+\frac{\boldsymbol{TR}}{\mathbf{2}}}$$

$$TR = 128\text{K}$$

150K was therefore selected since there is no 128K in the market.

Pin7: A 100ohms resistor and a 104 non-electrolytic capacitor is connected to this pin. This serves as a low pass filter.

Pin8: A 47uf capacitor is connected to this pin. This capacitor gives the system a soft start. The higher the capacitor, the longer it takes for the system to start.

Pin9: This pin gives out at most 5v output once the sg3524 is in operation.

Pin10: This serves as the shutdown pin. Once a signal is sent to it, the system shuts down.

Pin11: This serves as one part of the pulse output.

Pin12: This pin is grounded.

Pin13: It is connected to a 12v source, the battery in this case.

Pin14: This is the second output pin of the sg3524.

Pin15: This pin is also connected to the 12v source.

Pin16: A 5v signal is generated at this pin once the sg3524 is powered. This serves as the input voltage to the pin1.

4.1.1.3 Pre-amplifier Unit: Here consist of transistors connected in Darlington pairs. The connection helps to increase the output gain since current is amplified in the first stage and amplified further in the second stage. In the first stage where an NPN transistor is used (BC547), the base is biased with the output pulse from the oscillator. A 56k resistor was used as the pull up resistor and the resistor value is high to block negative signals during operation, with a 10K resistor at the collector output. At the second stage, the base is biased with the output from the collector of the first stage, with a base resistor of 1K.

4.1.1.4 Driver Unit: The driver circuit is needed to help MOSFET's to maximize the turn on and turn off time. If the MOSFET takes relatively long time going in and out of conduction, then we cannot use the advantage of using MOSFETs. This will cause the MOSFETs to heat up and device will not function properly. In this design MOSFET drivers use bootstrap circuit to create voltages to drive the gate to a higher voltage than the MOSFETs supply voltage. The gate of MOSFET acts like a capacitor to the driver, this means that the driver can turn on or off MOSFET very rapidly, by charging or discharging the gate respectively. In this unit the sixteen IRF450 MOSFETs (with maximum drain current of 48A and power of 150W) were connected in parallel, this is to withstand the maximum current that can be drawn by the 2KVA load.

4.1.1.5 Transformation Unit: A low frequency transformer was wound.

Core Design:

Length of Core = 17cm

Breadth of Core = 10cm

Height of Core = 12cm

Volume of Core = 17 * 10 *12 = 2040cm^3

Recall, Volume of Core = Maximum Power Capacity;

Therefore, Power Capacity of Transformer = 2040cm^3

Using the standard due to the permeability of the core = 42v/t/cm^3

Area of the core = Breadth * Height = 10 * 12 = 120cm^2

Voltage per Turn = $\frac{42}{120}$ = 0.35v/turn

Wire Gauge Selection:

For the Primary Winding: Power, P = Current(I) * Voltage(V)

$$2000 = I * 24$$

$$I = 83.33A$$

Since the wire gauge for 83.33A is too big, the wire gauge for half of the Current(I) was used but two pieces of the wire was used at once.

Half of the current, I = 83.33/2 = 41.67A

For the Secondary Winding: Power, P = Current(I) * Voltage(V)

$$2000 = I * 240$$

$$I = 8.33A$$

4.1.2 Control Unit Design: This involves all these circuits in the control section.

4.1.2.1 Circuit Diagram:

4.1.2.2 Monitor Unit: This unit consists of the overload monitor, under-charge monitor, over-charge monitor, low battery monitor and the automatic change over. The comparator used here is the lm324 IC.

Overload Monitor: A current transformer is connected between the inverter transformer and the output, this monitors the current drawn by the load. The output of the current is sent to the inverting terminal of the comparator through a variable resistor. A voltage divider is used to reference the non-inverting input of the comparator to 5v. The comparator sends an output signal when the load is above 2000w and this signal energizes the base of the transistor to switch off the system.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right) \boldsymbol{Vin}$$

$$2.5 = \left(\frac{5}{5+R1}\right) 5$$

$$R1 = 5\mathrm{K}$$

Under-charge monitor: Some part of the charger circuit output voltage is tapped, and sent to a comparator through a voltage divider. The inverting input of the comparator is referenced to 5V using a 5volts Zener diode. When the output voltage of the charger circuit is lower than the required voltage, the comparator sends out an output signal which switches off the charger circuit.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right)\boldsymbol{Vin}$$

$$5 = \left(\frac{5}{5+R1}\right) 15$$

$$R1 = 20\text{K}$$

Over-charge monitor: Voltage is tapped from the battery to keep check on when the battery is fully charged. This battery voltage through a voltage divider serves as an input to the inverting pin of the comparator. The non-inverting pin of the comparator is reference to 5V using a Zener diode.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right)\boldsymbol{Vin}$$

$$5 = \left(\frac{10}{10+R1}\right)26$$

$$R1 = 42 \cong 47\text{K}$$

Low battery monitor: The inverting pin of the comparator receives input from the positive terminal of the battery through a voltage divider. The non-inverting pin of the comparator is connected to the pin16 of the sg3524 IC that gives it a reference voltage of 5V. When the battery voltage is lower than the required level, the comparator sends an output signal to the pin10 of sg3524. This helps to shut down the system.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right)\boldsymbol{Vin}$$

$$5 = \left(\frac{10}{10+R1}\right)19$$

$$R1 = 27.99 \cong 30\text{K}$$

Automatic change over: A rectified mains source is connected to the inverting pin of the comparator, and the voltage from the battery is connected through a voltage divider to the non-inverting pin. When there is supply from the mains, the comparator sends an output signal to the transistor that in turn activates the changeover relay.

$$\boldsymbol{Vout} = \left(\frac{\boldsymbol{R1}}{\boldsymbol{R1+R2}}\right)\boldsymbol{Vin}$$

$$6 = \left(\frac{4.7}{4.7+R1}\right)24$$

$$R1 = 8.8 \cong 10\text{K}$$

4.1.3 Automatic Voltage Regulator (AVR) design: This shows the design approach of the AVR.

4.1.3.1 Circuit Diagram:

4.1.3.2 Control Unit: This unit is made up of the AC relays that selects the suitable input for the transformer, depending on the value of the mains supply. An IN4007 general purpose diode is connected in between the negative and positive terminal of the relay to prevent fly-back.

4.1.3.3 Sampling Unit: This unit consists of a 220k resistor, a diode and a 22uf/50V capacitor. Here a small sample of the incoming mains supply is taking, rectified and sent to the non-inverting terminal of the comparator unit.

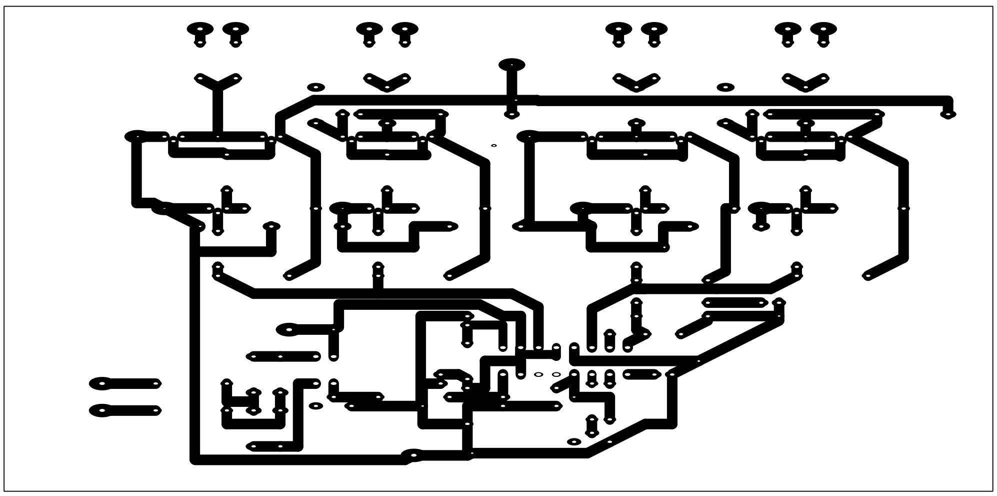
4.1.3.4 Comparator Unit: This unit consist of four comparators where each monitors a range of incoming mains voltage supply. For any range of voltage, the suitable comparator sends an output to the 9014 NPN transistor connected to its output pin. This transistor then switches on the corresponding AC relay in the control unit.

4.1.3.5 Voltage Reference Unit: Once there is an input voltage from the mains, an 11V voltage tapped from the transformer is sent through a diode (for rectification) to the BD139 NPN transistor. This switch 6.8V to the four variable resistors (since the emitter is connected in parallel with a 6.8V Zener diode). Each of the variable resistors is then used to preset a reference value for the non-inverting pin of the comparator. Their reference values will be different so that each comparator will monitor different level of mains input.

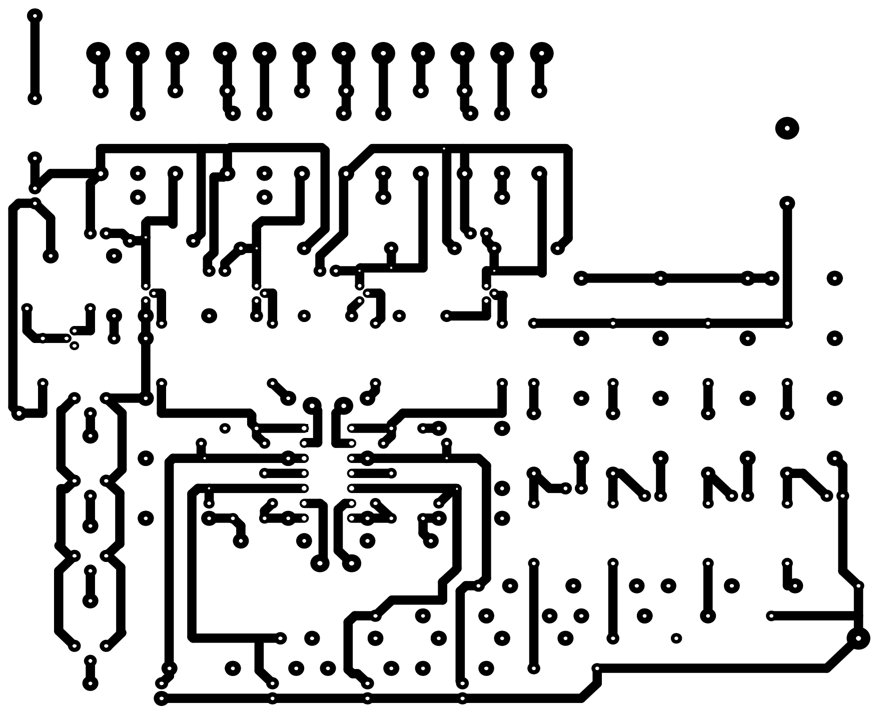
4.1.4 Printed Circuit Board (PCB) Design: The circuit diagram physical connections are implemented on this board.

The schematic diagram of the circuit to be implemented is first drawn on proteus environment and the printed out on a paper. The copper board to be used is cut out and the surface is cleaned and smoothened using a sandpaper. The circuit diagram on the paper is transferred to the PCB surface using a laser jet printer. This copper board now containing the imprint of the circuit diagram (made of carbon) is deep into a concentrated ferric chloride solution and left for about 20minutes. A chemical reaction takes place and the copper layers not covered with carbon are washed away. A mild sandpaper is used to remove the carbon covering the copper connections on the PCB board so that component can be easily be soldered on the board.

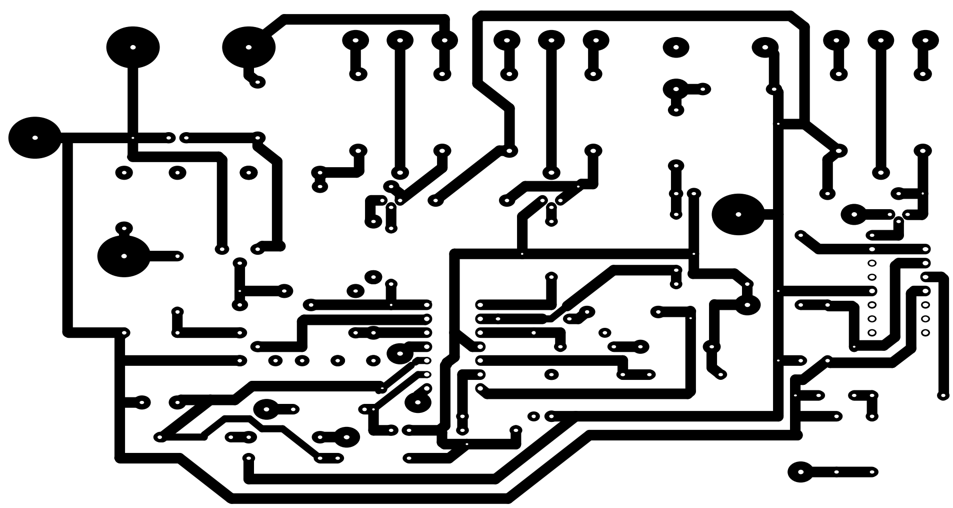
For the Inverter:



For the Automatic Voltage Regulator:



For the Control Unit:



5.1.1 Solar Panel Calculation:

Total load = 2000W

Period of operation or duration = 9 Working Hours.

Then, Total Watt-Hour = 2000×9= 18000w-hr.

The period of the solar panel exposed to the sun = 6 Hours (Averagely between 9am and 3pm)

Therefore, solar panel wattage $=\frac{18000}{6}= 3000W$

Hence solar panel of 3000W will be needed for this design. If solar panel of 300W is to be use the number of panels to arrange in parallel to achieve 3000Watt will be:

Number of panel $=\frac{3000}{300}=10$

This shows 10 of 300 Watt solar panel will be required for this design.

4.1.5 Casein design: The required measurements were taken and a sheet of metal was cut and folded into the desired shape, then the points that will be screwed were drilled open. Then the circuits and transformer were arranged inside this container and tighted with screws.

4.2 Testing: These are the various test carried out to ensure that each unit of the system functions properly when separate, as well as when coupled together.

4.2.1 Oscillator Test: The oscillator circuit was test by measuring the output of each pin with a multi-meter to check if they really correspond to the expected value.

Pin1 = 0V

Pin2 = 2.5V

Pin3 = No output (Not in use)

Pin4, 5, 8, 10, = 0V

Pin6 = 3V

Pin7 = 2.4V

Pin9 = 4.2V

Pon11 & 14 = 5.4V

Pin12 & 13 = +12v

Pin16 = 5V

4.2.2 Transformer Test: The transformer the transformer was supplied with a 24V input, and the output was measured to be 229V and this corresponds to the calculated value. The transformer was left to operate for long and no humming was observed.

4.2.3 No load Test: When no load is connected, the system tested and the current from the output was 0.9A, which the required current value in no load test.

4.2.4 Overload Test: Load below the 2KVA capacity was efficiently carried but the system shutdown when load greater than the specified capacity of 2KVA was applied

4.2.5 AVR Test: The AVR test was carried out, the input voltage was varied but the output voltage remained within 220 – 240V which is the calculated output value.

4.2.6 Charge Controller Test: The output of the charge controller was test and the voltage output read the required 24V and 20A of current.

4.2.7 Battery Charger Test: In this circuit, the voltage and current output values were measured the voltage was at 26V that is suitable for charging a 24V battery. The current was also measured to be 27A, which is up to 10% of our battery's current and hence is suitable for charging the battery cell.

4.2.8 Driver Unit Test: The voltage output from the MOSFETS were measured and it frequency of operation was confirmed to be 50Hz which corresponds to the calculation done in the oscillator part.

4.2.9 Solar Power Cell Test: The solar panel test was carried out by exposing the panel to peak day sunlight (2pm) and the voltage output was measured to be 29V

4.2.10 Battery Test: The battery was tested with an element which glowed red light with a green light also still on showing that the battery is in good condition.

4.2.11 System Test: The system was switched ON and the output voltage was measured to be 230V. A 220V/60W AC bulb was connected, then the output current was measured to be 0.26A.

4.2.12 System Reliability Test:

The system was tested over time, $t = 72$hrs

The number of failures, $k = 3$

Total number of components in the system, $N = 173$

Total Time, $T = [t_1 + t_2 + t_3 + (N\text{-}k)\ t_3]$

First item failed after time, $t1 = 18$hrs; a resistor got burnt suspectedly due to excessive current.

Second item failed after, t2 = 45hrs; a MOSFET blew when the system was overloaded.

Third item failed after, t3 = 62hrs; a capacitor got burnt probably due to over voltage.

T = [18 + 45 + 62 + (173-3) 62]

T = 10665

Failure Rate, $\lambda = \frac{Number\ of\ failures}{Total\ Time}$

$\lambda = \frac{3}{10665}$

$\lambda = 2.81 * 10^{-4}$

Reliability, R = exp-(λt)

$= exp-(2.81 * 10^{-4} * 72)$

R = 0.98

CHAPTER FIVE

5.1 DISCUSSION

The whole concept of the system cuts across the hardware implementation and the little software implementation. The system generates an output that conveniently powers an AC bulb, fan, personal computer etc.

During this work, a lot of challenges were faced.

- Some components got burnt during the implementation, which affected the initial plan of making the system affordable.
- Winding of transformer to give the required output.
- Epileptic power supply for soldering.
- Tracking of Printed Circuit Board on proteus IDE.
- Coupling the system and getting them to work as a unit.
- Gathering of materials.

5.2 RECOMMENDATIONS

For further advancement on this already existing system, the system can be:

- Made able to power inductive loads by designing a pure sine wave inverter.
- Expanded to use more sources of power like the wind and so on.
- Made to respond to remote signals.
- Controlled and monitored also with mobile devices from distant location.

  An improvement can also be made on the system by successfully use a single transformer for both the inverter and the transformer.

5.3 SKILLS ACQUIRED:

Some of the skills acquired during this project are:

- Transformer design.
- PCB design
- Inverter Design
- Automatic Voltage Regulator (AVR) design
- Use of Proteus IDE
- Basic knowledge of assembly language programming
- Anger management.
- Team management.

- ➢ Coupling and neat Packaging.

5.4 CONCLUSION

The provision of hybrid mains-solar energy system is very important so as to maintain a continuous electricity supply for industries and homes. Also, if the social and economic lives of people are to be improved, there is need to provide steady electricity.

It can be concluded that the sole aim of this project, which is the design, construction and implementation of a 2KVA smart hybrid uninterrupted power supply system was successfully realized at the end of this project.

When considering the cost, reliability and overall efficiency of a Smart Hybrid Uninterruptible Power Supply (SHUPS) system, it is advisable to embrace this system due to its intelligence and diverse power source.

REFERENCES

[1] https://en.wikipedia.org/wiki/Uninterruptible_power_supply

[2] Hafiz Zahid and Majid Ali, "Final year project synopsis Design and Implementation of Intelligent UPS".

[3] Carbon Trust, "Uninterruptible power supply",

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/376191/ECA778_Uninterruptible_Power_Supply.pdf

[4] http://www.engineersedge.com/instrumentation/purpose_ups.htm

[5] http://www.upspower.co.uk/what-are-the-key-differences-between-online-offline-and-line-interactive-upss/

[6] Standford University, "An Assessment of Solar Energy Conversion Technologies and Research Opportunities Global Climate and Energy Project",2006.

[7] Tyagi, V. V., Rahim, N. A. A., Rahim, N. A. and Selvaraj, J. A. L, "Progress in solar PV

technology: Research and achievement. Renewable and Sustainable Energy Reviews", 20, 443-461, 2013.

[8] Fonash, S. J, "Solar Cell Device Physics, Boston, Academic Press", 2010.

[9] Badawy, W. A, "A review on solar cells from Si-single crystals to porous materials and quantum dots. Journal of Advanced Research", 2013.

[10] Glunz, S. W, Preu, R. and Biro, D, "Crystalline Silicon Solar Cells: State-of-the-Art and Future Developments," In: SAYIGH, A. (ed.) Comprehensive Renewable Energy. Oxford: Elsevier, 1.16 2012.

[11] Wenham, S. R,"Applied Photovoltaics", UK, Earthscan, 2007.

[12] Actenergy. 2014 "The principle charactistics of a photovoltaic system [Online]. Available: http://actenergy.it/?lng=us&ms2=61&ms3=53&ctm=64 [Accessed 14th July 2014 2014].

[13] Badawy, W. A, "A review on solar cells from Si-single crystals to porous materials and quantum dots. Journal of Advanced Research", 2013.

[14] Rashmi Swami, "Solar Cell International Journal of Scientific and Research Publications", Volume 2, Issue 7, July 2012.

[15] Barbara M. Drazga, "Solar Power Applications", Technology for Life.

[16] Million Solar Roofs. Advantages of Solar Energy. http://www.millionsolarroofs.com.

[17] Roth, K. W., Goldstein, F. and Kleinman, J, "Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings", 2002.

[18] Chen, C. J, "Physics of Solar Cells", Hoboken, New Jersey, John Wiley & Sons, Inc. 2011.

[19] Chow, N. C. L, "Standby generator and UPS description". Lecture in Electrical Services Elective I City University of Hong Kong, 16 November 2012.

[20] Nasiri, A, "24 - Uninterruptible Power Supplies," In: RASHID, M. H. (ed.) Power Electronics Hand- book (Third Edition). Boston: Butterworth-Heinemann. 2011.

[21] Ward, D. J. "Power quality and the security of electricity supply," Proceedings of the IEEE, 89,

1830-1836, 2001.

[22] Shepherd, W and Zhang. L, “Power Converter Circuits”, New York, Marcel Dekker. 2004.

[23] Nishij Gapatrao Kulkarni, Vasudeo Bapuji Virulkar, “Power Electronics and its Application to Solar Photovoltaic Systems in India,” Energy and Power Engineering, 8, 76-91, 2006.

[24] Cavallaro, C. Musumeci, S, Santonocito, C. & Pappalardo, M. “Smart photovoltaic UPS system for domestic appliances”. Clean Electrical Power, International Conference on, 9-11 699-704. June, 2009.

[25] Jawaid, H., Ehsan, N., Mirza, E. & Bhatti, M. W. “Solar powered UPS. Procedia Technology”, 1, 217-224. 2012.