

Sudan University for Science & Technology
College of Engineering
School of Electrical & Nuclear Engineering

Design of UPS for Personal Uses

**تصميم مصدر قدرة كهربائية غير قابل للإنقطاع للإستخدام
الشخصي**

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

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October 2015

الآية

قال تعالى في محكم تدبره:

{ مَثَلُ الَّذِينَ يُنْفِقُونَ أَمْوَالَهُمْ فِي سَبِيلِ اللَّهِ كَمَثَلِ حَبَّةٍ أَنْبَتَتْ سَبْعَ سَنَابِلَ فِي كُلِّ سُنبُلَةٍ مِائَةُ حَبَّةٍ وَاللَّهُ يُضَاعِفُ لِمَنْ يَشَاءُ وَاللَّهُ وَاسِعٌ عَلِيمٌ (261) الَّذِينَ يُنْفِقُونَ أَمْوَالَهُمْ فِي سَبِيلِ اللَّهِ ثُمَّ لَا يُتْبِعُونَ مَا أَنْفَقُوا مَنًّا وَلَا أَذَى لَهُمْ أَجْرُهُمْ عِنْدَ رَبِّهِمْ وَلَا خَوْفٌ عَلَيْهِمْ وَلَا هُمْ يَحْزَنُونَ (262) قَوْلٌ مَعْرُوفٌ وَمَغْفِرَةٌ خَيْرٌ مِنْ صَدَقَةٍ يَتْبَعُهَا أَذَى وَاللَّهُ غَنِيٌّ حَلِيمٌ (263) يَا أَيُّهَا الَّذِينَ آمَنُوا لَا تُبْطِلُوا صَدَقَاتِكُمْ بِالْمَنِّ وَالْأَذَى كَالَّذِي يُنْفِقُ مَالَهُ رِئَاءَ النَّاسِ وَلَا يُؤْمِنُ بِاللَّهِ وَالْيَوْمِ الْآخِرِ فَمَثَلُهُ كَمَثَلِ صَفْوَانٍ عَلَيْهِ ثَرَابٌ فَأَصَابَهُ وَابِلٌ فَتَرَكَهُ صَلْدًا لَا يَقْدِرُونَ عَلَى شَيْءٍ مِمَّا كَسَبُوا وَاللَّهُ لَا يَهْدِي الْقَوْمَ الْكَافِرِينَ (264) }

صدق الله العظيم

سورة البقرة، الآيات (261-264)

DEDICATION

To our parents, who always find it in their purpose to guide us, inspire us and advise us, nothing of this could've been possible without the prospering which Allah blessed us with, and our parents, may Allah bless them all.

To our supervisor, Dr. Jeddani Osman, who's always donating his knowledge to us and never letting us down.

To our dear family members, to our friends and colleagues.

To everyone who is an integral part of our support group, we dedicate this work.

ACKNOWLEDGMENT

The greatest thanks to Allah above all always, before and after.

We would like to express our deep gratitude to everyone who has been helping us throughout this work at any step.

Most appreciation to our supervisor Dr. Jeddani Osman Adlan, for their expert support and valuable advices which guided us throughout this work and guided us at the beginning of our career life as engineers.

We would also like to thank all of our teachers in the school of electrical and nuclear engineering for all the help and knowledge that they gave us.

ABSTRACT

This project aims at the design of an uninterruptable power supply (UPS), specifically, a UPS designed for personal and home uses (small electrical appliances), not only to prevent the discontinuity of the electrical power to the loads connected to this UPS, but also to protect whatever loads to be connected from any unwanted disturbances on the electrical power supplying this UPS.

The designing process of this UPS was conducted in several steps, firstly by designing a proper rectifying circuit (to convert the AC power to DC), secondly, choosing, charging and controlling the battery, and finally designing an inverting circuit (to convert DC to AC power).

After designing the model, it was tested in a simulation program on the computer and got further improvements, and the results were discussed, also, instructions and recommendations were presented for future improvements for this UPS system.

المستخلص

هذا المشروع يهدف لدراسة و تصميم نظام لمصدر قدرة كهربائية غير قابل للإنقطاع, تحديداً, للإستخدام الشخصي أو المنزلي (أحمال كهربائية صغيرة), عمل هذا النظام لا يكمن فقط في حماية الأحمال المتصلة به من إنقطاع التيار الكهربائي, بل أيضاً يعمل على حماية الأحمال المتصلة به من التغيرات و المشاكل الغير مقبولة التي قد تطرأ في المصدر الكهربائي الذي يغذي هذا النظام.

عملية تصميم هذا النظام لمصدر القدرة الكهربائية الغير قابل للإنقطاع تمت على عدة خطوات, أولها تصميم دائرة مناسبة لتحويل التيار المتردد إلى تيار مستمر, ثانياً إختيار البطارية المناسبة و تصميم دائرة لشحنها و التحكم المناسب بهذه البطارية, ثالثاً و أخيراً تصميم دائرة لتحويل التيار المستمر لتيار متردد.

بعد عملية التصميم لدائرة هذا النظام, تم إستخدام برنامج محاكاة بواسطة الحاسب الآلي لدراسة فعالية هذا التصميم و تحسينه, وتم مناقشة النتائج المتحصل عليها من هذه المحاكاة, كما تم تقديم مقترحات لتحسين هذا النظام مستقبلياً بصورة أكبر.

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LIST OF SYMBOLS

V_{in}	Input voltage, v
T	Time, sec
ΔV_{bat}	Battery's terminal voltage (deference), v
$\mathcal{E}_1, \mathcal{E}_2$	Electrodes' emf.
$\mathcal{E}$	Ideal cell constant terminal voltage, v
Ω	Ohm
Q_p	Battery's capacity when discharged at a rate of 1 amp.
t	Amount of time that a battery can sustain, hours
k	A constant around 1.3
V_D	Diode's voltage, v
V_Z	Zener voltage, v
I_D	Current flowing through the diode, A
V_S	Voltage of the source, v
R_L	Resistance of the load, Ω
V_o	Voltage across load, v
V_m	Maximum voltage (peak value of sinewave), v
V_t	Terminal voltage, v
I_L	Load current, A
V_B	Battery voltage, v
I_B	Current withdrawn from battery, A
P_{in}	Input power, watt

P_{out}	Output power, watt
n	Peukert's exponent for the battery type (1.753 for lead acid)
H_r	The battery's hour rating, Hours
C_B	Capacity of the battery
T_H	Time in hours for the battery. Hours
I_{Dis}	The discharge current, A

LIST OF ABBREVIATION

DC	Direct Current
AC	Alternating Current
v	Volt/s
A/Amp	Ampere/s
K	Kilo
UPS	Uninterrupted Power Supply
H/hr	Hour/s
s/sec	Second/s
IT	Information Technology
BESS	Battery Electric Storage System
PF	Power Factor
lbs	Pound
SCR	Silicon Controlled Rectifiers
MOSFET	Metal Oxide Semi-conductor Field-Effect Transistor
MOSGIT	Metal Oxide Semi-conductor Insulated Gate Transistor
GTO	Gate Turn-Off
Btu	British Thermal Unit
dBA	A-weighted Decibels
US	United States
emf	Electro-Motive Force
VRLA	Valve Regulated Lead-Acid

AGM	Absorbed Glass Mat
NiCd	Nickel-Cadmium
NiZn	Nickel-Zinc
NiMH	Nickel Metal Hydride
Li-ion	Lithium-ion
USB	Universal Serial Bus
°F	Degree Fahrenheit
°C	Degree Celsius
W	Watt/s
SLI	Starting, Lighting, Ignition
D	Diode
R	Resistance
V	Voltage
F	Frequency
T/t	Time
RMS	Root mean Square
PWM	Pulse Width Modulation
L	Inductance
Op.Amps	Operational Amplifiers
TTL	Transistor-Transistor Logic
CMOS	Complementary Metal-Oxide Semi-conductor

NPN	Negative-Positive-Negative
PNP	Positive-Negative-Positive

CHAPTER ONE

INTRODUCTION

1.1 Overview

The electricity has become an essential part of life in the modern world; almost everything is powered by an electrical power source or has electricity as part of its operating or controlling. Electrical power consists of two parts: the voltage, and the current, both, as a product forms the electrical power as we know it. In general, the electrical power comes in one of two forms: as a direct current, this form is known as DC (figure 1.1 shows the waveform of the DC voltage wave), or as an alternating current, known as AC (figure 1.2 shows the waveform of the AC single phase voltage wave).

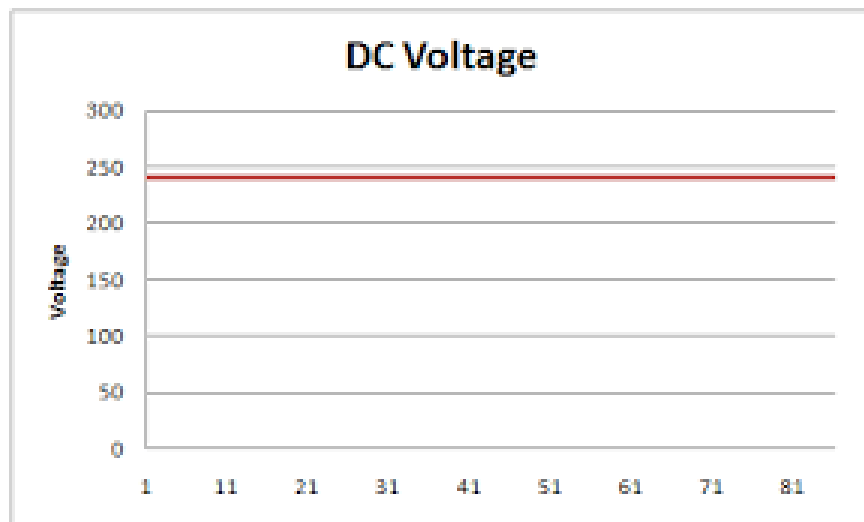


Figure 1.1: A basic DC voltage waveform

The electrical power is generated as AC three phase, then it is transmitted and distributed to the consumer as AC single phase (or even as three phase for special operations such as certain motors in industrial applications). Most electronic devices don't operate on AC directly, but it has an integrated circuit which converts AC to DC, such as: mobile phones, personal computers and even the protection equipment like relays and circuit breakers are powered with a DC source.

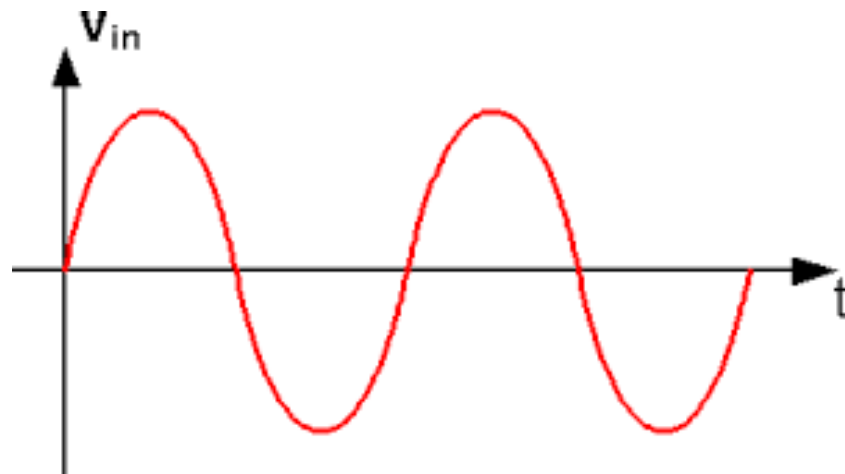


Figure 1.2: A basic AC voltage waveform

Some applications need a constant supply of electrical energy, and the outage of electricity could cause serious consequences, like data loss in desktop computers, and endangering lives which depends on the continuity of certain medical appliances in hospitals. As a solution for such cases and similar others, a special system was designed, and it's called: the uninterruptable power supply, or UPS for short.

The UPS depends on storing the electrical power inside it, and in case of an outage or emergencies, it acts as a temporary power source. Depending on the system that it was designed for, it can supply the system with electrical power for hours, or a matter of minutes.

1.2 Stand-by Power Supply

As mentioned, in certain cases, continuity of electrical power supply can be very crucial. In the electrical system environment, power disturbances will occur. A complete outage or even a decrement in power supply can lead to critical damage, even if there is a backup generator, this type of machine need a relatively long time to start and to reach the optimal level of its rated output supply. When the continuity of supply is a must, the uninterrupted power supply (UPS) is presented.

The Standby Power systems which UPS systems supply are used to support mainstream IT and communications infrastructures from the home office to the international Data Centre.

When mains power goes off, the Standby Power system will operate either from stored power usually within lead acid batteries installed within an uninterruptable power supply (UPS) or by generated power from a generator or a combination of both as an integrated hybrid system.

In many cases, before conventional generators reach operating power, there's a time delay between mains failure and full power. As modern electronic equipment is susceptible to even momentary breaks in power a conventional generator, on its own, is often insufficient to support a computer-based system.

Because of this a 'typical' Standby Power system for a computer room incorporates both a battery-powered UPS (to bridge the time gap whilst the generator starts) and a diesel generator to provide the extended runtime that may be required.

Of course ‘typical’ Standby Power installations rarely exist, in most cases noise, or weight, or footprint, or heat output, or exhaust fumes (amongst other factors) can cause a problem.

1.3 Problem Statement

UPS units are applied in electrical installations where the loss of power supply can cause undesirable impacts including;

- Loss of essential information, such as real-time or inter-active computer systems data.
- Loss of production processes such as boiler controls, flow, level and temperature controls.
- Shutdown of plant which has fail safe operation as in hydrocarbon production processes.
- Loss of essential information to process operators as in a central control of a distributed control system.
- Commercial/ financial loss due to disruption and damage caused by mains failures on critical loads.
- Endangering lives which depend on the continuity of certain medical appliances in hospitals.

A UPS maintains power by switching instantaneously to batteries in the event of a power failure, or even just a dip in power (a brownout).

1.4 Objectives

The objectives of this research are summarized as follows:

1. The study and design of a UPS system.
2. To make the UPS compatible to be used with variable loads.
3. To provide clean and pure electrical power as the UPS output.

1.5 Thesis Lay-out

This thesis is organized as follows:

- Chapter one gives brief introduction of the UPS and the principle of stand-by power supply, also it summarizes the research's problem statement and objectives.
- Chapter two covers the concept and different types of UPS, also the different applications in which UPS systems are used and the proper way of choosing the optimal UPS for specific use.
- Chapter three provides an insight and detailed view of the different components of the UPS as hardware; it covers the rectifying process and filtering, the inverter process, the battery, and finally the protection of the UPS system.
- Chapter four discusses the design process of the uninterruptible power supply (UPS) also the simulation results that have been done by the computer.
- Chapter five consists of the conclusion of this research and the recommendations presented by the students of this research.

CHAPTER TWO

UNINTERRUPTED POWER SUPPLY

(UPS)

2.1 Introduction

An uninterruptible power supply (also uninterruptible power source), UPS (or battery backup) is an electrical apparatus that provides emergency power to a load when the input power source, fails. A UPS differs from an auxiliary, emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries, super capacitors, or flywheels. The on-battery runtime of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment.

A UPS is typically used to protect hardware such as computers, data centers, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. UPS units range in size from units designed to protect a single computer without a video monitor (around 200 volt-ampere rating) to large units powering entire data centers or buildings. The world's largest UPS, the 46-megawatt Battery Electric Storage System (BESS), in Fairbanks, Alaska, powers the entire city and nearby rural communities during outages.

Also, the UPS provides protection of load against line frequency variations, elimination of power line noise and voltage transients, voltage regulation, and

uninterruptible power for critical loads during failures of normal utility source. An UPS can be considered a source of standby power or emergency power depending on the nature of the critical loads. The amount of power that the UPS must supply also depends on these specific needs. These needs can include emergency lighting for evacuation, emergency perimeter lighting for security, orderly shutdown of manufacturing or computer operations, continued operation of life support or critical medical equipment, safe operation of equipment during sags and brownouts, and a combination of the preceding needs.

The components of a basic UPS system contain a battery charger/rectifier, batteries, and an inverter. The battery charger is a rectifier that converts AC power to DC in order to charge the batteries. The batteries store power that is supplied to the load when there is a loss or decrease of a certain tolerance of utility supply power. The inverter converts the DC power from the battery to AC power used to supply the load.

2.2 Types of UPS's

In general, there are two major types of UPS systems:

- Rotary UPS: A rotary UPS (Figure 2.1) stores kinetic energy in the form of a rotating mass (a high-mass spinning flywheel) and this is used to power the load in the event of mains disturbances. The flywheel also acts as a buffer against power spikes and sags, yet it can only supply rated speed for a relatively short amount of time before it starts deaccelerating, that's why for high time operation it requires an auxiliary source.

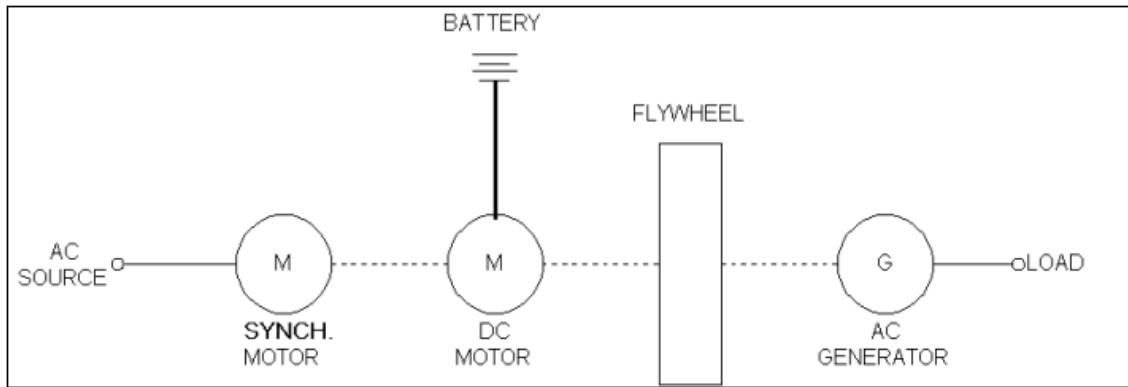


Figure 2.1: Rotary UPS schematic with auxiliary DC motor

- Static UPS: A Static UPS uses batteries to store the electrical power. Basically, there are three types of static UPS's (Figures 2.2),(Figure2.3):
 - Standby off-line UPS.
 - Standby Ferro-resonant UPS.
 - On-line UPS.

2.2.1 Standby Off-Line UPS

Under normal conditions an off-line UPS remains in a standby mode. The electric supply power is connected directly to the load and feeds a battery charger/rectifier to continually charge the battery. If the electric utility supply fails, the battery supplies power to an inverter, which is connected to the load by a static transfer switch that engages in a fraction of a cycle.

The off-line UPS is characterized by a switching delay of 1.5 to 4.0 milliseconds after supply voltage drops out of a specified tolerance band. The standby off-line UPS is typically suited for small loads (up to 1.5 kVA) that have a capacity in the power supply capable of riding through the transfer time.

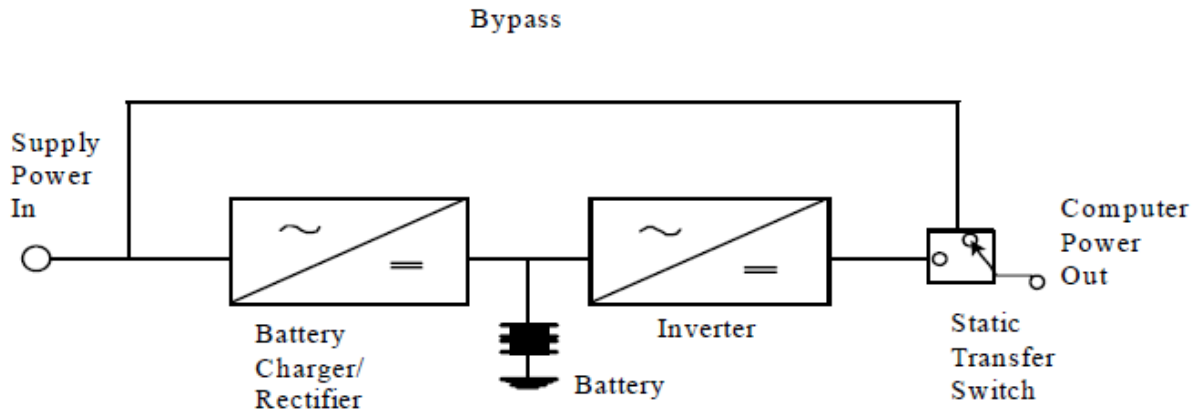


Figure 2.2: Stand-by off-line UPS

With the standby off-line UPS, the primary source of power comes from the utility. When the utility voltage drops out of the tolerance band, the transfer switch changes state and backup power comes from the battery via the inverter.

In operation, the system simply alerts the user that supply power failure has occurred and that the load now is on battery power. The available power from the battery will last approximately five to fifteen minutes. Some UPS's now have a smart charger to charge the batteries and to monitor for battery replacement.

If the electrical equipment being protected cannot withstand any outage, such as the one experienced when an off-line UPS transfers from utility power to battery, the user should consider purchasing an on-line UPS. In some instances the one-half to one cycle ride-through provided by a Ferro-resonant transformer may be adequate. Of the three types of UPS systems described in this research the off-line UPS is the most efficient and the least expensive.

2.2.2 On-Line UPS

An on-line or double conversion UPS, is the ultimate in UPS protection because the utility supply power does not flow directly to the load like the off-line UPS.

Instead, the power flows continuously through a charger/rectifier that feeds both a storage battery and an inverter. The inverter generates AC power to the load being protected. In the event of a power failure, the inverter is fed by the battery. Since the power flows through the rectifier and inverter before reaching the load, most power disturbances are eliminated through constant filtering. Therefore, an on-line UPS is a good idea for any system which is sensitive to transients, noise, and/or cannot tolerate any power interruption.

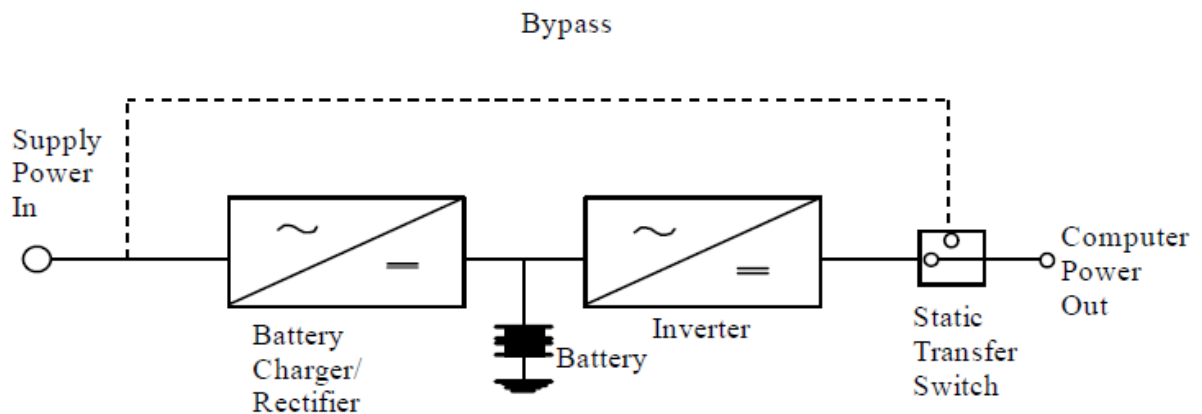
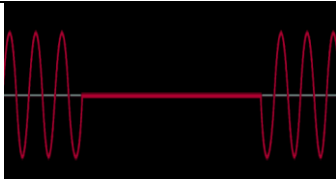
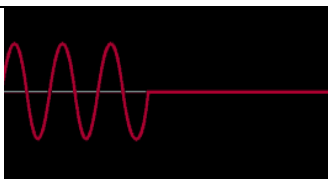
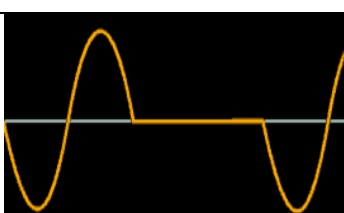
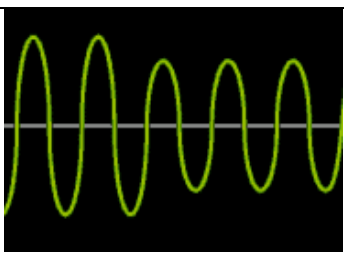
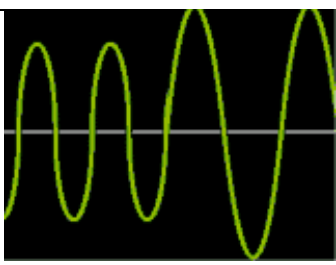
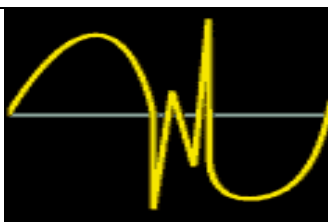
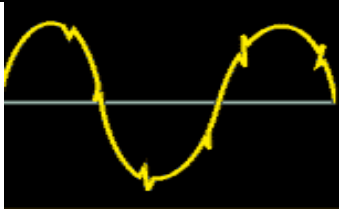
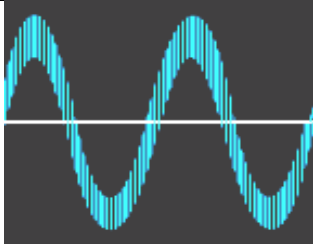
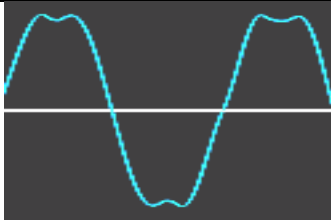


Figure 2.3: On-line UPS

The double conversion on-line UPS has all its power flow continuously through the input rectifier and DC voltage link. Hence, most disturbances on the input are isolated from the output. The bypass for this system may be used to take the UPS out of service.

Table 2.1: Power quality problems:

Power Quality Problem	Waveform	Description
Temporary Interruption		Planned or accidental total loss of utility power in a localized area of the community. Seconds to minutes
Long-Term Interruption		Planned or accidental total loss of utility power in a localized area of the community. Minutes to hours
Momentary Interruption		Very short planned or accidental power loss. Milliseconds to seconds
Sag or Under-Voltage		A decrease in utility Voltage Sags. (Milliseconds to a few seconds) Under-voltage. (Longer than a few seconds)
Swell or Over-Voltage		An increase in Utility voltage Swell (Milliseconds to a few seconds) Over-voltage. (Longer than a few seconds)
Transient, Impulse or Spike		A sudden change in voltage up to several hundreds to thousands of volts (Microseconds)

Notch		A disturbance of opposite polarity from the waveform (Microseconds)
Noise		An unwanted electrical signal of high frequency from other equipment (Sporadic)
Harmonic Distortion		An alteration of the pure sinewave (sinewave distortion), due to nonlinear loads such as computer switching power supplies.

There are other types of non-UPS mitigation equipment; the first three columns of the next table (Table 2.2) show the capabilities of the three basic types of UPS's. In addition, three other commonly used devices to mitigate the type of power disturbance as described in the left column are shown.

Table 2.2: A comparison of the capabilities of various types of power disturbance mitigation equipment:

Type of Disturbance	Standby Off-line UPS	Ferro-resonant UPS	On-Line UPS	Spike Arrester	Voltage Regulator	Isolation Transformer
Electrical Noise	No	Yes	yes	No	Minimal	Minimal
Impulses/Spikes	No	Yes	yes	Yes	Minimal	Minimal
Momentary Interruptions	Yes	Yes	yes	No	Minimal	No
Flickers	No	Yes	yes	No	Maybe	No
Voltage Dips/Sags	Most	Yes	yes	No	Yes	No
Swells	Yes	Yes	yes	No	Yes	No
Under Voltage Brownouts	Minimal	Yes	yes	No	Yes	No
Over Voltage High Line	Yes	Yes	yes	No	Yes	No
Outage/Blackout	Yes	Yes	yes	No	No	No
Frequency/Variation	Some Types	Some Types	yes	No	No	No

The three types of non-UPS mitigation equipment included in Table 2.2 can be described as follows:

- A spike arrester clips voltage peaks off spikes and transients in the voltage wave form.
- A voltage regulator maintains a constant voltage output under varying input voltage conditions.
- An isolation transformer electrically separates the electrical equipment from the power source, in effect filtering out common mode electrical noise.

It should be noted that most personal computers employ switched-mode power supplies, which are very tolerant as far as voltage fluctuations and wave shapes are concerned. Tests have also indicated that the capacitors in such power supplies provide a ride-through capability of about four cycles. Therefore, the

need for voltage regulators and Ferro-resonant transformers should be objectively evaluated. In addition to providing filtering, a Ferro's voltage regulation function can extend battery life considerably.

While UPS systems mitigate power quality problems, they do not solve grounding problems that may cause errors in transmission and reception of communication signals. When a UPS is packaged with an isolation transformer on the load side of the static transfer switch, neutral-to-ground bond can be re-established at the transformer secondary, reducing the neutral-to-ground impedance considerably.

2.3 Considerations When Selecting a UPS

There are various consideration when selecting a UPS, the important aspects of these considerations are shown as the following:

2.3.1 Out-put Power

It is necessary to consider the size of the load that is to be connected to the UPS. The load may consist of a specific type of computer, workstation, mini-mainframe, hard disk drive, or test equipment. Once the equipment requiring a continuous power source is identified, the necessary rating of the UPS system can be determined by adding the volt-ampere (VA) rating on the nameplate of the equipment to be served by the UPS.

The maximum power rating of a standby, off-line unit is approximately 1.5 kVA, while the on-line UPS systems power ratings typically start at 500 VA. Sometimes power ratings are given in watts. The conversion formula from watt to volt-ampere is typically:

$$VA = \frac{watt}{P.F.} \quad (2.1)$$

Sizing should always be based on volt-amps plus 50-100%. One might consider purchasing a UPS which is rated somewhat larger to accommodate future growth and peak currents of switching power supplies. However, UPS systems typically work most efficiently near their rated capacity. Figure 2.4 shows the efficiencies of the three types of UPS's of a percentage of the load.

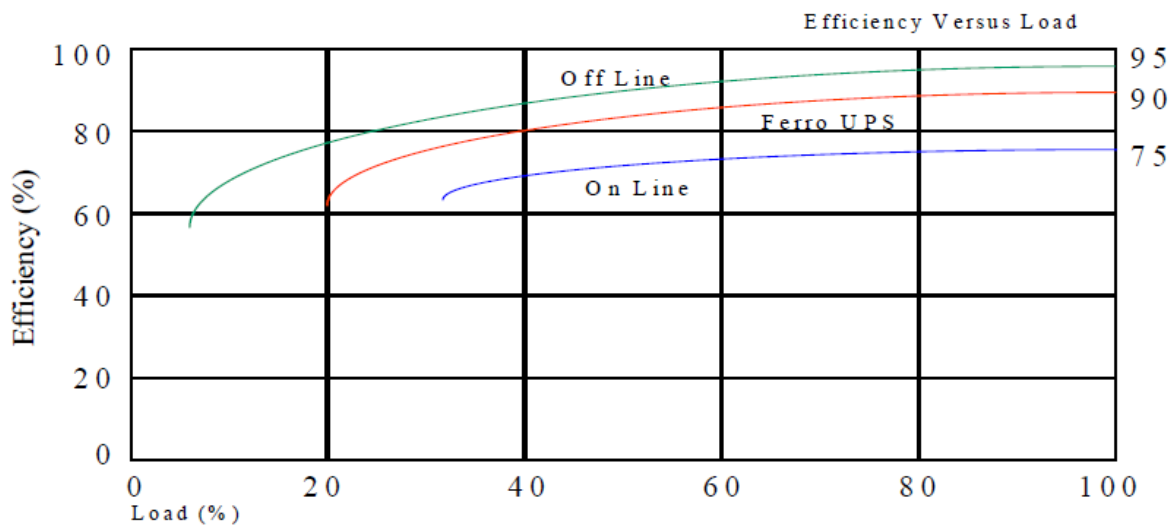


Figure 2.4: Efficiency vs. Load for a typical 1.5 kVA UPS

The efficiency of a standby Ferro-resonant type follows the efficiency curve of the off-line UPS but somewhat lower. The efficiency for an on-line UPS will be lower yet because of the AC/DC/AC conversion. Typically, the best efficiency expected for an on-line UPS will be about 75% for small stand-alone, single-phase UPSs for computer applications rated at 5 kVA and below.

2.3.2 Batteries

It should be mentioned that battery life is a major consideration for UPSs. Battery manufacturers' state a five-to seven-year life for the lead-acid batteries used in the UPS. However, the actual battery life is determined by how often the

battery is called upon to take over when there is an outage, surge, sag or swell. Each time the battery takes over, its useful life diminishes.

The batteries are the weakest component of UPS's. When battery failure occurs, UPS's are commonly sent back to the factory for service. However, it may be more economical to purchase a new UPS rather than to repair the old one. To solve this problem, user friendly, hot-swappable battery replacement systems are available. These are modular replaceable battery packs that can be quickly and safely swapped out without powering down the connected load (hot-swapped) by the user. No tools or disassembling of the unit is required. This saves the time and expense of returning the UPS to the factory for battery service.

Some other consideration including:

- Space and size: the type of UPS selected will also have an impact on physical size due to floor space availability and weight. The UPS and the addition of optional batteries decreases available floor space and increases the concentrated weight. The Ferro-resonant type UPS that contains a Ferro-resonant transformer is generally heavier than other types of systems. As an example, a Ferro-resonant UPS with a power rating of 2.0 kVA weighs 420 lbs., while a non-Ferro-resonant UPS with about the same power rating weighs 230 lbs. UPS systems using silicon controlled rectifiers (SCR) contain more circuitry but no large transformer, and therefore weigh less than the Ferro-resonant UPS. Even better, the UPS units with power MOSFET and GTO thyristor technology contain fewer components, and therefore weigh the least.
- Heat: the heat rejection or heat loss of a UPS is normally given by the manufacturer. For a single small unit of 1 kVA or less, the heat load to an office or room may be negligible. However, for multiple units or larger UPS systems, it is necessary to account for the additional heat load on the

room, office, or laboratory air conditioning system. A Ferro-resonant UPS typically has a lower heat rejection rating. For example, the heat rejection of a 5 kVA Ferro-resonant UPS is 1.9 KBtu/hr. and an on-line 5 kVA UPS system is 2.9 KBtu/hr.

- Noise: audible noise in a continuous UPS is a major concern when the supply is placed in a work area. Most systems have a noise level between 50-60 dBA at 6 feet.
- Diagnostic and communications: some UPS's have a microprocessor on board to monitor the state of the supply power, the internal parameters of the UPS, the output power and load current. These types of systems often can be connected to the computer installation to warn the user, for example, of any potential power line problems and the charge level of the battery. These systems will automatically close files and do an orderly shutdown should the battery reserve become low during a power failure.

After determining the specific UPS features required for the application and developing a list of qualifying UPS systems, selection principally becomes an issue of engineering quality, layout and economics.

CHAPTER THREE

UPS HARDWARE CONSTRUCTION

3.1 Introduction

The main components of the UPS system can be summarized as the following:

1. The battery.
2. The rectifying circuit.
3. The inverting circuit.

Also, some other aspects may be added to the components, which consist of the filtering process and the protection of the UPS system.

3.2 The Battery

An electric battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell contains a positive terminal, or cathode, and a negative terminal, or anode. Electrolytes allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work.

Primary (single-use or "disposable") batteries are used once and discarded; the electrode materials are irreversibly changed during discharge. Common examples are the alkaline battery used for flashlights and a multitude of portable devices. Secondary (rechargeable batteries) can be discharged and recharged multiple times; the original composition of the electrodes can be restored by reverse current. Examples include the lead-acid batteries used in vehicles and lithium ion batteries used for portable electronics.

Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to battery banks the size of rooms that provide standby power for telephone exchanges and computer data centers.

According to a 2005 estimate, the worldwide battery industry generates US\$48 billion in sales each year, with 6% annual growth.

Batteries have much lower specific energy (energy per unit mass) than common fuels such as gasoline. This is somewhat offset by the higher efficiency of electric motors in producing mechanical work, compared to combustion engines.

3.2.1 Principle of Operation

Batteries convert chemical energy directly to electrical energy. A battery consists of some number of voltaic cells. Each cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during discharge. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell. A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes.

Each half-cell has an electromotive force (or emf), determined by its ability to drive electric current from the interior to the exterior of the cell. The net emf of the cell is the difference between the emfs of its half-cells. Thus, if the electrodes have emfs $\mathcal{E}_1$ and $\mathcal{E}_2$, then the net emf is $\mathcal{E}_1 - \mathcal{E}_2$; in other words, the net emf is the difference between the reduction potentials of the half-reactions.

The electrical driving force or ΔV_{bat} across the terminals of a cell is known as the terminal voltage (difference) and is measured in volts. The terminal voltage of a cell that is neither charging nor discharging is called the open-circuit voltage and equals the emf of the cell. Because of internal resistance, the terminal voltage of a cell that is discharging is smaller in magnitude than the open-circuit voltage and the terminal voltage of a cell that is charging exceeds the open-circuit voltage.

An ideal cell has negligible internal resistance, so it would maintain a constant terminal voltage of $\mathcal{E}$ until exhausted, then dropping to zero. If such a cell maintained 1.5 volts and stored a charge of one coulomb then on complete discharge it would perform 1.5 joules of work. In actual cells, the internal resistance increases under discharge and the open circuit voltage also decreases under discharge. If the voltage and resistance are plotted against time, the resulting graphs typically are a curve; the shape of the curve varies according to the chemistry and internal arrangement employed.

The voltage developed across a cell's terminals depends on the energy release of the chemical reactions of its electrodes and electrolyte. Alkaline and zinc-carbon cells have different chemistries, but approximately the same emf of 1.5 volts; likewise NiCd and NiMH cells have different chemistries, but approximately the same emf of 1.2 volts. The high electrochemical potential changes in the reactions of lithium compounds give lithium cells emfs of 3 volts or more.

3.2.2 Categories and Types of batteries

Batteries are classified into primary and secondary forms.

- **Primary Batteries:** Or primary cells, can produce current immediately on assembly. These are most commonly used in portable devices that have low current drain, are used only intermittently, or are used well away from an alternative power source, such as in alarm and communication circuits where other electric power is only intermittently available. Disposable primary cells cannot be reliably recharged, since the chemical reactions are not easily reversible and active materials may not return to their original forms. Battery manufacturers recommend against attempting to recharge primary cells. In general, these have higher energy densities than rechargeable batteries, but disposable batteries do not fare well under high-drain applications with loads under 75 ohms ($75\ \Omega$). Common types of disposable batteries include:
 - Zinc–carbon batteries.
 - Alkaline batteries.
- **Secondary Batteries:** Also known as secondary cells, or rechargeable batteries, must be charged before first use; they are usually assembled with active materials in the discharged state. Rechargeable batteries are (re)charged by applying electric current, which reverses the chemical reactions that occur during discharge/use. Devices to supply the appropriate current are called chargers. The oldest form of rechargeable battery is the lead–acid battery. This technology contains liquid electrolyte in an unsealed container, requiring that the battery be kept upright and the area be well ventilated to ensure safe dispersal of the hydrogen gas it produces during overcharging. The lead–acid battery is relatively heavy for the amount of electrical energy it can supply. Its low

manufacturing cost and its high surge current levels make it common where its capacity (over approximately 10 Ah) is more important than weight and handling issues. A common application is the modern car battery, which can, in general, deliver a peak current of 450 amperes. Secondary batteries are not indefinitely rechargeable due to dissipation of the active materials, loss of electrolyte and internal corrosion. Other portable rechargeable batteries include several sealed "dry cell" types, that are useful in applications such as mobile phones and laptop computers. Cells of this type (in order of increasing power density and cost) include:

- Nickel–cadmium (NiCd).
- Nickel–zinc (NiZn).
- Nickel metal hydride (NiMH).
- Lithium-ion (Li-ion) cells.

Li-ion has by far the highest share of the dry cell rechargeable market. NiMH has replaced NiCd in most applications due to its higher capacity, but NiCd remains in use in power tools, two-way radios, and medical equipment.

3.2.3 Lead acid batteries

This type is considered the oldest type of rechargeable batteries. Some of the advantages of using this type of batteries:

- Inexpensive.
- Simple to manufacture.
- Reliable.
- Low self-discharge (among the lowest in the rechargeable batteries).
- Low maintenance requirements.
- Capable of high discharge rates.

There are however some limitations for using this type of batteries; some of the limitations are:

- It's environmentally unfriendly.
- Allows only a limited number of full discharge cycles (well suited for stand-by applications that require occasional deep discharge).

This type of batteries was chosen for the design of this UPS system for the above advantages.

3.2.4 Capacity and Discharge

A battery's capacity is the amount of electric charge it can deliver at the rated voltage. The more electrode material contained in the cell the greater its capacity. A small cell has less capacity than a larger cell with the same chemistry, although they develop the same open-circuit voltage. Capacity is measured in units such as amp-hour (A·h).

The rated capacity of a battery is usually expressed as the product of 20 hours multiplied by the current that a new battery can consistently supply for 20 hours at 68 °F (20 °C), while remaining above a specified terminal voltage per cell. For example, a battery rated at 100 A·h can deliver 5 A over a 20-hour period at room temperature. The fraction of the stored charge that a battery can deliver depends on multiple factors, including battery chemistry, the rate at which the charge is delivered (current), the required terminal voltage, the storage period, ambient temperature and other factors.

The higher the discharge rate, the lower the capacity. The relationship between current, discharge time and capacity for a lead acid battery is approximated (over a typical range of current values) by Peukert's law:

$$t = \frac{Q_p}{(I \times k)} \quad (3.1)$$

Where:

Q_p : is the capacity when discharged at a rate of 1 amp.

IB : is the current drawn from battery (A).

t : is the amount of time (in hours) that a battery can sustain.

k : is a constant (around 1.3).

The rated capacity of the battery in AH is applicable at a discharge rate of 20 Hours. As the discharge rate is increased, the usable capacity reduces due to “Peukert’s Effect”. This relationship is not linear but is more or less according to the Table 3.1.

Table 3.1 Battery Capacity versus Rate of Discharge

Hours of Discharge	Usable Capacity
20	100%
10	87%
8	83%
6	75%
5	70%
3	60%
2	50%
1	40%

Using the above table will show that a 100 AH capacity battery will deliver 100% (i.e. full 100 AH) capacity if it is slowly discharged over 20 hours at the rate of 5 Amperes. However, if it is discharged at a rate of 50 Amperes then theoretically, it should provide $100 \text{ AH} / 50 = 2$ hours. However, the Table above shows that for 2 hours discharge rate, the capacity is reduced to 50% i.e. 50 AH. Therefore, at 50 Ampere discharge rate the battery will actually last for $50 \text{ AH} / 50 \text{ Amperes} = 1$ Hour.

3.2.5 Sizing Battery Bank

One of the most important things is to know the size of the battery system and the load on the inverter. And in order to determine that, specific calculation can be done to determine the proper battery bank size. There are a few basic formulas and estimation rules that are used:

$$P = V \times I \quad (3.2)$$

For an inverter running from a 12 V battery system, the DC current required from the 12 V batteries is given:

$$I = \frac{P}{12} \quad (3.3)$$

For an inverter running from a 24 V battery system, the DC current required from the 24 V batteries is given:

$$I = \frac{P}{24} \quad (3.4)$$

$$J = Idc \times Th \quad (3.5)$$

Where:

J : is the energy required from the battery.

Idc : is the DC current to be delivered, A.

Th : is the time, Hours.

The first step is to estimate the total AC watts (W) of load(s) and for how long the load(s) will operate in hours (H). The AC watts are normally indicated in the electrical nameplate for each appliance or equipment. In case AC watts (W) are not indicated, formula (3.2) given above may be used to calculate the AC watts. The next step is to derive the DC current in Amperes (A) from the AC watts as per formulas (3.3 - 3.4) above.

3.2.6 Charging Batteries

The batteries can be charged by using good quality AC powered battery charger or from alternative energy sources like solar panels, wind or hydro systems. Make sure an appropriate battery charge controller is used. It is recommended that the batteries may be charged at 10% to 13 % of the Ampere Hour capacity (20 hour discharge rate). Also, for complete charging (return of 100 % capacity), it is recommended that a 3 stage charger may be used (Constant current bulk charging followed by constant voltage boost / absorption charging followed by constant voltage float charging).

- Stage 1 Bulk Charge: primary purpose of a battery charger is to recharge a battery. This first stage is typically where the highest voltage and amperage the charger is rated for will actually be used. The level of charge that can be applied without overheating the battery is known as the battery's natural absorption rate. For a typical 12 volt battery, the charging voltage going into a battery will reach 14.2-14.3 volts, while flooded batteries can be even higher. This stage will recharge batteries that are severely drained. There is no risk of overcharging in this stage because the battery hasn't even reached full yet.
- Stage 2 Absorption Charge: Smart chargers will detect voltage and resistance from the battery prior to charging. After reading the battery the charger determines which stage to properly charge at. Once the battery has reached 80% of its state of charge, the charger will enter the absorption stage. At this point most chargers will maintain a steady voltage, while the amperage declines. The lower current going into the battery safely brings up the charge on the battery without overheating it, this stage takes more time. For instance, the last remaining 20% of the battery takes much longer when compared to the first 20% during the bulk

stage. The current continuously declines until the battery almost reaches full capacity. *Actual state of charge Absorption Stage will enter will vary from charger to charger

- Stage 3 Float Charge: Some chargers enter float mode as early as 85% state of charge but others begin closer to 95%. Either way, the float stage brings the battery all the way through and maintains the 100% state of charge. The voltage will taper down and maintain at a steady 13.2-13.4 volts, which is the maximum voltage a 12 volt battery can hold. The current will also decrease to a point where it's considered a trickle. It's essentially the float stage where there is charge going into the battery at all times, but only at a safe rate to ensure a full state of charge and nothing more. Most smart chargers do not turn off at this point, yet it is completely safe to leave a battery in float mode for months to even years at a time. It's the healthiest thing for a battery to be at 100% state of charge.

3.2.7 Battery Life Time

Available capacity of all batteries drops with decreasing temperature. In contrast to most of today's batteries, the Zamboni pile, invented in 1812, offers a very long service life without refurbishment or recharge, although it supplies current only in the Nano-Amp range. The Oxford Electric Bell has been ringing almost continuously since 1840 on its original pair of batteries, thought to be Zamboni piles.

The battery's life time decreases due to several factors such as:

- Self-discharge: Disposable batteries typically lose 8 to 20 percent of their original charge per year when stored at room temperature (20°–30 °C). This is known as the "self-discharge" rate, and is due to non-current-

producing "side" chemical reactions that occur within the cell even when no load is applied. The rate of side reactions is reduced for batteries are stored at lower temperatures, although some can be damaged by freezing, old rechargeable batteries self-discharge more rapidly than disposable alkaline batteries, especially nickel-based batteries; a freshly charged nickel cadmium (NiCd) battery loses 10% of its charge in the first 24 hours, and thereafter discharges at a rate of about 10% a month. However, newer low self-discharge nickel metal hydride (NiMH) batteries and modern lithium designs display a lower self-discharge rate (but still higher than for primary batteries).

- Corrosion: Internal parts may corrode and fail, or the active materials may be slowly converted to inactive forms.
- Physical component change: The active material on the battery plates changes chemical composition on each charge and discharge cycle, active material may be lost due to physical changes of volume; further limiting the number of times the battery can be recharged.
- Charge/discharge speed: Fast charging increases component changes, shortening battery lifespan.
- Overcharging: If a charger cannot detect when the battery is fully charged then overcharging is likely, damaging it.
- Memory effect: NiCd cells, if used in a particular repetitive manner, may show a decrease in capacity called "memory effect". The effect can be avoided with simple practices. NiMH cells, although similar in chemistry, suffer less from memory effect.
- Environmental conditions: Automotive lead–acid rechargeable batteries must endure stress due to vibration, shock, and temperature range. Because of these stresses, few automotive batteries last beyond six years

of regular use. Automotive starting (SLI: Starting, Lighting, Ignition) batteries have many thin plates to maximize current. In general, the thicker the plates the longer the life. They are typically discharged only slightly before recharge.

- Deep discharging: Lead–acid batteries should never be discharged to below 20% of their capacity, because internal resistance will cause heat and damage when they are recharged. Deep-cycle lead–acid systems often use a low-charge warning light or a low-charge power cut-off switch to prevent the type of damage that will shorten the battery's life.
- Storage: Battery life can be extended by storing the batteries at a low temperature, as in a refrigerator or freezer, which slows the side reactions. Such storage can extend the life of alkaline batteries by about 5%; rechargeable batteries can hold their charge much longer, depending upon type.

3.3 The Rectifying Circuit

Semiconductor diodes are active devices which are extremely important for various electrical and electronic circuits. Diodes are active non-linear circuit elements with non-linear voltage-current characteristics. Diodes are used in a wide variety of applications in communication systems (limiters, gates, clippers, and mixers), computers (clamps, clippers, logic gates), radar circuits (phase detectors, gain-control circuits, power detectors, parameter amplifiers), radios (mixers, automatic gain control circuits, message detectors), and television (Clamps, limiters, phase detectors, etc.). The ability of diodes to allow the flow of current in only one direction is commonly exploited in these applications. Another common application of diodes is in rectifiers for power supplies.

3.3.1 Diodes

Diodes allow electricity to flow in only one direction. Diodes are the electrical version of a valve and early diodes were actually called valves. The schematic symbol of a diode is shown below. The arrow of the circuit symbol shows the direction in which the current can flow. The diode has two terminals, a cathode and an anode as shown in Figure 3.1. If a negative voltage is applied to the cathode and a positive voltage to the anode, the diode is forward biased and conducts. The diode acts nearly as a short circuit. If the polarity of the applied voltage is changed, the diode is reverse biased and does not conduct. The diode acts very much as an open circuit. Finally, if the voltage V_D is more negative than the Reverse Breakdown voltage (also called the Zener voltage, V_Z), the diode conducts again, but in a reverse direction. The voltage versus current characteristics of a silicon diode is shown in Figure 3.2.

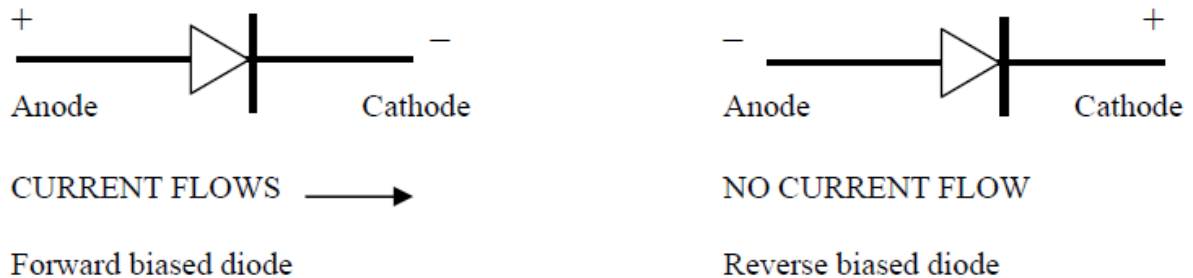


Figure 3.1: Diode operation

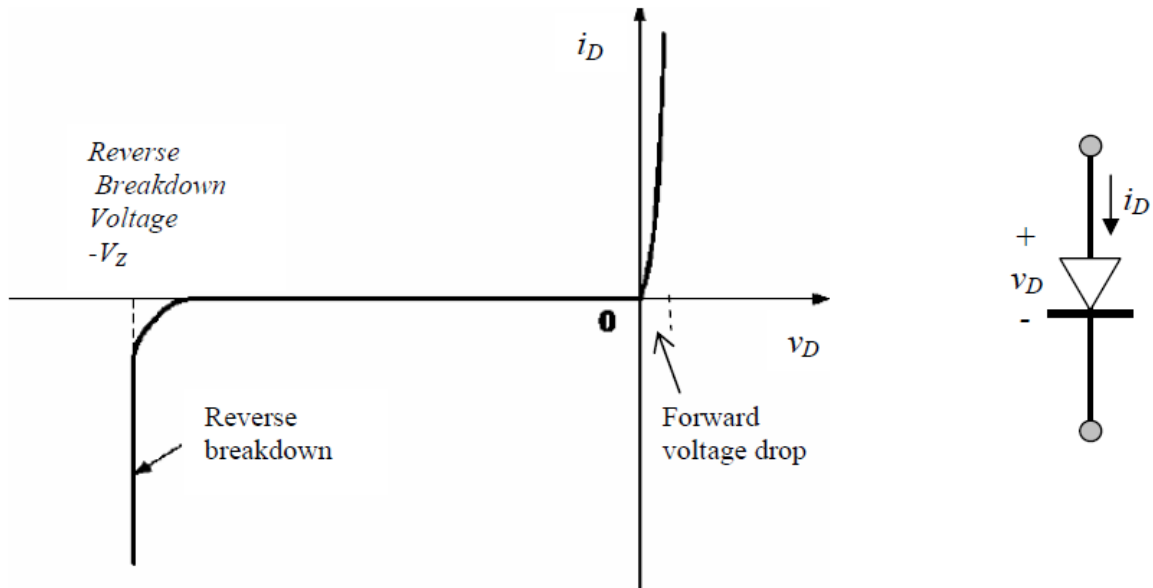


Figure 3.2: Voltage-current characteristics of a Silicon diode

- **Forward Voltage Drop:** electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the **forward voltage drop** and is about 0.7V for all normal diodes which are made from silicon. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (refer to current-voltage graph).
- **Reverse Voltage:** though we say that a diode does not conduct in the reverse direction, there are limits to the reverse electrical pressure that can be applied. The manufacturers of diodes specify a peak inverse voltage (PIV) that the diode can safely withstand. If this is exceeded, the diode will fail and allow a large current to flow in the reverse direction. This voltage is also called the Reverse Breakdown voltage.

3.3.2 Diode Rectifier Circuits

One of the important applications of a semiconductor diode is in rectification of AC signals to DC. Diodes are very commonly used for obtaining DC voltage supplies from the readily available AC voltage. There are many possible ways to construct rectifier circuits using diodes. The three basic types of rectifier circuits are:

- The Half Wave Rectifier
- The Full Wave Rectifier
- The Bridge Rectifier

3.3.2.1 Half-wave Rectifier

The easiest rectifier to understand is the half wave rectifier. A simple half-wave rectifier using an ideal diode and a load is shown in Figure 3.3.

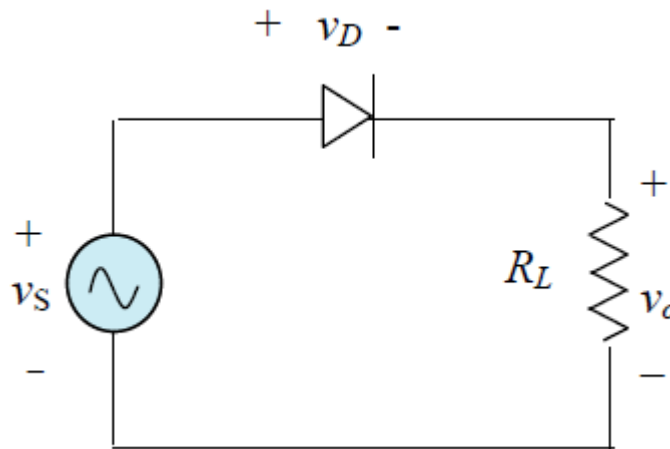


Figure 3.3: Simple half-wave rectifier circuit

The supply voltage is given by:

$$V_s = V_m \sin \omega t \quad (3.6)$$

where ω ($= 2\pi f = 2\pi/T$) is the angular frequency in rad/s.

Since the diode only conducts when the anode is positive with respect to the cathode, current will flow only during the positive half cycle of the input voltage.

During the positive half cycle of the source, the ideal diode is forward biased and operates as a closed switch. The source voltage is directly connected across the load. During the negative half cycle, the diode is reverse biased and acts as an open switch. The source voltage is disconnected from the load. As no current flows through the load, the load voltage v_o is zero. Both the load voltage and current are of one polarity and hence said to be rectified. The waveforms for source voltage v_s and output voltage v_o are shown in figure 3.4.

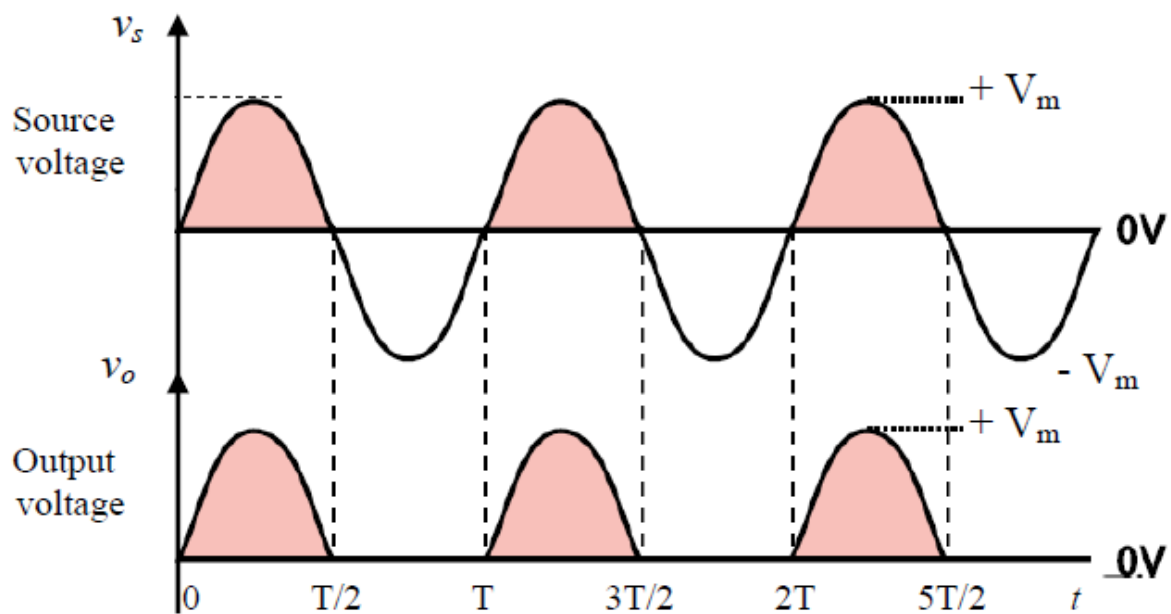


Figure 3.4: Source and output voltages

We notice that the output voltage varies between the peak voltage V_m and zero in each cycle. This variation is called “ripple”, and the corresponding voltage is called the peak-to-peak ripple voltage.

3.3.2.2 Full-Wave Rectifier

The full wave rectifier consists of two diodes and a resistor as shown in Figure 3.5. The transformer has a center-tapped secondary winding. This secondary winding has a lead attached to the center of the winding. The voltage from the center tap to either end terminal on this winding is equal to one half of the total voltage measured end-to-end.

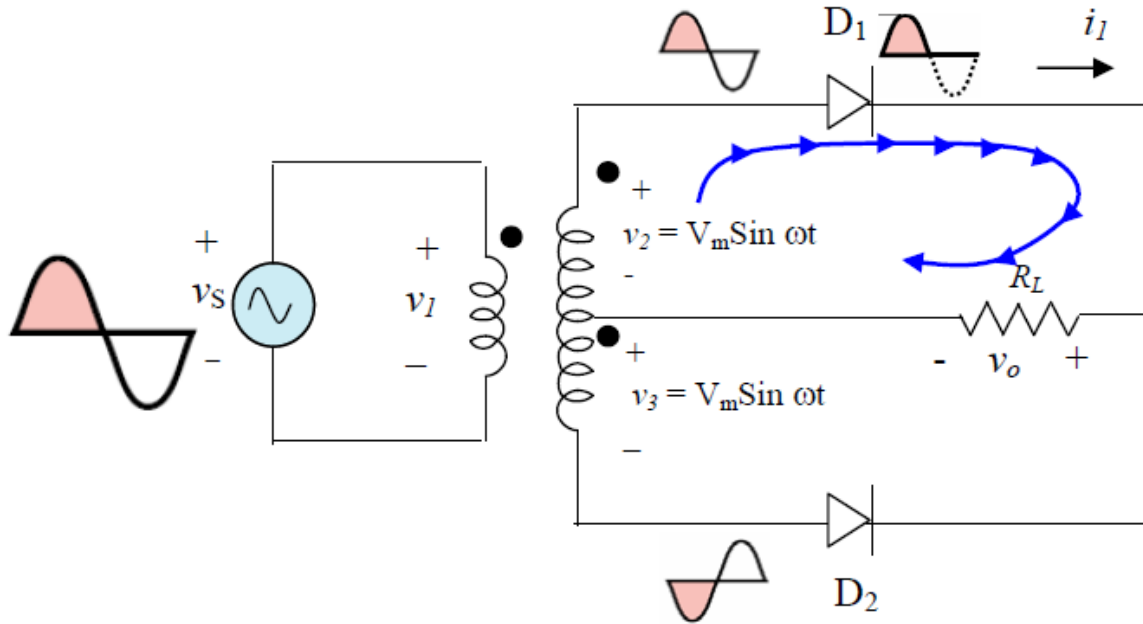


Figure 3.5: Full-wave rectifier- Circuit operation during positive half cycle

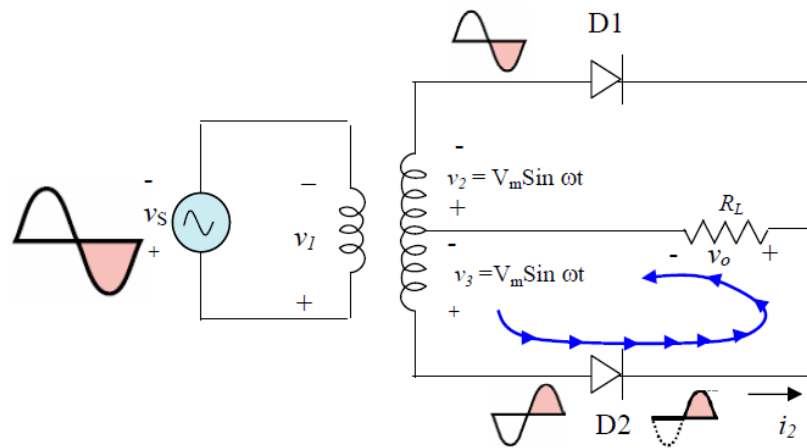


Figure 3.6: Full-wave rectifier – circuit operation during negative half cycle

Figure 3.5 shows the operation during the positive half cycle of the full wave rectifier. Note that diode D1 is forward biased and diode D2 is reverse biased. Note the direction of the current through the load. During the negative half cycle, (figure 3.6) the polarity reverses. Diode D2 is forward biased and diode D1 is reverse biased. Note that the direction of current through the load has not changed even though the secondary voltage has changed polarity. Thus another positive half cycle is produced across the load.

3.3.2.3 Full Wave Bridge Rectifier

In many power supply circuits, the bridge rectifier (Figure 3.7) is used. The bridge rectifier produces almost double the output voltage as a full wave center-tapped transformer rectifier using the same secondary voltage. The advantage of using this circuit is that no center-tapped transformer is required. During the positive half cycle, both D3 and D1 are forward biased. At the same time, both D2 and D4 are reverse biased. Note the direction of current flow through the load. During the negative half cycle D2 and D4 are forward biased and D1 and D3 are reverse biased. Again note that current through the load is in the same direction although the secondary winding polarity has reversed.

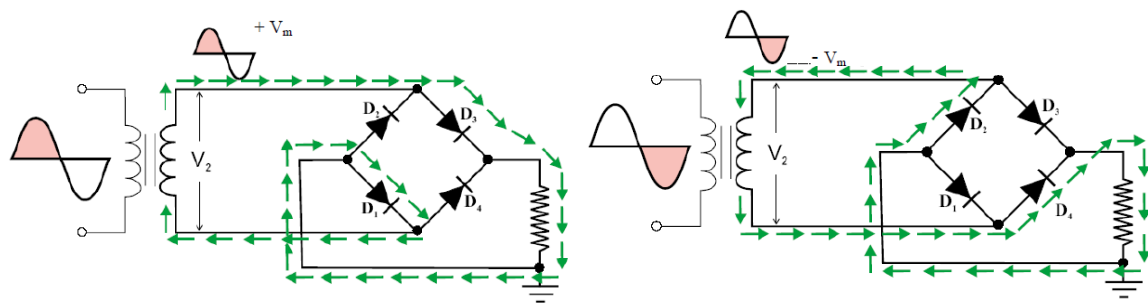


Figure 3.7: Operation during positive half and negative half cycle

3.3.3 Smoothing

The filter is simply a capacitor connected from the rectifier output to ground. In the next figure (Figure) the output of the capacitor is connected to a resistance which is equivalent to the resistance of the load.

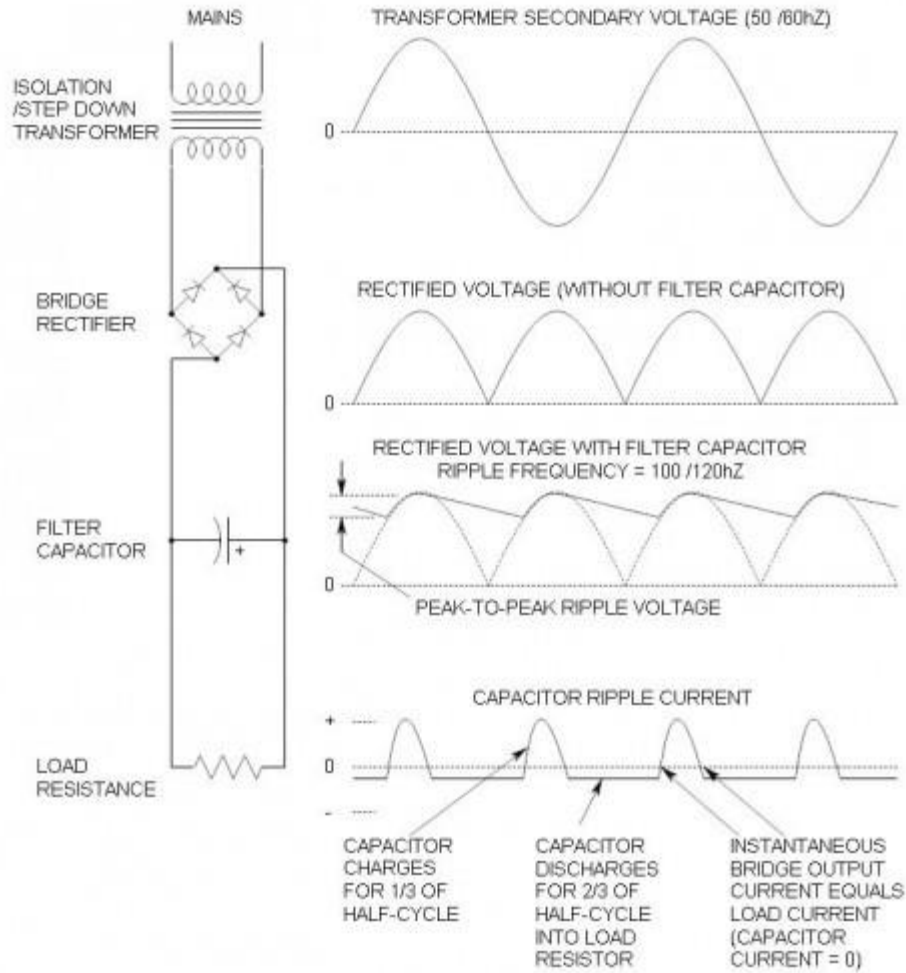


Figure 3.8: Full wave Bridge rectifier with capacitor input filter

$$dQ = c * dV \quad (3.7)$$

$$dQ = iC * dT \quad (3.8)$$

$$f = \frac{1}{T} \quad (3.9)$$

$$C = \frac{ic}{(dV*f)} \quad (3.10)$$

In full wave rectifier case the bridge output voltage wave have double the line frequency as can be seen in Figure 3.9 previously.

$$I_{load} = I_c + I_{rec}. \quad (3.11)$$

Where:

I_{load} : current drawn from the rectifier in amperes

I_c : current supplied to the load by the capacitor in amperes

I_{rec} : current supplied to the load by the rectifier in amperes

Portion of the load current is supplied by the capacitor and that in case that the load is constant (constant current is drawn from the source and the capacitor). The value of the capacitor will depend on the desired ripple voltage allowance, the maximum ripple allowed is determined by the regulator, the lower the ripple desired the larger the capacitor, if the same ripple is to be maintained while increasing the load, smoothing capacitor value must be increased to maintain that same ripple, therefore smoothing capacitor value is selected so that even at the maximum load the ripple voltage doesn't exceed the maximum ripple allowed by the regulator.

Two of the major specifications of a capacitor are its capacitance and working voltage. However for applications where large levels of current may flow (as in the case of a rectifier smoothing capacitor), a third parameter is of an importance; the maximum ripple current.

The ripple current is not just equal to the supply current. There are two scenarios:

- Capacitor discharge current: On the discharge cycle, the maximum current supplied by the capacitor occurs as the output from the rectifier

circuit falls to zero. At this point all the current from the circuit is supplied by the capacitor. This is equal to the full current of the circuit.

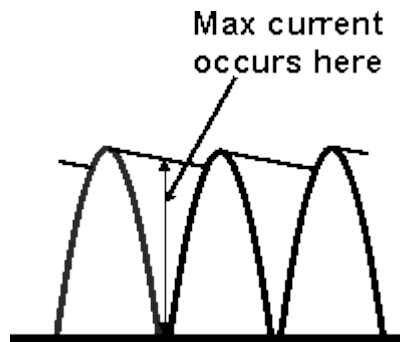


Figure 3.9: The discharge period of the capacitor

- **Capacitor charging current:** On the charge cycle of the smoothing capacitor, the capacitor needs to replace all the lost charge, but it can only achieve this when the voltage from the rectifier exceeds that from the smoothing capacitor. This only occurs over a short period of the cycle. Consequently the current during this period is much higher. The larger the capacitor, the better it reduces the ripple and the shorter the charge period.

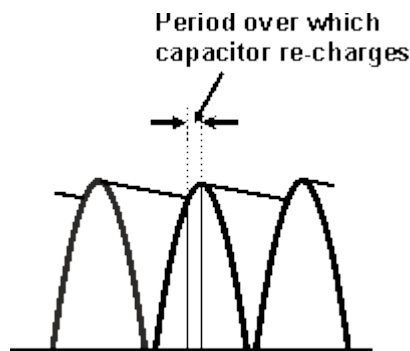


Figure 3.10: The charging period of the capacitor

When large currents are involved, caution must be taken in mind to ensure that the ripple current does not exceed the rated values for the capacitor.

3.3.4 The Effects of Ripple

Ripple is undesirable in many electronic applications for a variety of reasons:

- The ripple frequency and its harmonics are within the audio band and will therefore be audible on equipment such as radio receivers, and recorders.
- The ripple frequency is within television video bandwidth. Analogue TV receivers will exhibit a pattern of moving wavy lines if too much ripple is present.
- The presence of ripple can reduce the resolution of electronic test and measurement instruments. On an oscilloscope it will manifest itself as a visible pattern on screen.
- Within digital circuits, it reduces the threshold, at which logic circuits give incorrect outputs and data is corrupted.
- High-amplitude ripple currents shorten the life of electrolytic capacitors

3.3.5 Voltage Regulation

While filters can reduce the ripple from power supplies to a low value, the most effective approach is a combination of a capacitor-input filter used with a voltage regulator. A voltage regulator is connected to the output of a filtered rectifier and maintains a constant output voltage (or current) despite changes in the input, the load current, or the temperature. The capacitor-input filter reduces the input ripple to the regulator to an acceptable level. The combination of a large capacitor and a voltage regulator helps produce an excellent power supply. Most regulators are integrated circuits and have three terminals—an input terminal, an output terminal, and a reference (or adjust) terminal. The input to the regulator is first filtered with a capacitor to reduce the ripple to $< 10\%$. The regulator reduces the ripple to a negligible amount.

One of the many voltage regulators is an integrated circuit called: LM723 voltage regulator (Figure 3.11). The reason for using the LM723 as voltage regulator is that its output voltage and output current value ranges. Output

voltage is adjustable from 2V to 37V and output currents which exceed 10A are possible by adding external transistors.

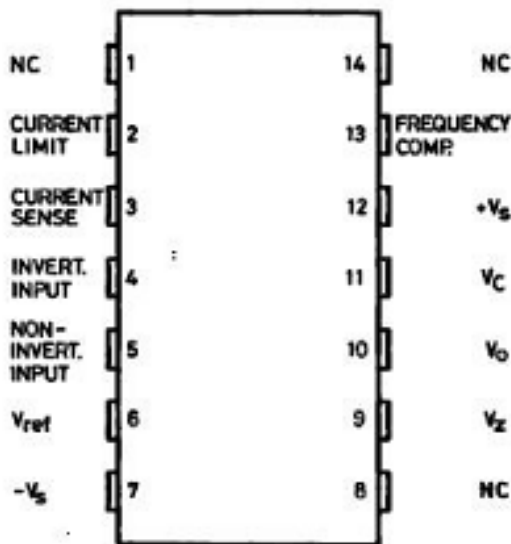


Figure 3.11: LM723 pins diagram

3.4 The Inverting Circuit

An inverter, or inverting circuit, (also known as power inverter) is a device which can convert the DC power into AC power.

Inverters' output varies depending on the type of the inverter, it can be a square wave, or a three steps wave which is referred to as the modified wave, and the steps of the wave can be increased until the wave form resembles a sinewave.

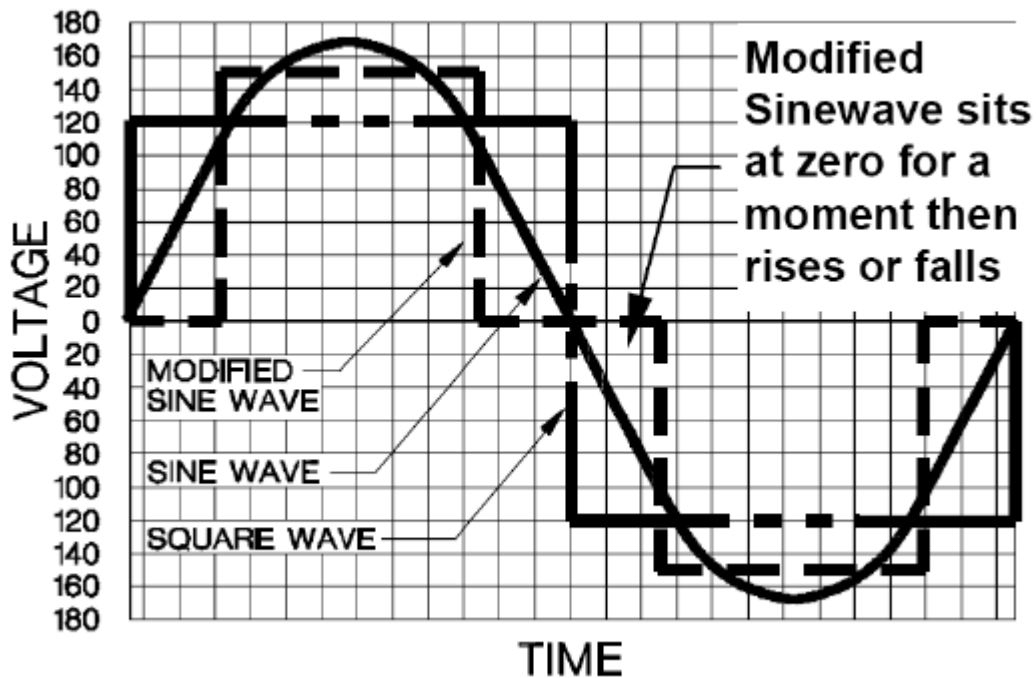


Figure 3.12: Square, Modified, and Pure Sine Wave

A modified sine wave is similar to a square wave but instead has a “stepping” look to it that relates more in shape to a sine wave. This waveform is easy to produce because it is just the product of switching between 3 values at set frequencies. The modified sine wave inverter provides a cheap and easy solution to powering devices that need AC power. It does have some drawbacks as not all devices work properly on a modified sine wave, products such as computers and medical equipment are not resistant to the distortion of the signal and must be run off of a pure sine wave power source.

Pure sine wave inverters are able to simulate precisely the AC power that is delivered by a wall outlet. Usually sine wave inverters are more expensive than modified sine wave generators due to the added circuitry. This cost, however, is made up for in its ability to provide power to all AC electronic devices, allow inductive loads to run faster and quieter, and reduce the audible and electric noise in audio equipment, TV’s and fluorescent lights.

3.4.1 Basic Construction of the Inverter

To convert the DC voltage to AC voltage, a switching mechanism is required, so that it switches between the DC voltage value and the negative value of the same DC voltage, thus creating an alternating voltage wave. So the main components of an inverter are a switching drive and a circuit which controls the switching process of the drive. The most common drives consist of power electronic switches like the transistors.

3.4.2 Transistors

A transistor is an electronic device that controls the flow of an electric current, most often used as a switch or as a signal amplifier. Usually, transistors are constructed from three layers of semi-conductor material, in which the flow of an electric current across the outer layers is regulated by the voltage or current applied to the middle layer.

The power transistors can be classified broadly into three categories:

- Bipolar junction transistors (BJTs).
- Field-effect transistors (FETs).
- Insulated-gate bipolar transistors (IGBTs).

3.4.2.1 Bipolar junction transistor (BJT)

It has two main types: NPN and PNP as shown in Figure

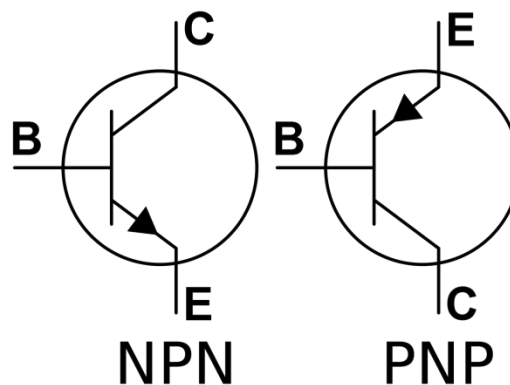


Figure 3.13: Bipolar NPN and PNP transistors

And it can be connected in one of three ways: common base, common emitter, and common collector. The characteristic operation curve of a common emitter BJT is shown in Figure 3.14.

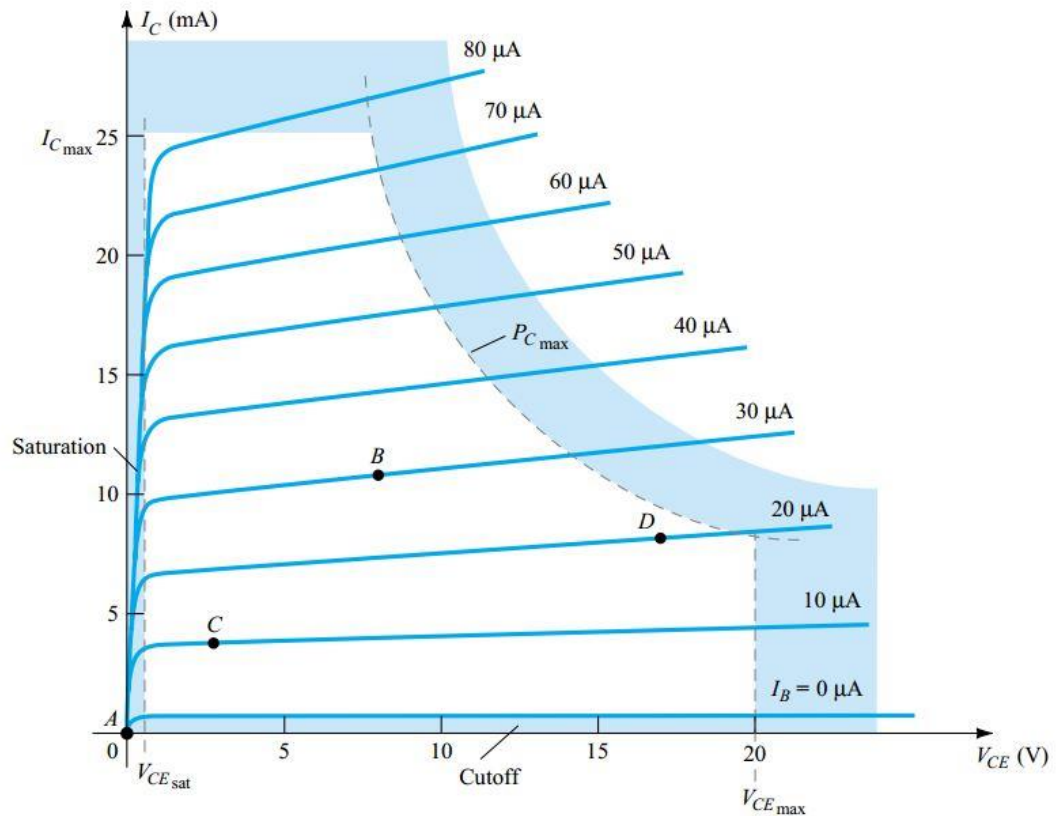


Figure 3.14: Output characteristic for a common emitter transistor

When the transistor is operating between cut-off and saturation region it's in switch mode.

P_C represents the power dissipation, which is equal to:

$$P_C = I_C \times V_{CE} \quad (3.12)$$

Where:

I_C : is the collector current in amperes.

V_{CE} : collector to emitter voltage in volts

This power should not exceed the maximum power dissipation (normally determined by the manufacturer).

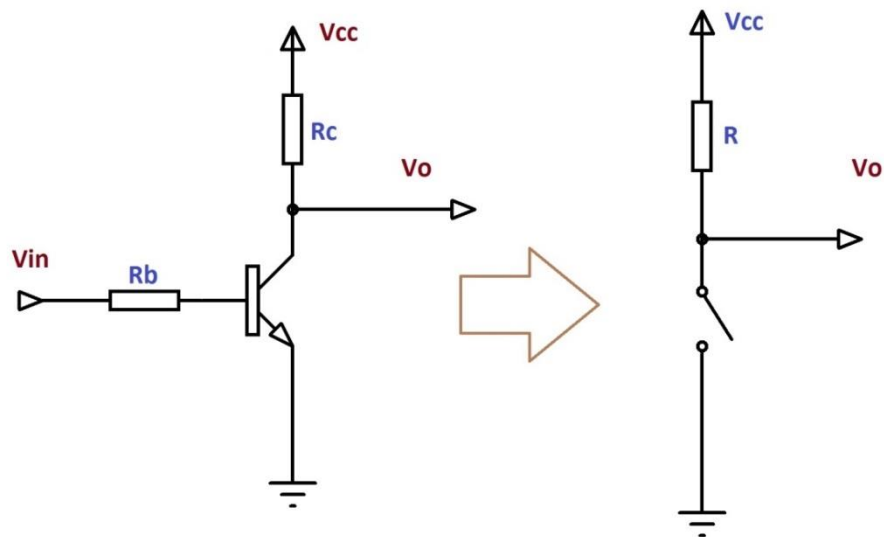


Figure 3.15: Transistor operating as a switch

When the transistor is operating in the middle area (the white area in Figure 3.14, it's operating as an amplifier as shown in Figure 3.16, with a current gain equal to h_{fe} or β .

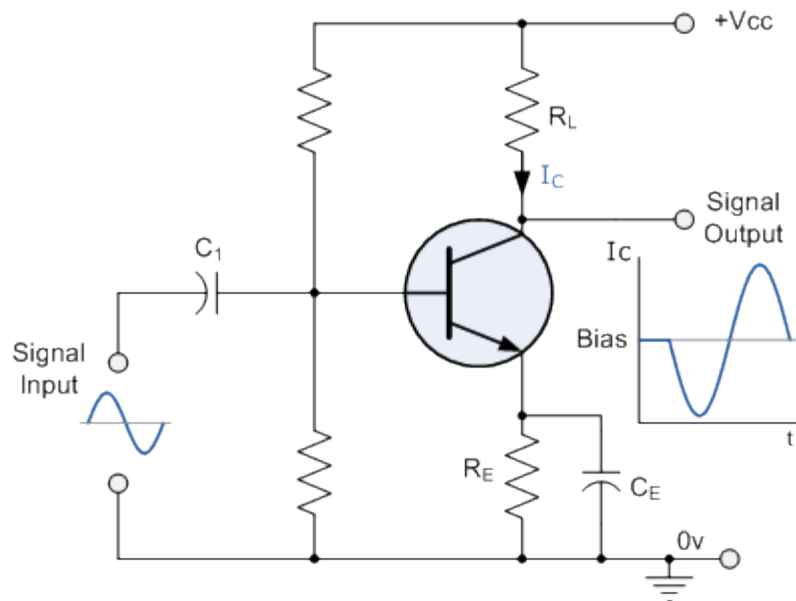


Figure 3.16: Transistor operating as an amplifier

3.4.2.2 Field-effect transistor (FET)

FETs are unipolar devices because, unlike BJTs that use both electron and hole current, they operate only with one type of charge carrier. The two main types of FETs are the junction field-effect transistor (JFET) and the metal oxide semiconductor field-effect transistor (MOSFET).

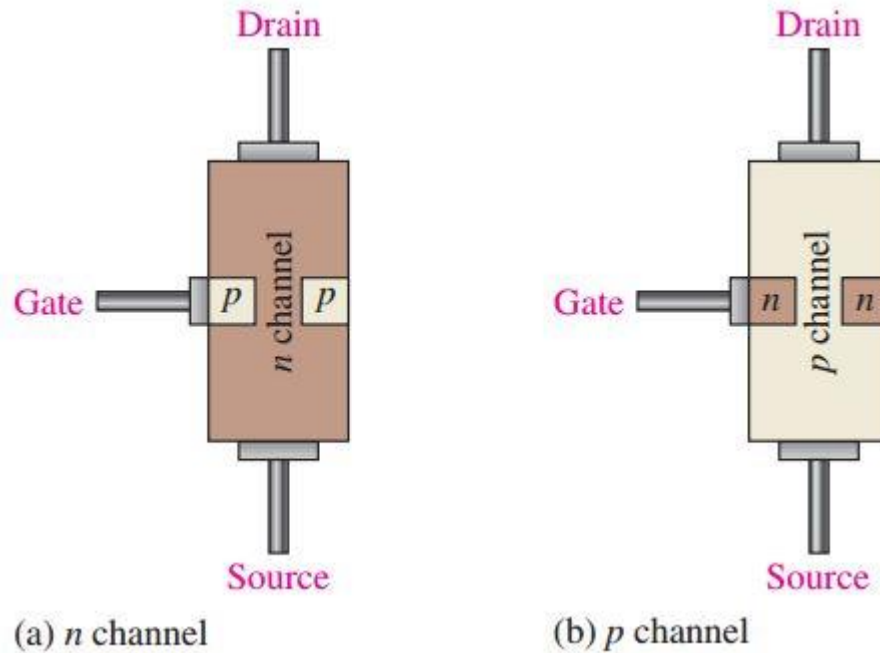


Figure 3.17: FIT n channel and p channel diagram

3.4.2.3 Insulated-gate bipolar transistor (IGBT)

The IGBT (insulated-gate bipolar transistor) combines features from both the MOSFET and the BJT that make it useful in high-voltage and high-current switching applications.

3.4.3 H-Bridge Configuration

An H-Bridge or full-bridge converter is a switching configuration composed of four switches in an arrangement that resembles an H. By controlling different switches in the bridge, a positive, negative, or zero potential voltage can be

placed across a load. When this load is a motor, these states correspond to forward, reverse, and off. The use of an H-Bridge configuration to drive a motor is shown in Figure 3.18.

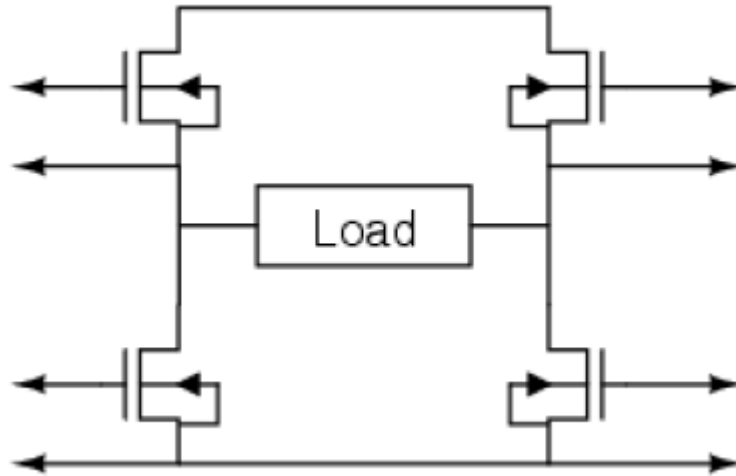


Figure 3.18: H-Bridge Configuration using N-Channel MOSFETs

As shown in Figure 3.18 the H-Bridge circuit consists of four switches corresponding to high side left, high side right, low side left, and low side right. There are four possible switch positions that can be used to obtain voltages across the load. These positions are outlined in Table 3.2. Note that all other possibilities are omitted, as they would short circuit power to ground, potentially causing damage to the device or rapidly depleting the power supply.

Table 3.2: Valid H-Bridge Switch States

High Side Left	High Side Right	Low Side Left	Low Side Right	Voltage Across Load
On	Off	Off	On	Positive
Off	On	On	Off	Negative
On	On	Off	Off	Zero Potential
Off	Off	On	On	Zero Potential

The switches used to implement an H-Bridge can be mechanical or built from solid state transistors. Selection of the proper switches varies greatly. The use of

P-Channel MOSFETs on the high side and N-Channel MOSFETs on the low side is easier, but using all N-Channel MOSFETs and a FET driver, lower “on” resistance can be obtained resulting in reduced power loss. The use of all N-Channel MOSFETs requires a driver, since in order to turn on a high side N-Channel MOSFET, there must be a voltage higher than the switching voltage. This difficulty is often overcome by driver circuits capable of charging an external capacitor to create additional potential.

3.4.4 The Discrete 555 Timer Kit:

The 555 timer consists basically of two comparators, a flip-flop, a discharge transistor, and a resistive voltage divider, as shown in Figure 3.19 on the next page. The flip-flop (bi stable multi-vibrator) is a digital device which is, briefly, a two-state device whose output can be at either a high voltage level (set, S) or a low voltage level (reset, R). The state of the output can be changed with proper input signals

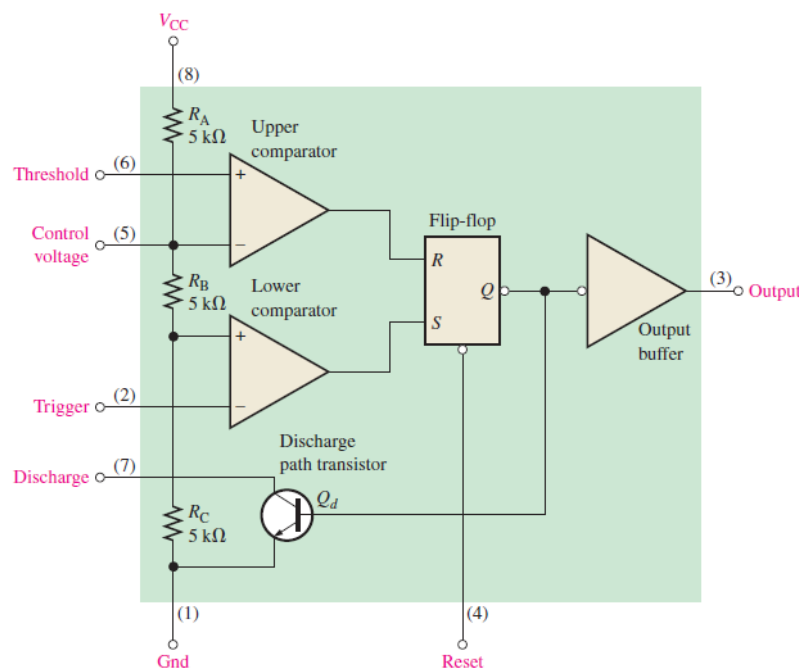


Figure 3.19: Internal diagram of a 555 integrated circuit timer

The resistive voltage divider is used to set the voltage comparator levels. All three resistors are of equal value; therefore, the upper comparator has a reference of $2/3 V_{CC}$, and the lower comparator has a reference of $1/3 V_{CC}$. The comparators' outputs control the state of the flip-flop. When the trigger voltage goes below $1/3 V_{CC}$, the flip-flop sets and the output jumps to its high level. The threshold input is normally connected to an external RC timing circuit. When the external capacitor voltage exceeds $2/3 V_{CC}$, the upper comparator resets the flip-flop, which in turn switches the output back to its low level.

When the device output is low, the discharge transistor (Q_d) is turned on and provides a path for rapid discharge of the external timing capacitor. This basic operation allows the timer to be configured with external components as an oscillator, a one-shot, or a time delay element.

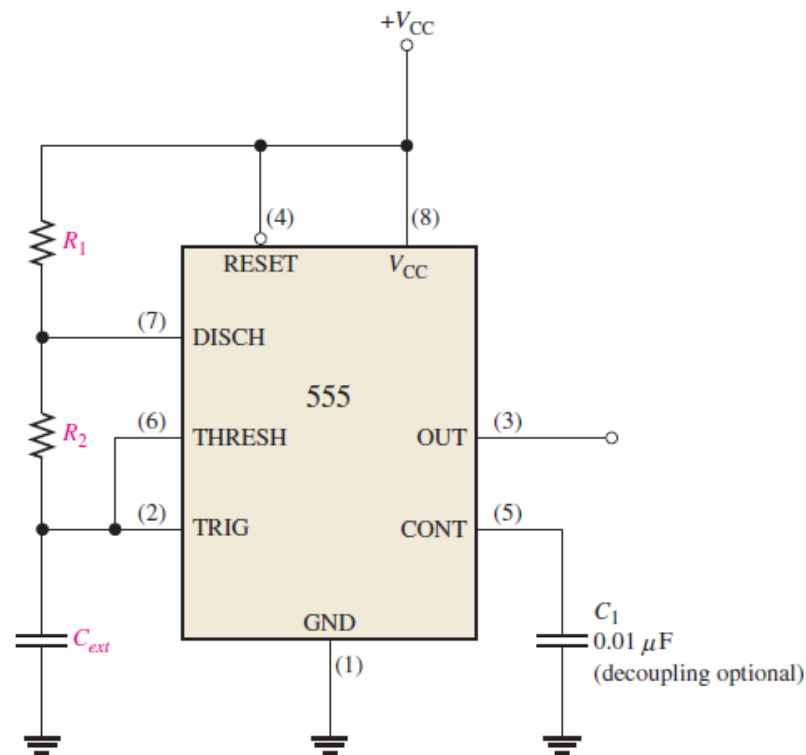


Figure 3.20: The 555 timer connected as an astable multi-vibrator

A 555 timer connected to operate in the stable mode as a free-running relaxation oscillator (a stable multi-vibrator) is shown in Figure 4.11 above. Notice that the threshold input (THRESH) is now connected to the trigger input (TRIG). The external components R_1 , R_2 , and C_{ext} form the timing circuit that sets the frequency of oscillation. The capacitor connected to the control (CONT) input is strictly for decoupling and has no effect on the operation.

3.5 Filtering

Filters come in many different packages, with many different advantages and disadvantages. For example, a digital filter is easily reconfigurable and can have almost any frequency response desired. If the response is simply low-pass, high-pass, bandpass behavior with a set frequency, an active filter can be made to have a very sharp edge at the cutoff, resulting in enormous reductions in noise and very little attenuation of the signal. These, however, require Op.Amps. Since the Op.Amp. must be able to source hundreds of watts, and must be very large to do so without burning. Digital filters have a similar drawback and, designed with TTL and CMOS technology, can only work with small signals. Lastly we come to a passive filter. Generally large in size and very resistive at low frequencies, these filters often seem to have more of a prototyping application, or perhaps use in a device where low cost is important, and efficiency is not.

So in general, the advantages of the active filters in comparison with the passive filters are as follows:

- Low cost: as a variety of cheaper Op.Amps. are easily available, so active filters are more economical than passive filters.
- Small components: The components used in active filters are smaller in size as compared to passive fillers components.

- Gain and frequency adjustment flexibility: in active filters as an Op.Amp. can provide a gain, the input signal is not attenuated and active filters are easy to tune so easy frequency adjustment is possible.
- No loading problem: as Op.Amp. has a high input resistance and low output resistance.
- Inter-stage isolation and control of impedance: allowing the control of the input and the output impedances.

But active filters have some disadvantages as well, as the following:

- As the Op.Amp. has a finite gain bandwidth product, active filters are limited in their frequency range.
- Active filters require DC power supply for their operation.
- Active filter can't handle large amount of power.
- They are only suitable for low or moderate frequencies.

Inverter output can be considered a square wave that contains higher order harmonics. MATLAB has been used to analyze such a wave.

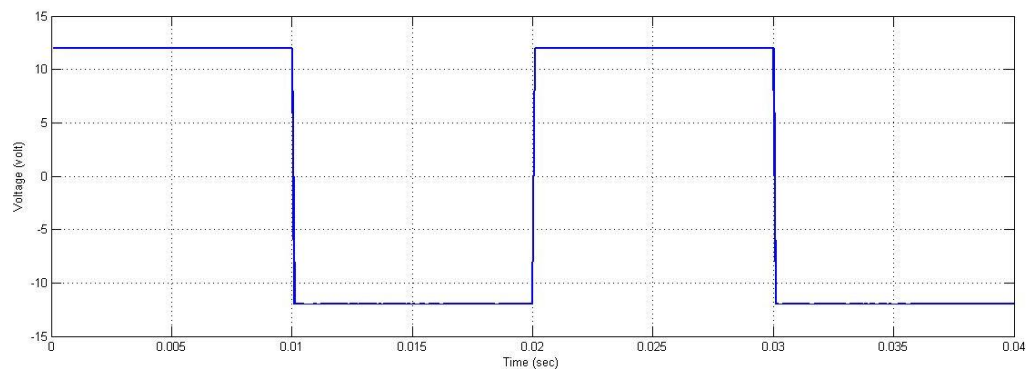


Figure 3.21: inverter output

By transforming this square wave into its equivalent Fourier series:

$$f(\omega) = a_0 + \sum_{n=1}^{\infty} a_n * \cos(n\omega t) + \sum_{n=1}^{\infty} b_n * \sin(n\omega t) \quad (3.13)$$

$$\omega = 2\pi f \quad (3.14)$$

$$T = \frac{1}{f} \quad (3.15)$$

$$a_0 = \frac{1}{T} \int_0^T f(t) dt \quad (3.16)$$

$$a_n = \frac{2}{T} \int_0^T f(t) \cos(n\omega t) dt \quad (3.17)$$

$$b_n = \frac{2}{T} \int_0^T f(t) \sin(n\omega t) dt \quad (3.18)$$

where:

$f(\omega)$: Fourier series

a_0 : the average value of the main wave

T : full cycle period of the main wave

f : frequency of the main wave (Hz)

Since square wave is quarter-wave symmetry of an odd signal

$$a_0 = 0$$

$$a_n = 0$$

$$b_n = 0 \text{ for even numbers of } n$$

$$b_n = \frac{4 \cdot A}{\pi \cdot n} \text{ for odd numbers of } n \quad (3.19)$$

$$f(\omega) = 15.28 \sin(\omega t) + 5.09 \sin(3\omega t) + 3.056 \sin(5\omega t) + 2.18 \sin(7\omega t) + 1.7 \sin(9\omega t) + \dots \quad (3.20)$$

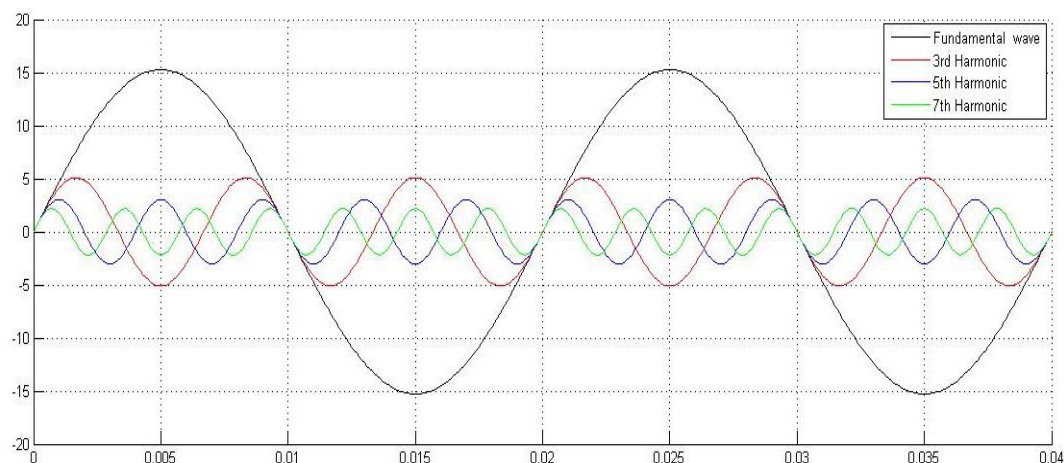


Figure 3.22: fundamental wave with 3rd, 5th and 7th harmonic

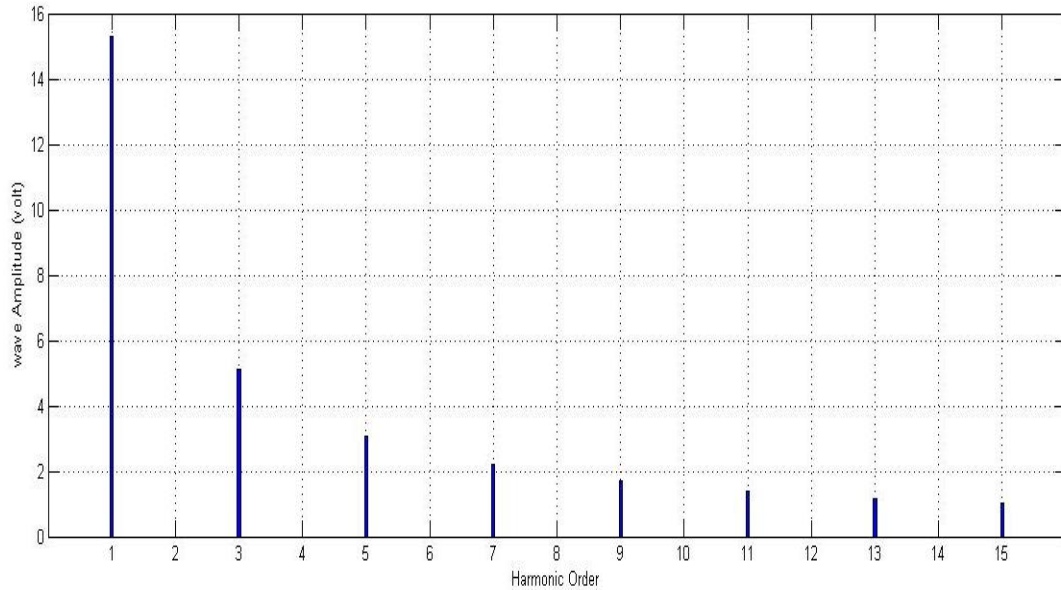


Figure 3.23: Spectrum diagram of harmonic order against harmonic amplitude

Since:

- Fundamental wave frequency has 50 Hz
- 3rd Harmonic Frequency has 150 Hz
- 5th Harmonic Frequency has 250 Hz

To get rid of the inverter output Harmonics a low pass filter is required that can allow 50 Hz to pass and prevent 150 HZ (or more) from passing.

For the L-C low-pass filter (Figure 3.24), we have selected for the filter to have 60 Hz cut frequency.

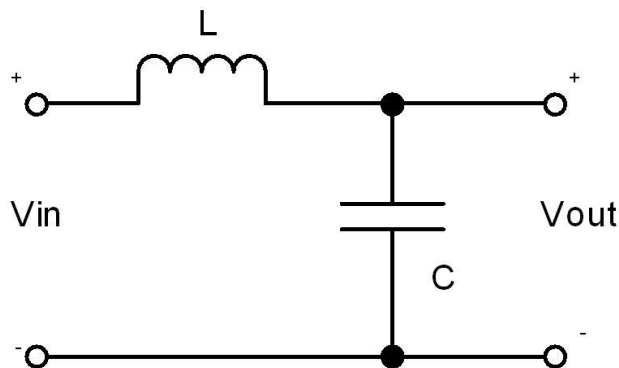


Figure 3.24: L-C low-pass filter

$$f_o = \frac{1}{2\pi\sqrt{L.C}} \quad (3.21)$$

3.6 Output voltage and loading problems

We can use a normal transformer to amplify V_c to 220-240 volt which would be at 50 Hz at no load, but the problem lies when connecting the load, a major disadvantage of passive filter that their output voltage drop harshly when a load is connected across V_c (Figure).

There are two main load types (voltage consideration):

- Constant load : In this case the passive filter and its transformer can be selected so that when connect that load v_{out} will be 220 volt that can be done by increase V_c on-load so that it drop to 220 when connecting the load selecting a suitable transformer that higher ratio down side It's hard to find such a specific ratio voltage transformer incase the load is desired to be changed the filter has to be remade no-load voltage will be way higher than 220 volt
- Variable load : An Op-Amp can be used to block the load effect, since op-Amp has small output impedance and large input impedance.

For a variable load, a unity follower Op-amp connection can be used as the follows:

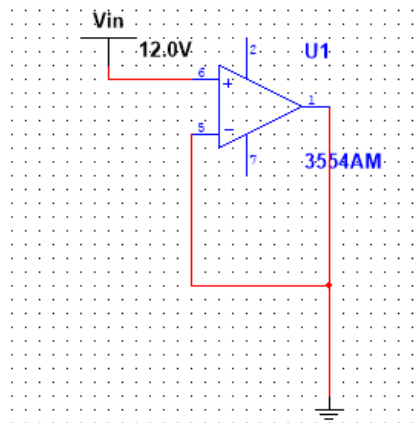


Figure 3.25: operation amplifier with unity gain

$$V_{out} = A_o \times (V_{in} - V_{out}) \quad (3.22)$$

$$V_{out} = \frac{A_o}{1+A_o} \times V_{in} = \lim_{A_o \rightarrow \infty} v_{in} \times \frac{1}{1+\frac{1}{A_o}} = V_{in}$$

$$\frac{V_{out}}{V_{in}} = 1 \quad (3.23)$$

Another connection can be used to control the Op-Amp gain, where in this case:

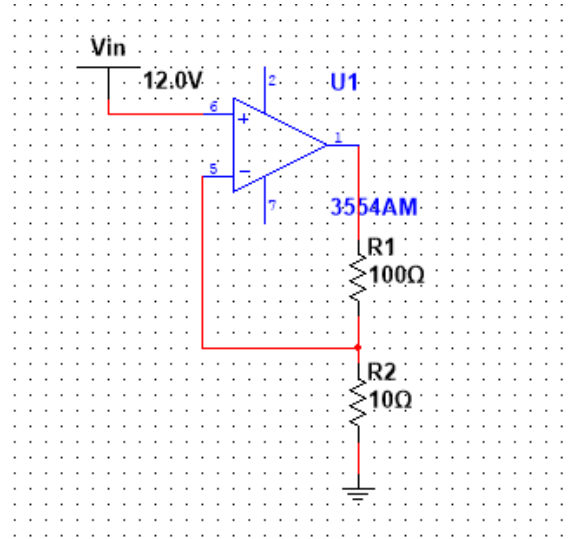


Figure 3.26: operation amplifier with gain

$$\frac{v_{out}}{v_{in}} = \frac{R2+R1}{R2} \quad (3.24)$$

With this connection even when load change the output voltage will remain the same (220-240 volt), but OP-Amp has Downside that's mean can't handle large loads.

CHAPTER FOUR

DESIGN AND SIMULATION

4.1 Overview

In order to make the design process simple, the design of the UPS system was divided into four main steps:

1. Designing the rectifier circuit.
2. Designing the inverter circuit.
3. Choosing the battery.
4. The design of the battery charging and control circuit.

As for the simulation software used in this project, Multisim was chosen, also MATLAB was used for certain calculations and plotting.

4.2 Designing the Rectifier Circuit

The first step here was to supply the circuit to be made, with an AC 18v which is enough to compensate the drop in the bridge rectifier and still supplies the battery with 13.8v to charge it with the float voltage. We used a step down transformer and its input voltage is supplied directly from an AC power source of a 220v, which is the input of the UPS. And the primary to secondary ratio is 220v/18v.

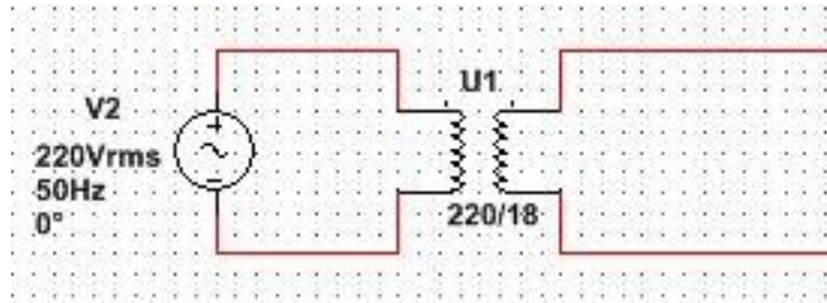


Figure 4.1: The step down transformer

A full wave bridge rectifier called 1B4B42 was used. Its input was 18v AC. The voltage drop across the bridge rectifier is equal to the drop of two silicon diodes which is 1.4v so the final output is:

$$(18 \times \sqrt{2}) - 1.4 = 24v$$

This output is varying as shown in Figure 4.2 with an average value of:

$$\frac{1}{\pi} \int_0^{\pi} 24 \sin(\phi) d\phi = 15.28v$$

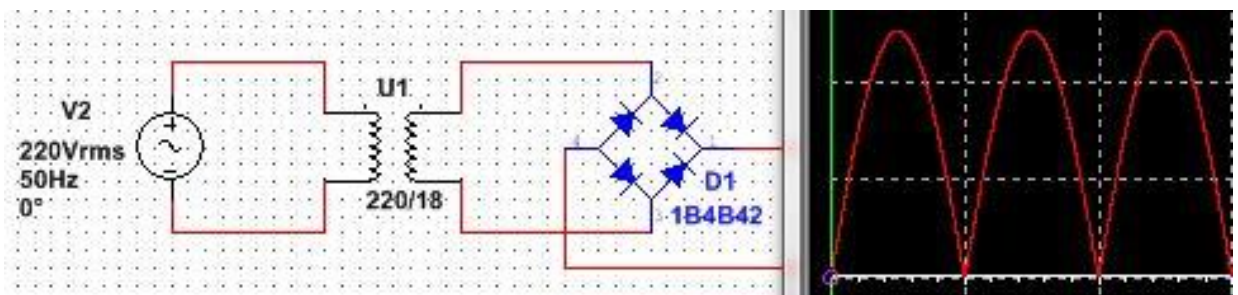


Figure 4.2: rectifier output voltage waveform

Now, in order to make this voltage varying as small as possible, a smoothing capacitor with a capacitance of 1000μF (value was chosen due to reasons mentioned in chapter three smoothing section). The capacitor was used to smooth the output voltage from varying greatly to varying in just small ripples, as shown in Figure 4.3.

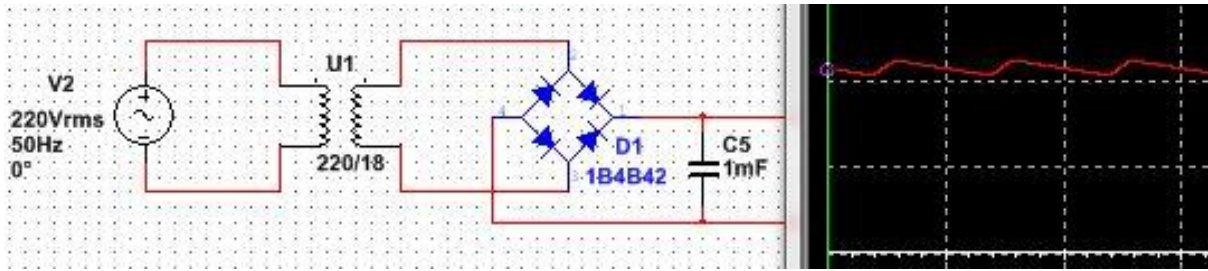


Figure 4.3: smoothed voltage waveform

Now this small ripple can be eliminated by using a voltage regulator, the voltage regulator LM723 eliminates the ripple by setting DC output to a fixed voltage 13.8v, as shown in Figure 4.4.

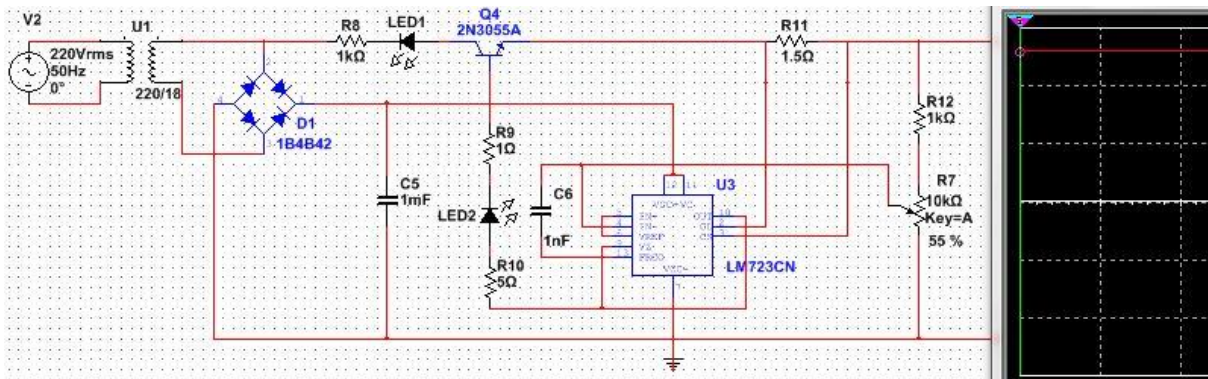


Figure 4.4: regulated DC voltage waveform

The battery voltage is 12V, and the regulator drop is 3V, and there is the drop of the two diodes (rectifier) which is 1.4V, and then we take a 10% volt as safety.

So the final voltage across the transformers' secondary should be:

$$12 + 3 + 1.4 + (12 \times 0.1) = 17.6\text{v} \sim 18\text{v}$$

That's why, the transformer was selected to have a ratio of 220v/18v instead of 220v/12v.

Also, the power of the 18V transformer is related to the current of the battery to be charged. The charging current is approximately 0.1 of battery capacity. And since current limitation is handle by the regulator, it is not dangerous to

use higher powers. But using lower power will not be sufficient to charge the battery

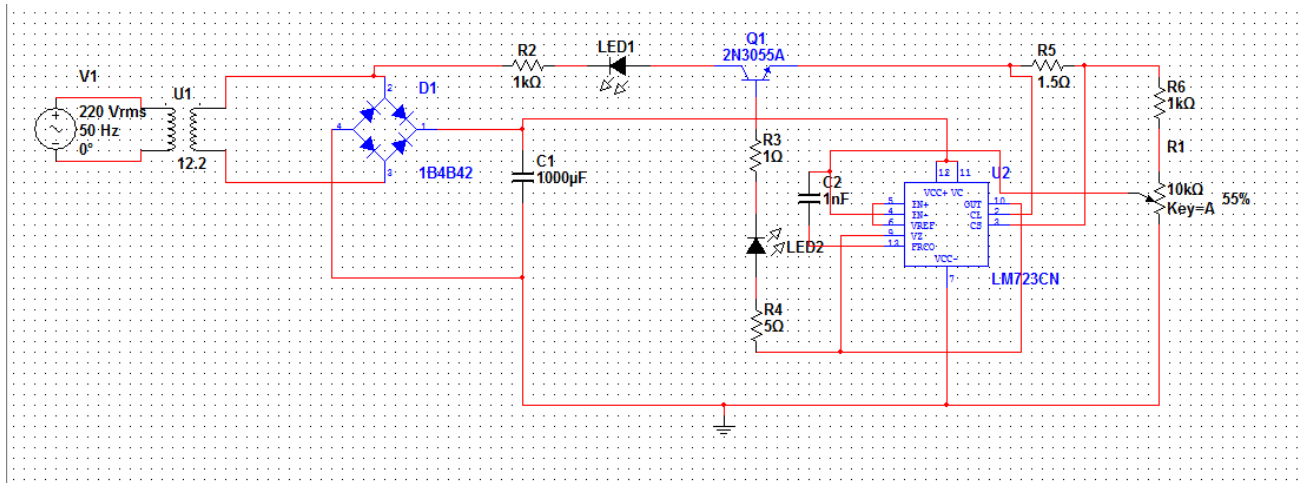


Figure 4.5: complete rectifier circuit

LED1 is called power led. This led is connected between AC input and DC output of bridge rectifier. It is used as an indicator to show if there is AC input from the transformer to the bridge rectifier or not.

All of the connections regarding LM723 are connected with its datasheet as the reference. 2N3055A is used as an external transistor along with the LM723 to provide the desired current.

In the LM723 voltage pins are 12, 11 and 7 pins. Pin number 12 is positive voltage. Pins number 12 and 11 are connected to DC voltage at the output of the smoothing capacitor. Pin number 7 is connected to ground. Pins number 1, 14 and 8 are not connected as expressed in the datasheet of LM723.

In this integrated circuit, pin number 2 is current limit and pin number 3 is current sense as showed previously in Figure 4.5. Pin number 3 is connected to the positive pole of the battery. By this connection, voltage regulator obtains the charging current and controls this current during charging. Pin number 2 supplies source current over the resistance 1.5Ω in order to make a

reference point to limit the current. This pin also is connected to the transistor emitter. The collector of transistor is connected to positive voltage.

A capacitor is connected between pins number 13 and 4, as instructed in the datasheet. Pin number 4 is called inverting input. It gets a reference voltage and it is used on the 10K Ω potential transformer. This voltage obtained from 10K Ω potential transformer is actually the charging voltage. Before charging, output voltage should be adjusted until it matches the charging voltage. The charging voltage should be set 2.3-2.4V per 2V cell. So, a 12V battery (6 cells of 2V) is charged at:

$$6 \times 2.3 = 13.8v$$

LM723 determines the charging condition comprising the data from pins number 2, 3 and reference voltage. By combining pins number 9 and 10 by triggering the current controlling the transistor, it supplies voltage output over yellow led. Voltage to the base pin puts the transistor in transmission to LED2 which is called the charging led, and it is lit while charging..

4.3 Designing the Inverter Circuit

For the inverter circuit, the input voltage is the battery 12v DC, and then there is the Discrete 555 Timer. The information for this timer can be found in its datasheet; also the connection method was applied using its datasheet as the reference, lastly there is the center tap transformer which is connected to the output of this inverter circuit.

4.3.1 The “Three Fives” Discrete 555 Timer Kit:

The 555 timer is used to generate the pulse signal for the switch drives, and it's connected as shown in Figure.

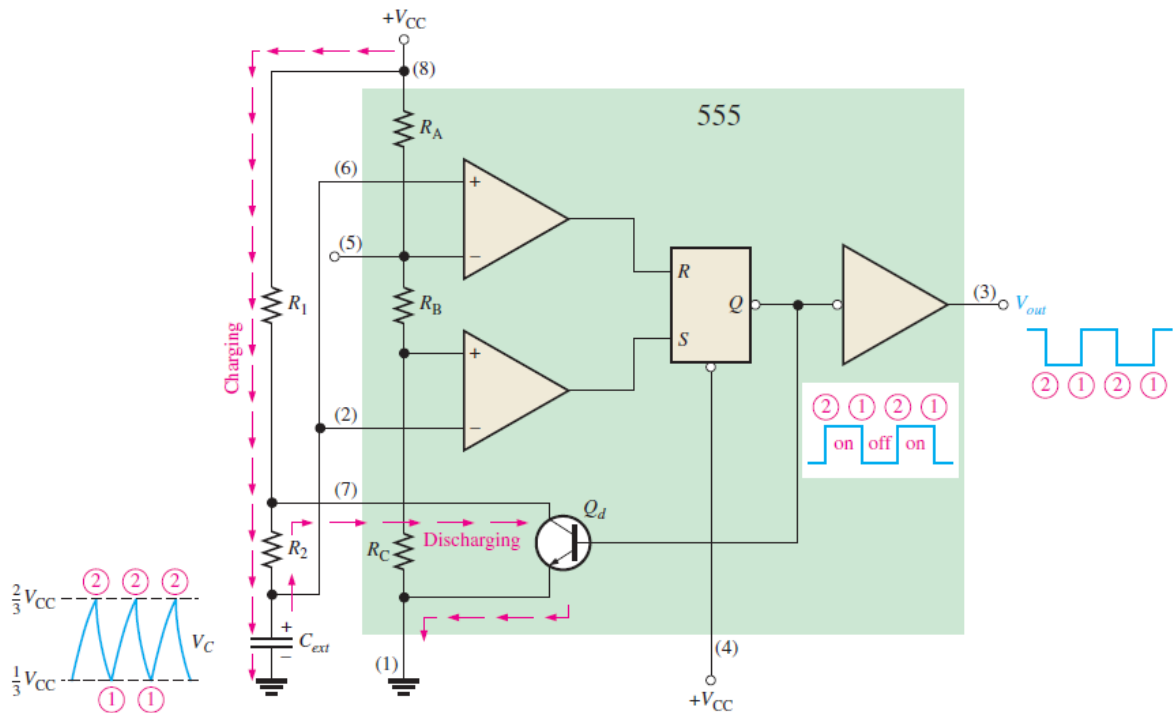


Figure 4.6: Operation of the 555 in the astable mode

Initially, when the power is turned on, the capacitor C_{ext} is uncharged and thus the trigger voltage (pin 2) is at 0 V. This causes the output of the lower comparator to be high and the output of the upper comparator to be low, forcing the output of the flip-flop, and thus the base of Q_d , low and keeping the transistor off. Now, C_{ext} begins charging through R_1 and R_2 as indicated in Figure 4.12. When the capacitor voltage reaches $\frac{1}{3}V_{CC}$, the lower comparator switches to its low output state, and when the capacitor voltage reaches $\frac{2}{3}V_{CC}$, the upper comparator switches to its high output state. This resets the flip-flop, causes the base of Q_d to go high, and turns on the transistor. This sequence creates a discharge path for the capacitor through R_2 and the transistor, as indicated. The capacitor now begins to discharge, causing the upper comparator to go low. At the point where the capacitor discharges down to $\frac{1}{3}V_{CC}$, the lower comparator switches high, setting the flip-flop, which makes the base of Q_d low and turns off the transistor. Another charging cycle begins, and the entire

process repeats. The result is a rectangular wave output whose duty cycle depends on the values of R1 and R2.

$$f_r = \frac{1.44}{(R1+2R2)C_{ext}} \quad (4.1)$$

Where:

f_r : the frequency of oscilation (Hz).

By selecting R1 and R2 the duty cycle of the output can be adjusted. Since C_{ext} charges through $R1 + R2$ and discharges only through R2 duty cycles approaching a minimum of 50 percent can be achieved if $R2 \gg R1$ so that the charging and discharging times are approximately equal.

A formula to calculate the duty cycle is developed as follows. The time that the output is high (t_H) is how long it takes C_{ext} to charge from $1/3V_{CC}$ to $2/3V_{CC}$. It is expressed as

$$t_H = 0.694(R1 + R2)C_{ext} \quad (4.2)$$

Where:

t_H : the time that the output is high (sec).

4.3.2 Center Tap Transformer:

The center tap transformer have a contact made to a point half way along it's winding, as shown on the Figure 4.7 below, the full voltage of the winding is measured from the outer two taps (the winding as a whole), and exactly half of this voltage from each outer tap to the center tap (half the winding). These two halves are 180° degrees out of phase with each other.

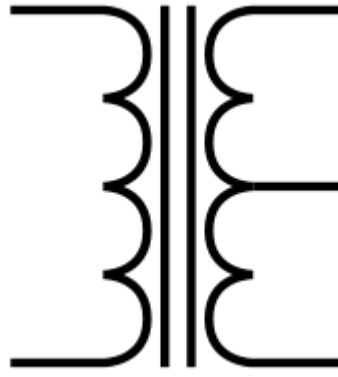


Figure 4.7: Diagram of center-tapped transformer

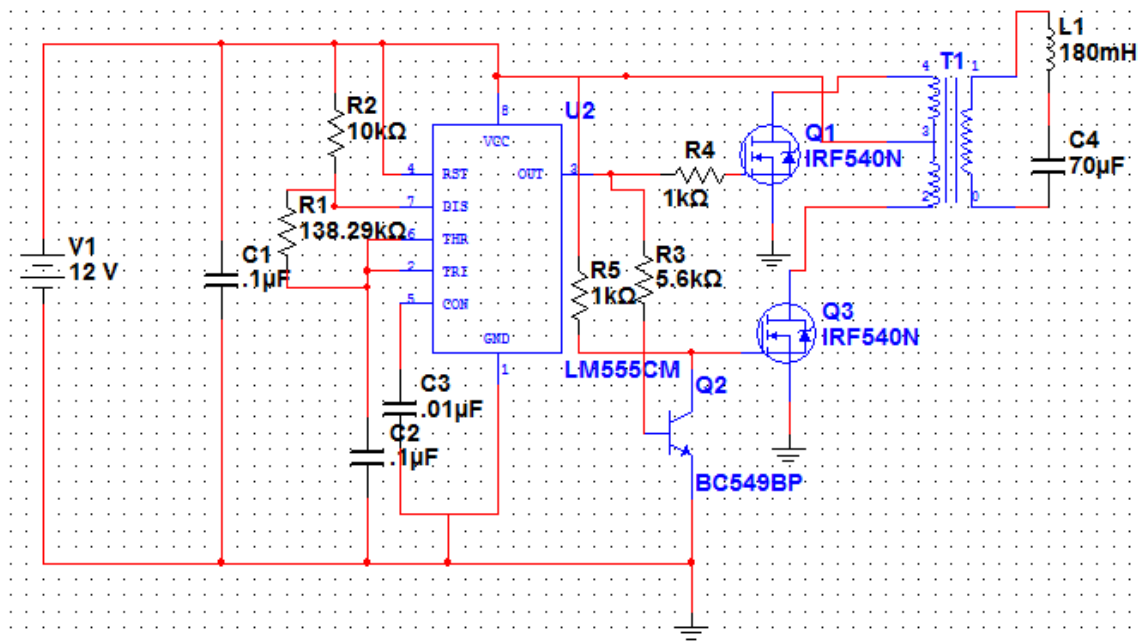


Figure 4.8: completed inverter circuit

The battery was represented by a constant DC source of 12v. The output of the timer is connected to two transistors with resistors in series to limit the current, these transistors act as gates, when a signal triggers the gate, the gate opens and the power will flow from the emitter, and the output of these transistors is connected to a center tap transformer to step up the voltage to 220v.

The inverter power basically depends on the transistors, that's why sometimes several transistors are connected in series to increase the power, however, the

transistors will have various resistances (even if they were the same type) which will lead to a current flowing more through the lower resisting transistor.

After the center tap transformer, there is a filter circuit, consists of an inductance and a capacitance. The product of the capacitor and the inductance is constant, and to increase the output voltage, we increase the voltage amplitude by increasing the capacity of the capacitance, however this will affect the frequency directly, and to solve this, the frequency must be tuned by changing the values of R1 and R2 shown in figure 4.8.

4.4 Choosing the Battery Size

For the UPS to supply a load of 310 w for 1 hour at 230 volt

$$I_{load} = \frac{P_{out}}{V_{out}} \quad (4.3)$$

$$= \frac{310}{230} = 1.348 \text{ A}$$

$$R = \frac{V_{out}}{I_{load}} \quad (4.4)$$

$$= \frac{230}{1.348} = 170.623 \Omega$$

When connecting this load (170 ohm), actual data found from the simulation (Figure 4.8):

Load voltage $V_{out} = 299.8 \text{ volt}$

Load current $I_{Load} = 1.352 \text{ Amp}$

Battery voltage $V_B = 12 \text{ volt}$

Current taken from the battery $I_B = 34.52 \text{ Amp}$

$$\zeta = \frac{P_{in}}{P_{out}} = \frac{V_t * I}{V_b * I_B} \quad (4.5)$$

where:

ζ is the inverter efficiency

$$\zeta = \frac{229.8 \times 1.352}{12 \times 34.52} = 0.75 = 75\%$$

Since 34.5 Amp is drawn from the battery to supply the load we can say the battery must be able to supply 35Amp for an hour therefor supplying 35 AH.

But since the battery must never be fully discharged, the minimum capacity of discharging is 30%

Battery capacity – 30% remaining capacity = 35 AH

Battery capacity = 50 AH

And yet again since batteries are to operate at 20 hours for full capacity and our battery is operating for 1 hour, according to Peukert's effect the actual rate for the battery can be evaluated from table 3.2.

1 hour → 40% capacity

Actual rated need for the battery = 50 AH / 0.4

Battery rate = 125 AH

Now with our design 125 AH battery will supply 310 watt load for 1 Hour before we disconnect it with 30% of its capacity remaining.

But if a lower load or higher loads are to be connected to this UPS it will operate for a different time

Assume a 100 watt is to be connected

Battery current $I_B = 100 \text{ watt} / (0.75 \text{ efficiency} \times 12 \text{ V}_B) = 11.111 \text{ Amp}$

125 AH / 11.111 Amp = 11.25 hours

But since it's not 20 hours the equivalent battery rate from table 3.2 shows a capacity of 89%.

125 * 0.89 = 111.2 AH

And since it will be disconnect at 30% remaining capacity

111.25 * (100-30)/100 = 77.9 AH (effective capacity)

77.9 Ah / 11.111 = 7 hours

Our inverter is built to handle maximum of 400 w

Peukert's Equation

$$Th = Hr \left(\frac{CB}{I_{dis} \times Hr} \right)^n \quad (4.6)$$

Where:

I_{dis} : is the discharge current

T_h : is the time in hours

CB : is capacity of the battery AH

n : is Peukert's exponent for that particular battery type (= 1.753 for lead acid batteries).

H_r : is the battery hour rating, (i.e. 100 hour rating, 20 hour rating, 10 hour rating etc. by default it is 20 hours as standard unless stated otherwise in the battery datasheet).

The following MATLAB program was used to evaluate exactly for how long (time) the UPS can supply a specific load.

```
Load=20:5:400;           // the load assumed min 20 wat and the max 400 wat
IB=Load./(0.75*12);      // battery current = output power / (efficiency*
                          // battery voltage)
T=20.*power((125./(IB.*20)),1.753); // time in hours
plot(Load,T)
```

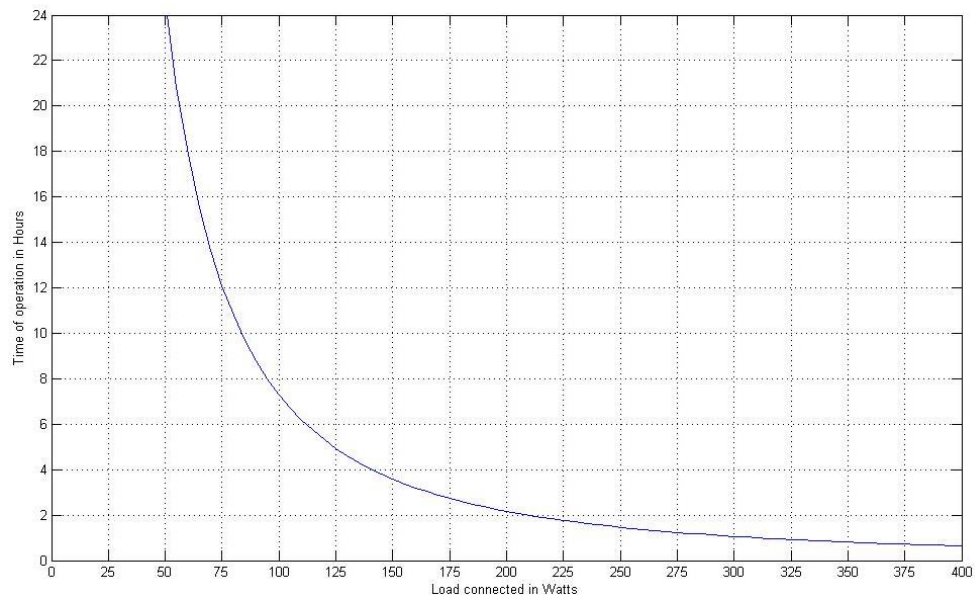


Figure 4.9: Peukert's Equation plot diagram for time against load

4.5 The Design of the Battery Control Circuit

The battery shouldn't reach less than 30% from its total capacity to avoid deep discharge problems, when the battery reach that level the voltage across it drops to 11.5 volt, a simple comparator circuit can check for this condition and disconnect the battery from the inverter circuit thus, the load.

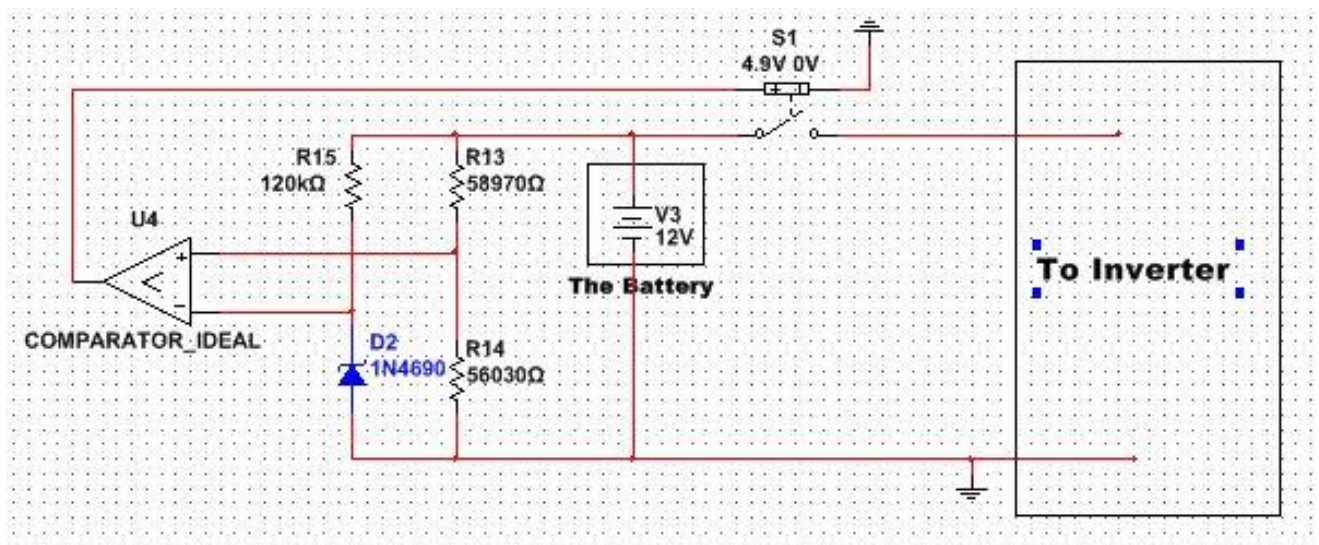


Figure 4.10: Battery controlling circuit

One of the simplest type of comparators is an Op.Amp. operating at open loop and that has a low saturation voltage so that when the error signal, which is the difference between the positive input and the negative input is higher than zero it will be amplified by a very high gain yet since the output can't exceed the saturation voltage the saturation voltage will be the one to appear on the output. As for the connection, the zener diode 1N4690 has 5.6 zener voltage and it's used for the negative input, a voltage divider was then used to get the positive input and it will be equal to 5.6v when the battery voltage is 11.5v. The relay is connected so as it will disconnect the battery from the inverter only and not from the rectifier circuit so that incase the power has returned, it will start charging the battery directly.

The resistances R_{13} , R_{14} and R_{15} draw current and consume power, the higher their value the lower their losses .

For the voltage divider:

$$\begin{aligned}\frac{V_{pos}}{V_{bat}} &= \frac{R_{14}}{R_{13}+R_{14}} \\ &= \frac{5.6}{11.5}\end{aligned}\tag{4.7}$$

Therefore

$$\frac{R_{14}}{R_{13}} = 0.95$$

So the values of the resistances are:

$$R_{13} = 58.97 \text{ K}\Omega$$

$$R_{14} = 56.03 \text{ K}\Omega$$

$$R_{15} = 120 \text{ K}\Omega$$

4.6 Simulation Results

The results of the simulation for the converter circuit are shown in the next Figure 4.11, left side representing the source input to the transformer, and the right side represents the output of the converter circuit.

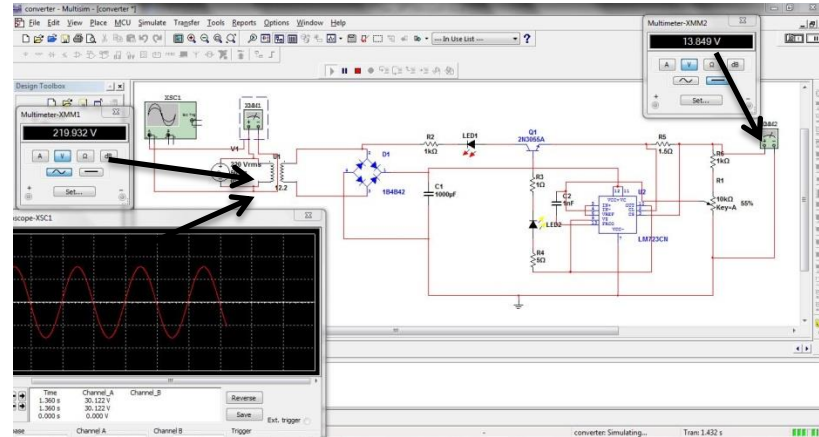


Figure 4.11: simulation results for the completed converter circuit

The full UPS model is shown next, with a load of 170Ω connected, and by changing the load we change the time the UPS will keep supplying the new load as shown previously.

Also, the results of the simulation are shown in the form of voltage waveforms and magnitude on key locations for each of the components of this UPS, also the frequency waveform and magnitude is shown on the input of the UPS and on the output with the load connected.

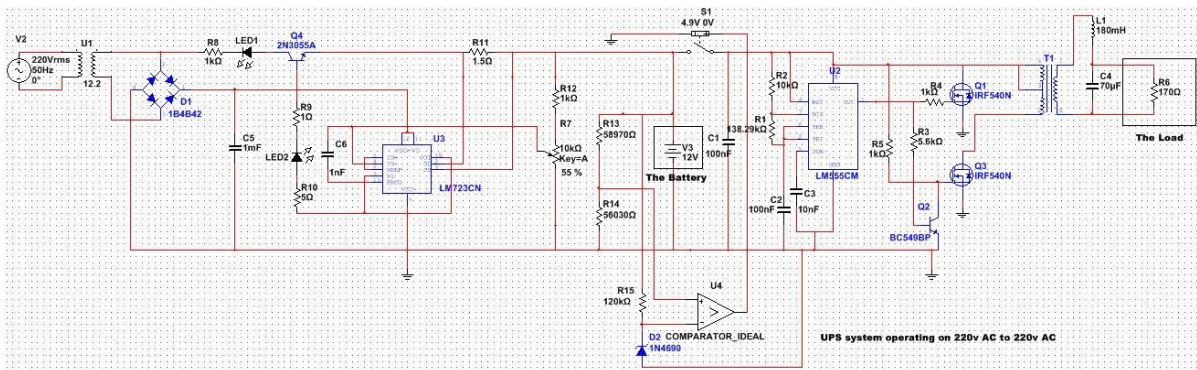


Figure 4.12: UPS completed model

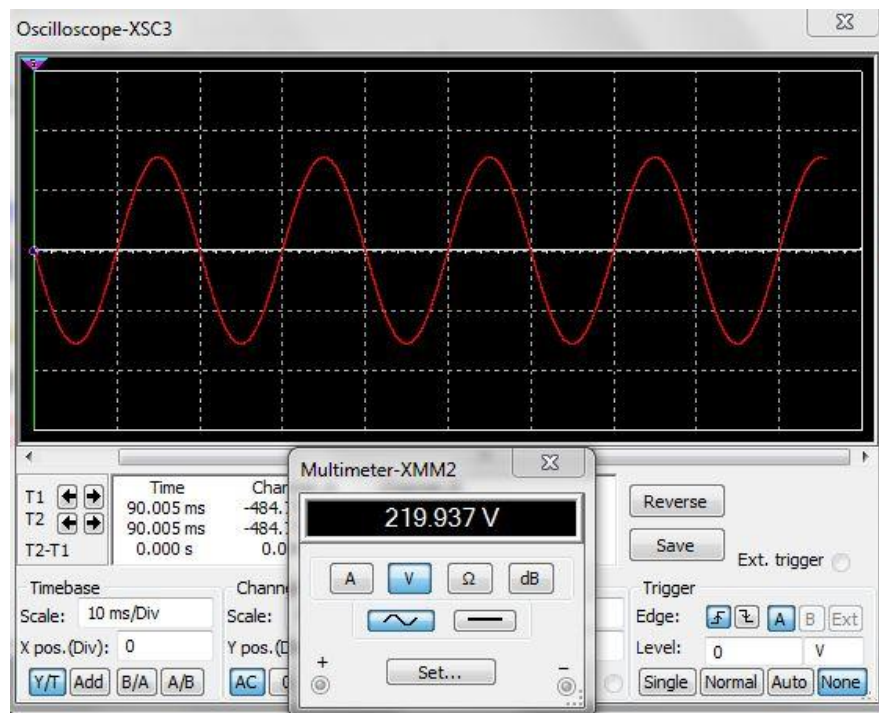


Figure 4.13: UPS input voltage waveform

As seen on the waveform above, this is the input of the UPS, specifically, the input of the rectifying circuit.

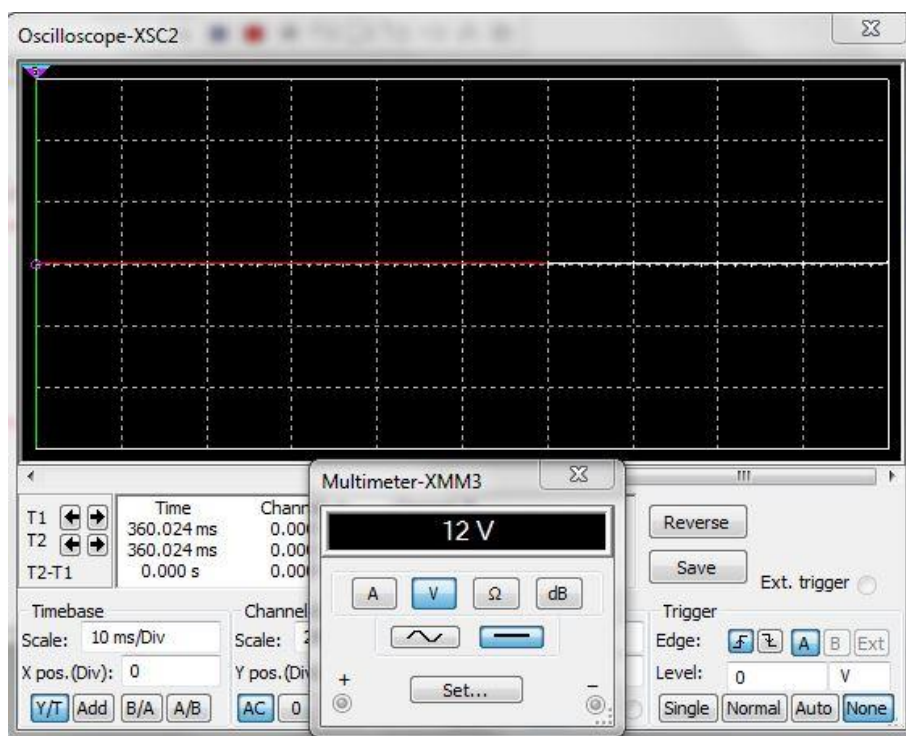


Figure 4.14: battery terminal voltage

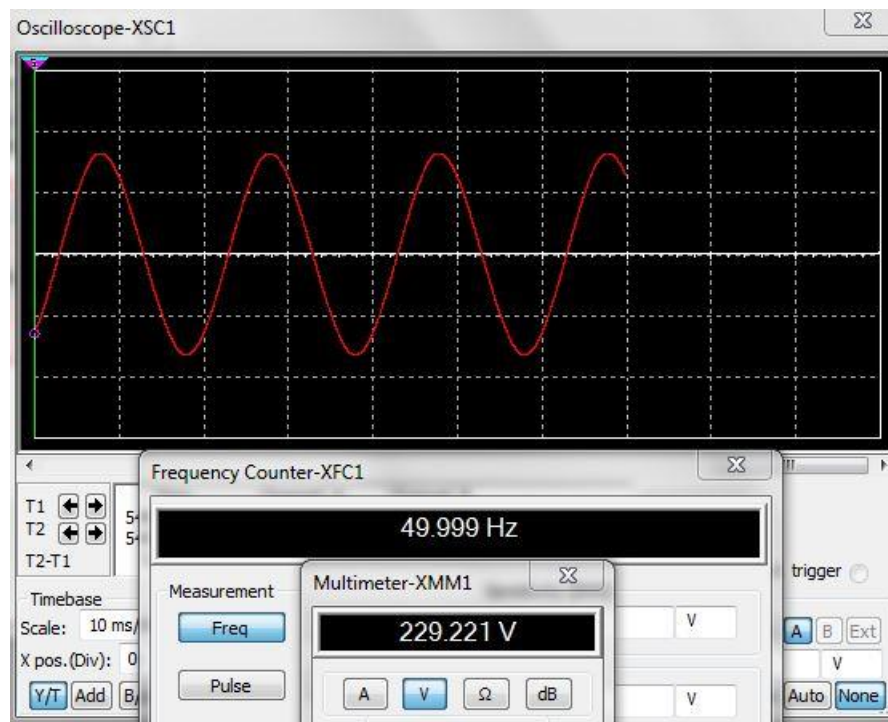


Figure 4.15: UPS output voltage and frequency waveform

The previous Figure 4.15, shows the output voltage waveform of the UPS, as seen it's a pure sinewave with 230v and a frequency of 50HZ.

A load test was then conducted on this design, with the input voltage of the transformer on the output side being a constant 12v and an output voltage of 230v (also a constant value), the inverters' efficiency is 75%. Also, the maximum current of the inverter is 50A. The test was conducted by changing the value of the load which was represented by a resistance. The results are shown on Table 4.1.

Table 4.1: Loading test results as input current and power against output current and power for different loads:

Resistance(Ω)	I input (A)	P input (watt)	I output (A)	P output (watt)	T operation (Hours)
100	38.25	612	2.2	459	0.835
110	34.77	556.3	2	417.23	0.987
140	27.32	437.1	1.57	327.8	1.507
170(optimum)	22.8	364.8	1.29	273.6	2.069
200	19.17	306	1.1	230	2.804
230	16.67	266	0.95	200	3.582
280	13.66	218.5	0.78	163.9	5.079
350	10.9	174.8	0.62	131.1	7.544
400	9.57	153	0.55	114.8	9.477
800	4.78	76.5	0.275	57.4	32.002
1200	3.19	51	0.1833	38.25	65.223

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research, a complete design of an uninterrupted power supply (UPS) was accomplished, starting from determining the loads to be connected to the UPS system, and then choosing the right battery size to give the wanted time of continuous supply. After that a battery charging and control system was designed so that the battery will never be fully discharged and will be considered empty automatically on 30% capacity.

Finally the system was tested on the normal loading condition and the system output was within the accepted range regarding the voltage, and regarding the frequency, the system delivered a frequency of 50 Hz with an error range of 0.005 Hz which is optimal.

The UPS system depends on the battery, because it's where the electrical power is stored, having a dysfunctional battery will cause the failure of the whole UPS system, and there are a lot of factors that affects the battery as mentioned on chapter three.

The second main component that affects the UPS directly is the inverter, an inverter with low efficiency will cause a lot of loss concerning the power converted from DC to AC which can decrease the operating time of the UPS sharply.

A UPS can be portable depending on the size of the components (specially the battery).

5.2 Recommendations

1. To get the most out of the UPS system, an inverter with a very good efficiency is required, however, on the market the better the inverter the more expensive it will be, so depending on your application of the UPS system, try to get the optimal inverter for your system.
2. As shown previously, operating charging a battery beyond 100% can lead to the battery losing life time greatly over time, that's why three steps charging method is required to get the most out of the battery before its lifespan is over.
3. The battery can be charged from a free electrical power source, like solar power (or even a DC dynamo charger), and by doing so, the charging cost plus the consumption rate from the battery are reduced, so adding an optional solar charger to the battery's charging circuit will increase discharging time greatly.

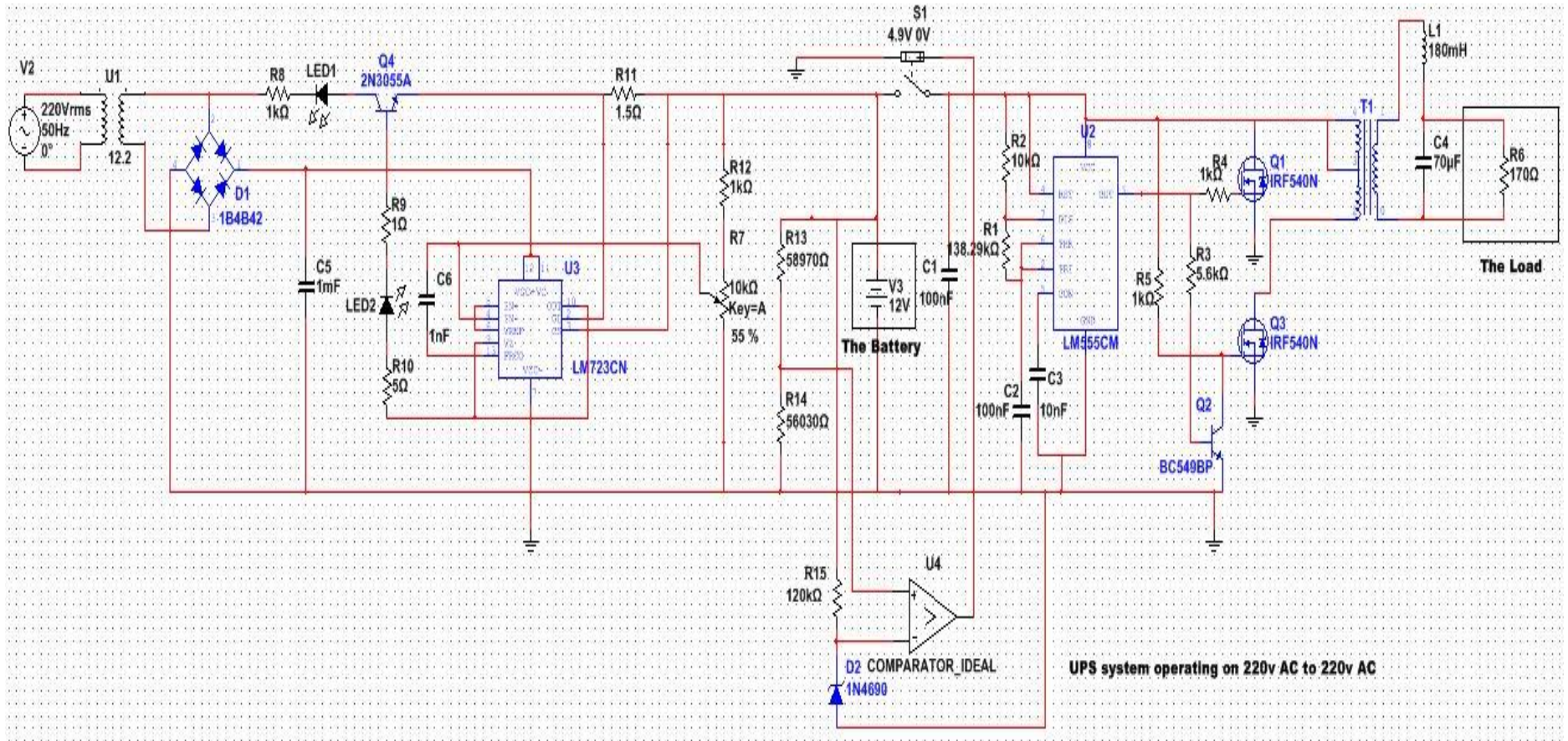
REFERENCES:

1. Tom Sperrey, "UPS Systems", UK, January 2010.
2. Solter, W., "A new international UPS classification by IEC 62040-3, doi:10.1109/INTLEC.2002.1048709", (2002).
3. "Electricity storage: Location, location, location ... and cost - Battery storage for transmission support in Alaska". eia.gov. Energy Information Administration (EIA). 2012. Retrieved July 23, 2012.
4. My Ton (Ecos Consulting), Brian Fortenbery (EPRI), William Tschudi (LNBL). DC Power for Improved Data Center Efficiency, Lawrence Berkeley National Laboratory, January 2007
5. Tripp Lite, "UPS Buying Guide", Tripp Lite company, Chicago US.
6. Raymond, Eric Steven. "UPS HOWTO", section 3.3. The Linux Documentation Project, 2003–2007.
7. "How to calculate battery run-time". PowerStream Technologies. Retrieved 2010-04-26.
8. Michael F. Hordeski , "Emergency and backup power sources: preparing for blackouts and brownouts".
9. "Uninterruptible power supply system selection, installation, and maintenance for command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) facilities" - Technical manual, headquarters, department of the army, 31 MAY 2002.
10. Pacific Gas and Electric Company PG&E, Power quality, "Uninterruptible Power Supply".
11. Draper Fisher Jurvetson, "Power Shift: DFJ on the lookout for more power source investments".
12. Bellis, Mary. "History of the Electric Battery".

13. “Battery History, Technology, Applications and Development”, MPower Solutions Ltd.
14. Energizer Rechargeable Batteries and Chargers: Frequently Asked Questions. Energizer.
15. Thomas L. Floyd, “Electronic Devices, conventional Current Version”, Ninth Edition, Prentice Hall, 2012.
16. SAMLEX AMERICA, “user manual, Pure sine wave DC-AC inverter”, AC power source.
17. Keith W. Whites, “Lecture 7: Diode Rectifying Circuits (/half Cycle, Full Cycle, and Bridge)”, 2009.
18. Jim Doucet, Dan Eggleston, Jeremy Shaw, “DC/AC pure sine wave inverter”, WPI, NECAMSID.
19. Muhammad Harunur Rashid, “Power Electronics Circuits, Devices, and Applications”, Prentice Hall, Englewood Cliffs, New Jersey 07632

APPENDIX A

UPS SYSTEM MODEL



APENDEX B

MATLAB CODE

```
Load=20:5:400;           // the load assumed min 20 wat and the max 400 wat
IB=Load./(0.75*12);       // battery current =
                           // output power / (efficiency* battery voltage)
T=20.*power((125./(IB.*20)),1.753); // time in hours
plot(Load,T), grid, title('Peukert's Equation plot diagram for time against load'),
xlabel('Load connected in Watts'),
ylabel('Time of operation in Hours')
```

APENDEX C

MATLAB CODE

```
%for squere wave representation
```

```
t=0:0.0001:0.04;  
y=sin(2*pi*50*t);  
y=12*y./abs(y);  
plot(t,y)
```

```
%for harmonic 1st 3rd 5th 7th orders vs time and
```

```
u=1;  
y=[];  
t=0:0.0001:0.04;  
for n=1:2:9  
    y(u,:)=4*12/n/pi*sin(2*pi*50*n*t);  
    plot(t,y(u,:))  
    hold on  
    u=u+1;  
end
```

```
%for harmonic amplitude vs the harmonic order (specter diagram)
```

```
A=zeros(15,1);  
for n=1:2:15  
    A(n)=4/pi*12/n;  
end  
plot(A)
```

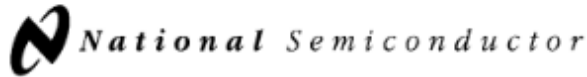
APENDEX D

DESIGN PRICING (IN SDG)

Component name	Price / unit	Quantity	Total price
Bridge rectifier	5	1	5
LED	1	2	2
Resistance	1	14	14
Potentiometer (variable resistance)	3	1	3
Capacitors	3	6	18
Inductance (coil)	5	1	5
220v/12v transformer	50	1	50
12v/220v transformer	50	1	50
LM723CN (regulator)	10	1	10
LM555CN (timer)	5	1	5
Relay	15	1	15
Operational Amplifier (comparator)	25	1	25
IRF540N (MOSFET)	10	2	20
Coolant (for MOSFET)	10	2	20
BC549BP (transistor)	10	1	10
2N3055A (transistor)	10	1	10
1N4690 (Zener diode)	2	1	2
125AH Battery	1750	1	1750
Total price		2014	
Total price without the battery		264	

APENDEX E

LM723/LM723C DATA SHEET



December 1984

LM723/LM723C Voltage Regulator

LM723/LM723C Voltage Regulator

General Description

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA; but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either linear or foldback current limiting.

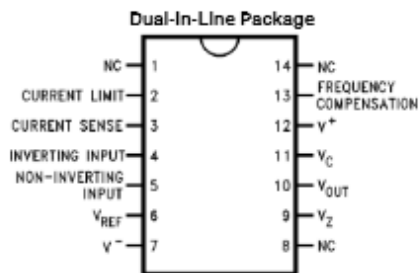
The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller.

The LM723C is identical to the LM723 except that the LM723C has its performance guaranteed over a 0°C to +70°C temperature range, instead of -55°C to +125°C.

Features

- 150 mA output current without external pass transistor
- Output currents in excess of 10A possible by adding external transistors
- Input voltage 40V max
- Output voltage adjustable from 2V to 37V
- Can be used as either a linear or a switching regulator

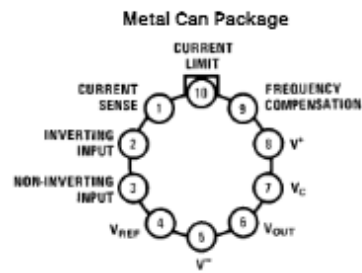
Connection Diagrams



Top View

Order Number LM723J/883 or LM723CN
See NS Package J14A or N14A

TL/H/8583-2

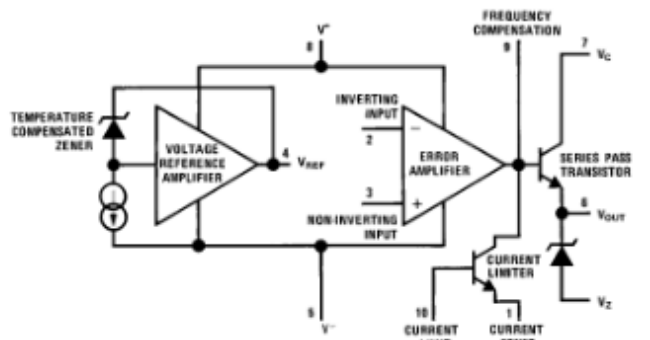


Top View
Note: Pin 5 connected to case.

Order Number LM723H, LM723H/883 or LM723CH
See NS Package H10C

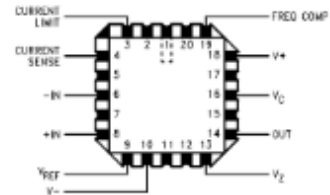
TL/H/8583-3

Equivalent Circuit*



*Pin numbers refer to metal can package.

TL/H/8583-4



Top View

Order Number LM723E/883
See NS Package E20A

TL/H/8583-20

APENDEX F

LM555 TIMER DATA SHEET



July 2006

LM555 Timer

LM555 Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200mA or drive TTL circuits.

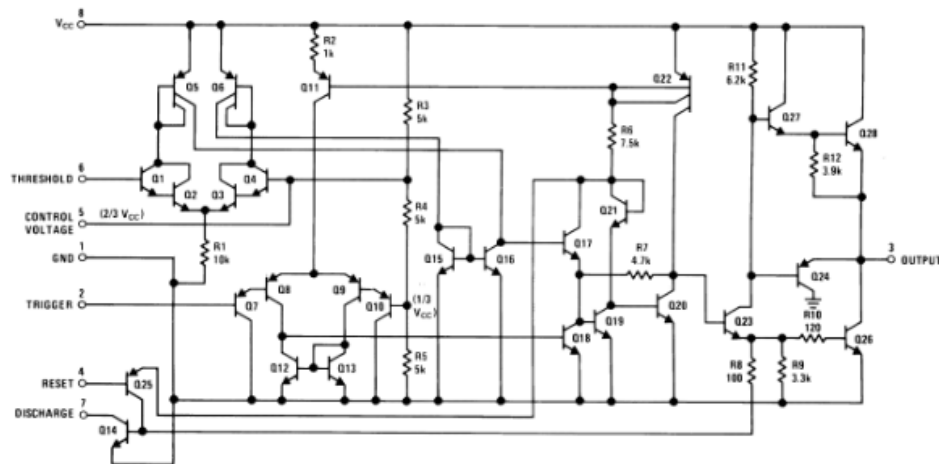
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output
- Available in 8-pin MSOP package

Applications

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram



00755101