CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1INTRODUCTION

Our dear nation Nigeria is faced with the challenge of steady power supply. It has become a thing of necessity for consumers to own an alternative source of power. Epileptic power supply to households/office appliances, agriculture, healthcare, computer systems and other appliances pose a threat to the survival and well being of our dear nation. Failure in power supply to some persons is only a trivial issue but to others, it is a problem that could cripple/wreck the economy especially, the business sector, offices and industries. It could cause damages worth a couple of millions, lost of vital information in the computer system, damage to foods and supplies in the storage facilities and in worst scenario lost of lives in healthcares.

In essence, the healthcare, small and large scale industries, factories, homes and offices need steady power supply to protect lives and properties as well enhance the growth and development of business activities.

From the foregoing, it becomes imperative to design and construct a Single Phase 3 level cascaded H-bridge Inverter to check the effect of power outage, to enhance mobility and versatility and to avert physical and economic damages due to power failure.

This project work focuses on DC to AC power inverters which have the ability to efficiently and conveniently synthesize an AC power (signal) from DC power source at required output voltage and frequency level, similar to the AC supply available at the mains.

An inverter is a power electronic device which is capable of synthesizing an AC power (signal) from DC power at required output voltage and frequency level. One example of such a situation would be converting electrical power from a car battery to run a laptop, TV or cell phone.

The method, in which the low voltage DC power is inverted, is completed in two steps. The first being the conversion of the low voltage DC power to a high voltage DC source, and the second step being the conversion of the high DC source to an AC waveform using pulse width modulation.

This project focuses on Multilevel inverter, which is entirely a new concept introduced in the power industries for conversion of low dc supply to require ac supply.

Multilevel means that the inverter has more than one group of switches. It Provide another approach to harmonic cancellation. Provide an output waveform that exhibits multiple steps at several voltage levels. The elementary concept of a multilevel inverter is to achieve higher power signal employing a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform close to a pure sine wave. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple DC voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

There are essentially three topologies of multilevel DC/AC inverters available on the market, which are classified by their methods of design and construction, there are:

- The diode clamped multilevel inverter
- The capacitor clamped multilevel inverter and
- The cascaded H bridge multilevel inverter.

1.2 Diode- clamped Multi – level inverter

A diode clamped (m-level) multilevel inverter typically consists of (m-1) capacitor on the dc bus and produces m levels on the phase voltages. Figure shows full bridge five level diode clamped converter. The numbering order of the switches is Sa1, Sa2, Sa3, Sa4, S'a1, S'a2, S'a3, S'a4. The dc bus voltage consists of four capacitors C1, C2, C3, and C4. For a dc voltage Vdc, the voltage across each capacitor is V dc/4, and each devices voltage stress is limited to one capacitor voltage level V dc/4 through clamping diodes. An m-level inverter leg requires (m-1) capacitors, 2(m-1) switching devices and (m-1) X(m-1) clamping diodes.

1.2.1(a) Principle of operation

To produce a stair case output, let consider only one leg of five level inverter, as shown in Figure 1.1. The steps to synthesize the five level voltages are as follows:

a) Voltage level Van= V dc; turn on all upper switches S1, S2, S3 and S4.

b) Voltage level Van= V dc/2, turn on the switches S2, S3, S4 and S1′.

c) Voltage level Van= 0, turn on the switches S3, S4, S1′ and S2′.

d) Voltage level Van= - V dc/2 turn on the switches S4, S1′, S2′, S3′.

e) Voltage level Van= - V dc; turn on all lower switches S1′, S2′, S3′ and S4′.

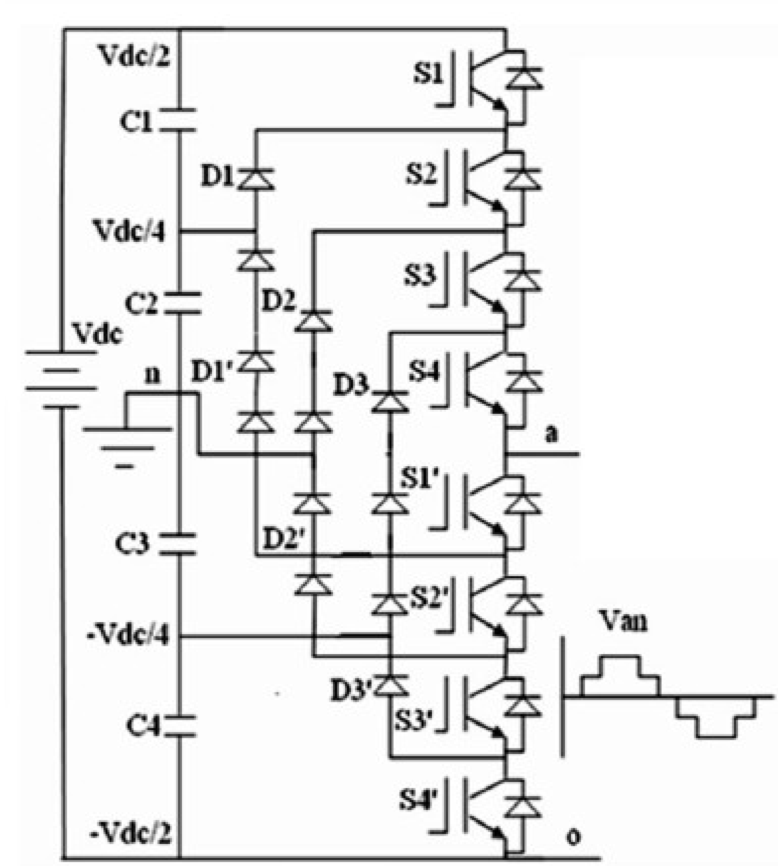

Fig 1.1 Single phase Diode clamped inverter

2.2.1(b) Advantages:

a) When the number of levels is high enough, the harmonic content is Low enough to avoid the filters.

b) Inverter efficiency is high because all devices are switching at the Fundamental frequency.

c) The control method is simple.

1.2.1(c) Disadvantages:

a) Excessive clamping diodes are required when the number of levels is high.

b) It is difficult to control the real power flow of the individual Converter in multi-level converter system.

1.3 Single phase flying capacitor inverter:

The figure 1.2 shows a single phase full bridge 5-level inverter based on flying capacitors. Each phase leg has an identical structure. Assuming that each capacitor has the same voltage rating, the series connection of the capacitors indicates the voltage level between calming points. All phase legs share the DC link capacitors C1 to C4.

1.3.1(a) Principle of operation:

To produce a staircase output voltage, the switching instants of MOSFETS are shown below.

1) Voltage level Van = Vdc/2, turn on all upper switches S1 - S4.

2) Voltage level Van = Vdc/4, there are three combinations.

a) Turn on switches S1, S2, S3 and S1′. (Van = Vdc/2 of upper C4‟s - Vdc/4 of C1‟s).

b) Turn on switches S2, S3, S4 and S4′. (Van = 3Vdc/4 of upper C3‟s - Vdc/2 of C4‟s).

c) Turn on switches S1, S3, S4 and S3′. (Van= Vdc/2 of upper C4‟s – 3Vdc/4 or C3‟s + Vdc/2 of upper C2„).

3) Voltage level Van= 0, turn on upper switches S3, S4, and lower switch
S1′, S2′.

4) Voltage level Van= -Vdc/4, turn on upper switch S1 and lower switches
S1, S2′ and S3’.

5) Voltage level Van= -Vdc/2, turn on all lower switches S1′, S2′, S3′ and S4′.

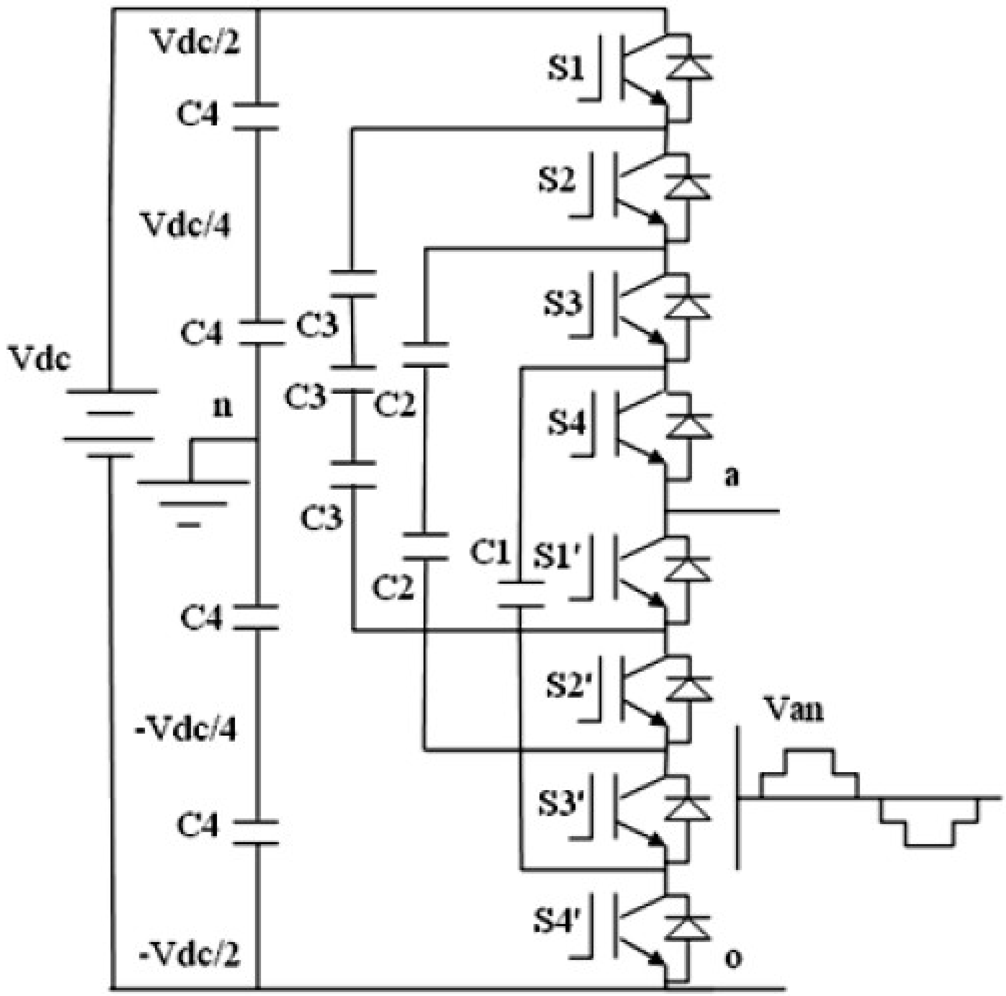

Fig 1.2 single phase flying capacitor inverter

1.3.1(c) Advantages:

a) Large amount of storage capacitors can provide capabilities during Power outages.

b) These inverters provide switch combination redundancy for balancing different voltage levels.

c) With the number of voltages levels increased, the harmonic content is low enough to avoid the filters.

d) Both real and reactive power flow can be controlled.

1.3.1(d) Disadvantages:

a) An excessive number of storage capacitors are required when the Number of levels is high. High-level inverters are more difficult to Package with the bulky power capacitors and expensive too.

b) The inverter control can be very complicated and switching Frequency and switching losses are high for real power Transmission.

1.4 Cascaded Multi-level inverter:

A relatively new inverter structure called Cascaded Multilevel inverter, can avoid extra clamping diodes or voltage balancing capacitors. The converter topology used here is based on the series connection of single phase inverters with separate DC sources.

1.4.1(a) The different topologies by with H-bridge are designed are:

- Cascade H-bridge
- Hybrid H-bridge

1.4.1(b) Cascade H-bridge:

Figure 1.3 shows the basic block of cascade H-bridge Multi-level inverter and its associated switching instants. As shown it consists of four power devices and a DC source. The switching states for four power devices are constant i.e., When S1 is on, S2 cannot be on and vice versa, similarly with S3 and S4.

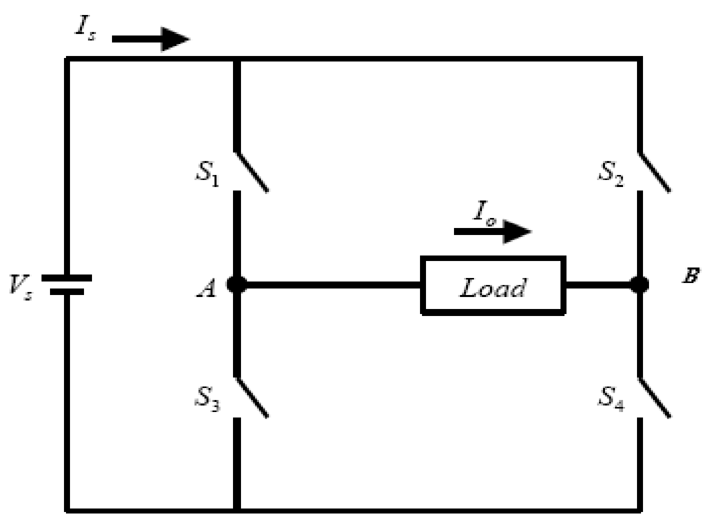

Fig 1.3 Block of a h-bridge Multi-level inverter

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1.5 SCOPE OF THE PROJECT

This project work can only be used for small and medium appliances (appliances up to a few hundred watts) in homes, offices, hotels, farms and banks.

1.6 PROBLEM STATEMENT

The demands for quality healthcare, Agriculture products, advance technology and water supply etc. have mandated the increase in demand for electrical device capable of synthesizing continuous power. While households, offices, healthcares, military and other establishments suffer setbacks due to incessant and indiscriminate power outages, the need for alternative power continues due to increased dependence on electrically powered equipment. Imagine, during an operation, that a patient's heart stopped and no defibrillator was available because the grid suffered a brownout. Sadly, this is an all-too-common occurrence in much of the developing countries of the world, Nigeria inclusive. This project work "Design and construction of H Bridge Cascaded inverter" is therefore aimed at providing immediate remedy to the epileptic supply.

Our goal is to fill a niche which seems to be lacking in the power inverters market. This goal is not to only design an uninterruptible power supply to provide remedy when mains power fails but to also ensure that five major constraints which other inverters have not been able to overcome are vividly addressed. These constraints include:

- Safety
- Output waveform(stepped wave closed to the desired waveforms)
- Power output
- Output voltage
- Efficiency

1.7AIMS AND OBJECTIVES

The purpose of this project is to eliminate certain harmonics from the output voltage of the cascaded multilevel inverter by using PWM technique. The objectives are summarized as follows:

1. To design the circuit of a Cascaded H bridge inverter
2. To implement/simulate the circuit of a cascaded H bridge using Proteus Software
3. To construct the circuit of a Cascaded H Bridge multilevel inverter using MOSFETS.

1.8LITERATURE REVIEW

1.8.1 INVERTERS

Multilevel inverter is power electronic system that synthesizes a desired voltage from several levels of direct current voltage as inputs.

1.8.2 APPLICATIONS OF MULTILEVEL INVERTERS

1. Reactive power compensator

When a Multi-level inverter draws pure reactive power, the phase voltage and current are 90 degrees apart, and the capacitor charge and discharge can be balanced. Such a converter, when serving for reactive power compensation is called Static VAR Generator. The multi-level structure allows all the converters to be directly connected to a high voltage distribution or transmission system without the need of a step down transformer. All the three Multi – level inverters can be used in reactive power compensation without having voltage unbalanced problem.

2. Back to Back intertie

Inter connection of two Multi-level inverter with a DC link in between is called a Back to back intertie. In this type of circuit the left hand side converter servers as rectifier, while the right hand side serves as the inverter. The purpose of the back to back intertie is to connect to synchronous systems of different frequencies. It can be treated as:

a) Frequency connector

b) Phase shifter

c) A power flow controller.

3. Utility compatible adjustable speed drives

An ideal utility compatible adjustable speed drives requires unity power factor, negligible harmonics and high efficiency. By extended the back to back intertie, the multilevel inverter can be used for a utility compatible adjustable speed drive with the input as constant frequency AC source and the output has the variable frequency AC source. The major differences when using as a utility compatible adjustable speed drives and for back to back intertie, are the control design and size of capacitor.

1.5.3FACTORS TO CONSIDER IN DESIGNING AN INVERTER

i) APPLICATION ENVIRONMENT

Where is the inverter to be used? Inverters are available for use in buildings (including homes), for recreational vehicles, boats, and portable applications. Will it be connected to the utility grid in some way? These are questions that must be answered if the right inverter will be designed. The purpose for design and the inverter’s application environment must be clearly stated.

ii) ELECTRICAL STANDARDS

The DC input voltage must conform to that of the electrical system and battery bank.12, 24 and 48 volts are the common standards energy system available.

The inverter's AC output must also conform to the conventional power in the various region in order to run locally available appliances. The standard for AC utility service in North America is 115 and 230V at a frequency of 60 Hertz (cycles per second). In Europe, South America, Nigeria and other countries, it's 220V at 50 Hertz.

iii) POWER CAPACITY

This explains the load capacity of the inverter. Its power output is rated in Watts (watts = amps x volts). There are three levels of power rating- a continuous rating, a limited-time rating, and a surge rating.

Continuous rating is the amount of power the inverter can handle for an indefinite period of hours. When an inverter is rated at a certain number of watts, that number generally refers to its continuous rating. The limited-time rating is a higher number of watts that it can handle for a defined period of time, typically 10 or 20 minutes. The inverter specifications should define these ratings in relation to ambient temperature (the temperature of the surrounding atmosphere). When the inverter gets too hot, it will shut off. This will happen more quickly in a hot atmosphere. The third level of power rating, surge capacity, is critical to its ability to start motors.

iv) POWER QUALITY – STEPPED WAVE vs. "MODIFIED SINE WAVE"

Some inverters produce "cleaner" power than others. Sine wave is clean; anything else is dirty. A sine wave has a naturally smooth geometry, like the track of a swinging pendulum. It is the ideal form of AC power. The utility grid produces sine wave power in its generators and (normally) delivers it to the customer relatively free of distortion. A sine wave inverter can deliver cleaner, more stable power than most grid connections.

Other specifications to consider are RMS voltage regulation which keeps lights steady. It should be plus or minus 5 percent or less. Peak voltage (V_p) regulation needs to be plus or minus 10 percent or less also.

A "modified sine wave" inverter is less expensive, but it produces a distorted square waveform that resembles the track of a pendulum being slammed back and forth by hammers. In truth, it isn't a sine wave at all. The misleading term "modified sine wave" was invented by advertising people. Engineers prefer to call it "modified square wave."

The "modified sine wave" has detrimental effects on many electrical loads. It reduces the energy efficiency of motors and transformers by 10 to 20 percent. The wasted energy causes abnormal heat which reduces the reliability and longevity of motors and transformers and other devices, including some appliances and computers. The choppy waveform confuses some digital timing devices.

About 5 percent of household appliances simply won't work on modified sine wave power at all. A buzz will be heard from the speakers of nearly every audio device. An annoying buzz will also be emitted by some fluorescent lights, ceiling fans, and transformers. Some microwave ovens buzz or produce less heat. TVs and computers often show rolling lines on the screen. Surge protectors may overheat and should not be used.

Modified sine wave inverters were tolerated in the 1980s, but since then, true sine wave inverters have become more efficient and more affordable. Some people compromise by using a modified wave inverter to run their larger power tools or other occasional heavy loads, and a small sine wave inverter to run their smaller, more frequent, and more sensitive loads. Modified wave inverters in renewable energy systems have started fading into history.

v) EFFICIENCY

It is not possible to convert power without losing some of it (it's like friction). Power is lost in the form of heat. Efficiency is the ratio of power out to power in, expressed as a percentage. If the efficiency is 90 percent, 10 percent of the power is lost in the inverter. The efficiency of an inverter varies with the load. Typically, it will be highest at about two thirds of the inverter's capacity. This is called its "peak efficiency." The inverter requires some power just to run itself, so the efficiency of a large inverter will be low when running very small loads.

In a typical home, there are many hours of the day when the electrical load is very low. Under these conditions, an inverter's efficiency may be around 50 percent or less.

vi) INTERNAL PROTECTION

vii)

An inverter's sensitive components must be well protected against surges from nearby lightning and static, and from surges that bounce back from motors under overload conditions. It must also be protected from overloads. Overloads can be caused by a faulty appliance, a wiring fault, or simply too much load running at one time.

An inverter must include several sensing circuits to shut itself off if it cannot properly serve the load. It also needs to shut off if the DC supply voltage is too low, due to a low battery state-of-charge or other weakness in the supply circuit. This protects the batteries from over-discharge damage, as well as protecting the inverter and the loads. These protective measures are all standard on inverters that are certified for use in buildings.

1.5.5OVERVIEW OF REVIEW

Owing to some selected past project works that have been reviewed, it is therefore evident that a stepped wave close to a desired sine wave inverter can only be achieved if the constraints of safety, output wave form, power output and efficiency are addressed.

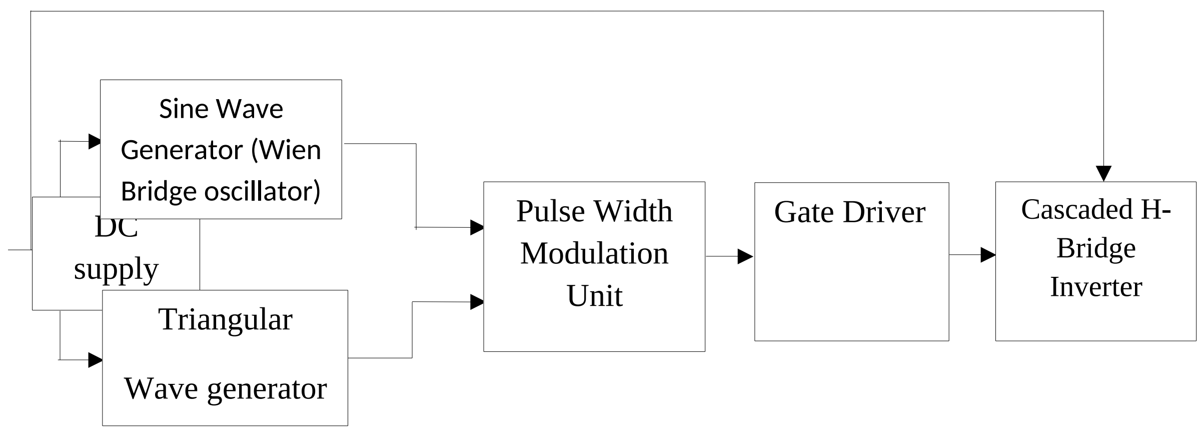
Therefore, this project work titled “Design and construction of a DC/AC Multilevel Inverter” is aimed at achieving near sinusoidal waveform using MOSFETS and a 3-level pulse width modulation technique to obtain the pulse width modulated signals needed to control electronic switches(H-bridge).

CHAPTER 2

THEORETICAL BACKGROUND

2.1 INTRODUCTION

The theoretical knowledge of the components used in this work will enable a proper understanding of the operation of the three levels Cascaded H bridge inverter. This chapter therefore, contains the block diagram of the Cascaded H bridge inverter and a brief theoretical background of components used.



Block Diagram of a Single Phase 3 Level Cascaded H Bridge Inverter

2.2 THEORY OF COMPONENTS

An electronic circuit is defined as an interconnection of electronic components, arranged in such a manner as to acquire a specified aim. An electronic circuit is made up of components whose individual characteristics and behaviors determine the overall performance of the circuit. Therefore, this section contains brief information about the components used in the design.

2.2.1 DIODE

A diode is a two-lead electronic component that acts as a one-way gate to electric current. When the anode of a diode's lead is made more positive than its cathode lead, the diode is said to be forward biased. However, if the polarities are reversed (the anode is made more negative in voltage than the cathode), the diode is reverse biased i.e. it acts to block current flow. Fig 3 shows the diode symbol.

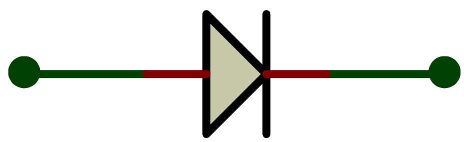


Fig 1: Diode Symbol

Diodes are most commonly used in circuits that convert ac voltages and currents into dc voltages and currents (Rectifier) e.g. ac/dc power supply. Diodes are also used in voltage-multiplier circuits, voltage shifting circuits, voltage-limiting circuits and voltage regulator circuits. [1]

2.2.2 RESISTORS

Resistors are electrical devices that reduce current flow and at the same time lower voltage levels within the circuit. The relationship between the voltage applied across a resistor and the current through it is given by $V = IR$.

There are numerous applications of resistors. Resistors are used to set operating current and signal levels, provide voltage reduction, set precise gain values in precision circuits. Figure 2 shows a fixed resistor symbols. [1]

Fig 2: A fixed resistor symbol

2.2.3 CAPACITOR

A capacitor is an electronic component that stores electric charge. A typical capacitor consists of two parallel plates separated by an insulator called the dielectric. Other uses of capacitor include:-

1. Filtering the output of a power supply
2. Controlling the frequency of an oscillator
3. Separating ac from dc (blocking) by coupling or decoupling
4. Controlling current in an ac circuit.

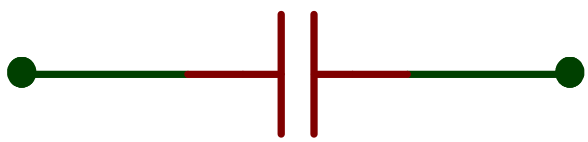


Fig 3: A typical capacitor symbol

2.2.4 OSCILLATOR

An oscillator can be defined in any of the following acceptable ways:

1. It is a circuit which converts dc energy into ac energy at a very high frequency.
2. It is an electronic source of alternating current or voltage having sine, square or saw tooth wave or pulse shapes.
3. It is a circuit which generates an ac output signal without requiring any externally applied input signal.
4. It is an unstable amplifier.

An oscillator is classified broadly into two groups:

i) Sinusoidal (or harmonic) oscillators-which produce an output having sine waveform.

ii) Non-sinusoidal (or relaxation) oscillators- they produce an output which has square, rectangular or sawtooth wave forms of pulse shapes.

A major requirement for an oscillator is that the output must be constant in both amplitude and frequency and to achieve this desired output, it must satisfy the “BARKHAUSEN CRITERION” which states that the product of the amplifier gain and the feedback factor must be equal to one for oscillators to be self-starting and self-perpetuating.

2.2.5 WIEN BRIDGE OSCILLATOR

The Wien Bridge is one of the simplest and best known oscillators used extensively in Audio circuit applications. It is one of the electronic oscillators that generate sine waves. It is a low-frequency (5Hz-500kHz), low-distortion, tunable, high-purity sine wave generator. A typical Wien bridge oscillator circuit is shown in the Figure 6. The bridge circuit comprises of four resistors and two capacitors. Its characteristic feature is the RC network consisting of R and C in series with a parallel combination of R and C. The resistors and capacitors can be different in value, but it is much simpler to make them equal. One major advantage of the Wien bridge oscillator is the simplicity of tuning. It also has extremely low distortion and high amplitude stability and good sine wave output / frequency stability.

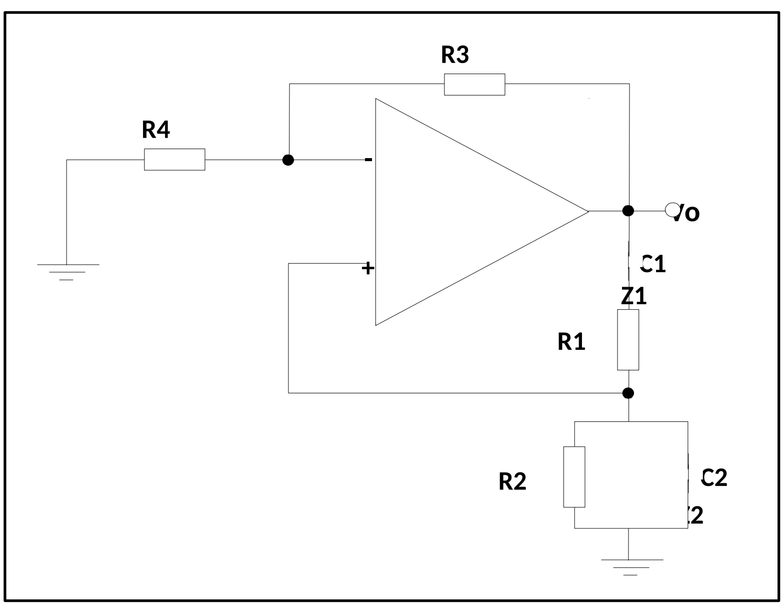


Fig 4: A Wien bridge oscillator

2.2.6 TRIANGLE WAVE OSCILLATOR

A triangle wave oscillator is a non-sinusoidal oscillator whose output waveform is triangular. It is a circuit in which voltage or current changes abruptly from one value to another and which continues to oscillate between these two values as long as dc power is supplied. The simplest triangle wave generator known is one composed of a Schmitt trigger oscillator that generates square wave and an integrator to achieve the desired triangular waveform. A typical triangle wave oscillator is shown in figure 8.

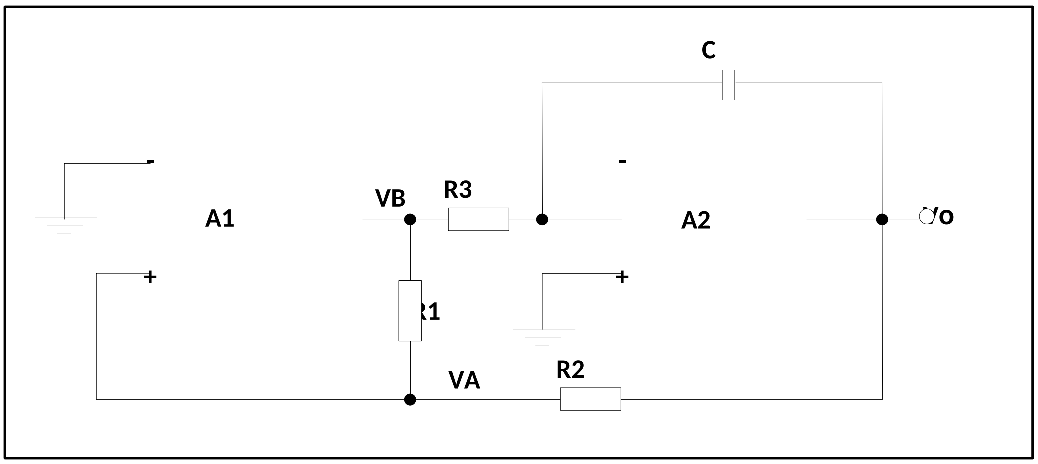


Fig 5: A triangle wave oscillator

2.2.7OPERATIONAL AMPLIFIER (OP-AMP)

An operational amplifier is a very high gain, high input impedance directly coupled amplifier which can amplify signals having frequency ranging from $0\,Hz$ to a little beyond $1\,MHz$ .Although an operational amplifier is a complete amplifier, it is so designed that external components (resistors, capacitors etc.) can be connected to its terminals to change its characteristics. When an OP-AMP is operated without connecting any resistor or capacitor from its output to any one of its input (i.e. without feedback), it is said to be in the open loop condition. An ideal OP-AMP has an infinite open loop gain, infinite resistance, zero output resistance and an infinite bandwidth. A typical OP-AMP symbol is shown in figure 11.

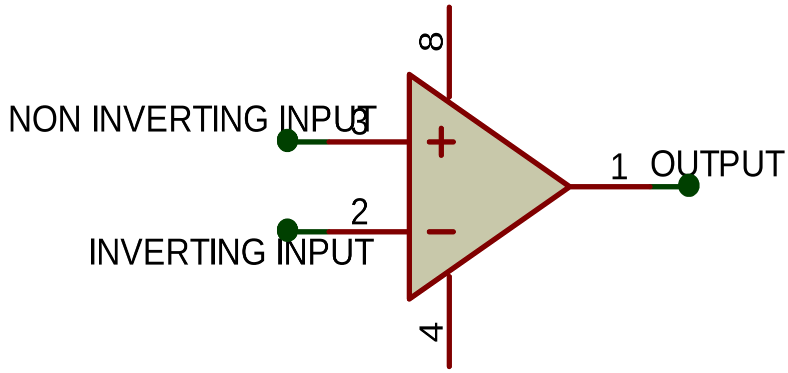


Fig 6: An Operational amplifier (OP-AMP)

2.2.8COMPARATOR

A comparator is a device that compares two voltages or currents and gives a digital signal output indicating which is larger. It has two analog input terminals and one binary digital output. Figure 8shows the diagram of a comparator.

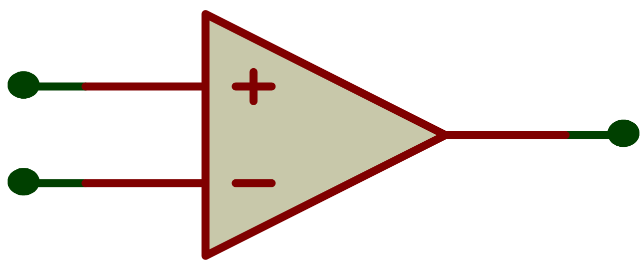


Fig 7: A comparator

2.2.9FILTER

A filter is an electrical network needed to transmit signals within a specified frequency range. In other words a filter is a device that passes electric signals at certain frequencies or frequency ranges while preventing the passage of other. It allows a particular frequency range to pass which is known which is known as bandpass. On the other hand, the suppressed zone is termed stop band or attenuation band. A cutoff frequency demarcates the pass band and the attenuation band. If a filter is designed with passive elements, it is called passive filter. If any active element is present, it is called active filter. Examples of filters include: high pass filters, low pass filters, band pass filters, all pass filters, band stop filters etc.

Filters are used in a variety of applications. The high pass filters are used in detection circuits to separate the carrier frequency signal from the audio frequency. Band pass filters are used in multichannel communication systems. Low pass filters are used in electronics to reduce harmonic distortion by eliminating undesired frequency components. The following figures show some commonly used filters.

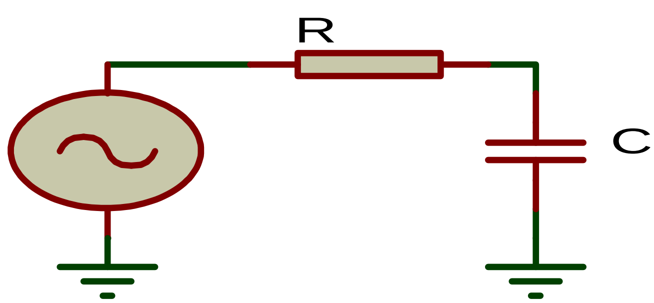


Fig 8: A low pass filter

2.2.10PULSE WIDTH MODULATION

The most common and popular technique of digital pure-sine wave generation is pulse-width-modulation (PWM). The pulse width modulation technique involves generation of a digital waveform, for which the duty-cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave.

In power inverters and motors, pulse width modulation is used extensively as a means of powering alternating current (AC) devices with an available direct current (DC) source or for advanced DC/AC conversion. Variation of duty cycle in the pulse width modulation signal to provide a DC voltage across the load in a specific pattern will appear to the load as an AC signal. The pattern at which the duty cycle of a pulse width modulation signal varies can be created through simple analog components, a digital microcontroller, or specific PWM integrated circuits.

Pulse Width Modulation control requires the generation of both reference and carrier signals which when compared together, yields output signals based on the difference between the signals. The reference signal is sinusoidal and at the frequency of the desired output signal, while the carrier signal is often either a sawtooth or triangular wave at a frequency significantly greater than the reference. When the carrier signal exceeds the reference, the comparator output signal is at one state, and when the reference is at a higher voltage, the output is at its second state. In order to source an output with a PWM signal, transistor or other switching technologies are used to connect the source to the load when the signal is high or low. Full or half bridge configurations are common switching schemes used in power electronics.

2.30-LEVEL PULSE WIDTH MODULATION

The simplest way of producing a pulse width modulated signal is through comparison of a low-power reference sine wave with a triangle wave or a sawtooth wave .Using these two signals as input to a comparator, the output will be a 2-level pulse width modulated signal. This pulse width modulated signal can then be used to control switches connected to a high-voltage bus, which will replicate this signal at the appropriate voltage. the frequency analysis shows that the primary harmonic is still truncated, and there is a relatively high amount of higher level harmonics in the signal. The 2-level pulse width modulation comparison signals, its unfiltered output and its filtered output is shown in the following figures.

2.3.1PULSE WIDTH MODULATION UNIT

In order to control electronic switches such as the H-bridge efficiently, it is necessary to carry out what is called pulse width modulation. This pulse width modulation is centered around a pulse width modulation circuit. Although there several pulse width modulation chips around, a comparator is chosen for this project work. The comparator generates the pulse width modulated signal by comparing the reference sine wave and the carrier wave (triangular wave).

2.3.2CASCADED H-BRIDGE INVERTER

An H-Bridge or full bridge 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. Generating a sine wave centered on zero volts requires both a positive and negative voltage across the load, for the positive and negative parts of the wave, respectively. This can be achieved from a single source through the use of four MOSFET switches arranged in an H-Bridge configuration. To minimize power loss and utilize higher switching speeds, N Channel MOSFETs were chosen as switches as the H-bridge MOSFET. IRF1407 MOSFET was chosen.

The key components in the hardware implementation of Single phase three level cascaded H bridge inverter are:

1. Power MOSFETs
2. NOT Gate
3. IR 2112

Power MOSFETs are used as switching devices, NOT Gate is in a single level inverter to give signal to negative half inverse to that of the positive half and the IR 2110 is to give gating pulses of modulated pulse width and also for phase shifting. A brief description of the above components is given in the following section.

2.3.3 Power MOSFETs

Metal oxide semiconductor field effect transistor (MOSFET) is a power transistor. They are extensively employed in dc-dc and dc-ac converters. A power MOSFET is a voltage-controlled device and requires only a small input current. The switching speed is very high and the switching times are of the order of nanoseconds. As the MOSFETs conduct in the duration for which the gate pulse is present and it doesn’t conduct when the gate pulse is removed, there is no need for an external commutation circuitry.

Power MOSFETs find increasing applications in low-power high frequency converters. The input impendence is very high, 10^9 to 10^{11} ohms. They require very low gate energy and low switching and low conduction losses. However MOSFETs have the problem of electrostatic discharge and also its difficult to protect them in the event of short circuit.

The two types of MOSFETs are:

1. Depletion MOSFETs, and
2. Enhancement MOSFETs.

A depletion type MOSFET remains on at zero gate voltage where as an enhancement type of

MOSFET remains off at zero gate voltage, the enhancement type MOSFETs are generally used as switching devices in power electronics. In this project we have used n-channel enhancement MOSFETs.

Choice of MOSFETs over other power transistors:

The other types of power transistors are BJTs (Bipolar Junction Transistors), SITs (static induction transistors), IGBTs (insulated gate bipolar transistors) and COULUMBS. MOSFETs do not have the problem of second breakdown phenomena as do BJT. A BJT is a current controlled device and its current gain is highly dependent on the junction temperature. The high on-state drops in SITs limit its applications for general power conversions. The switching speed of IGBTs is inferior to that of MOSFETs. IGBTs are costlier than the MOSFETs.

COULUMBS is a new technology for high voltage power MOSFETs, except for switching losses (same as the conventional MOSFETs) COULUMBS is an advanced and improved version of power MOSFET. Our hardware implementation is limited to three level inverters which doesn't need COULUMBS technology which is much costlier than MOSFETs.

PIN DIAGRAM OF A MOSFET

A practical MOSFET consists of three pins namely G-gate, D-drain, and S-source. Gate signal is between G and S. Supply is a given between D and S. it's called the common source connection.

MOSFET symbol

2.3.4 NOT Gate

The NOT Gate performs a basic logic function called inversion or complementation. The purpose of the gate is to change one logic level to opposite logic level. It has one input and one output, when high level is applied as an input low level will appear at output and vice versa.

NOT GATE SYMBOL

A X=-A

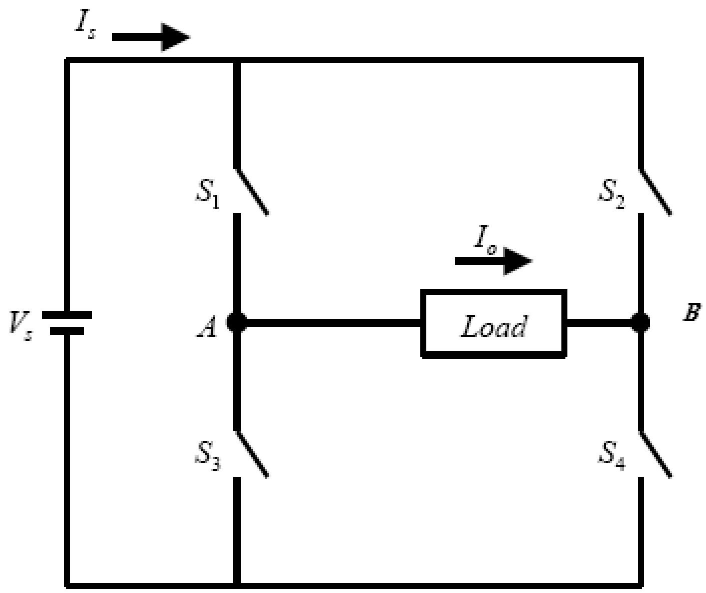
NOT GATE TRUTH TABLE

S/N	A	X=-A
1	1	0
2	0	1

The NOT gate has been used in this project to provide inversed gate signal to the negative half of single level inverter in its hardware implementation.

2.3.5 Single H-bridge

For obtaining single level, MOSFETs are connected as shoe in the figures below. Here MOSFETs are shown as switches and are numbered for easy understanding. The applied source is a low voltage DC supply (say 15V) and the load may be a resistive one (10000 ohms).



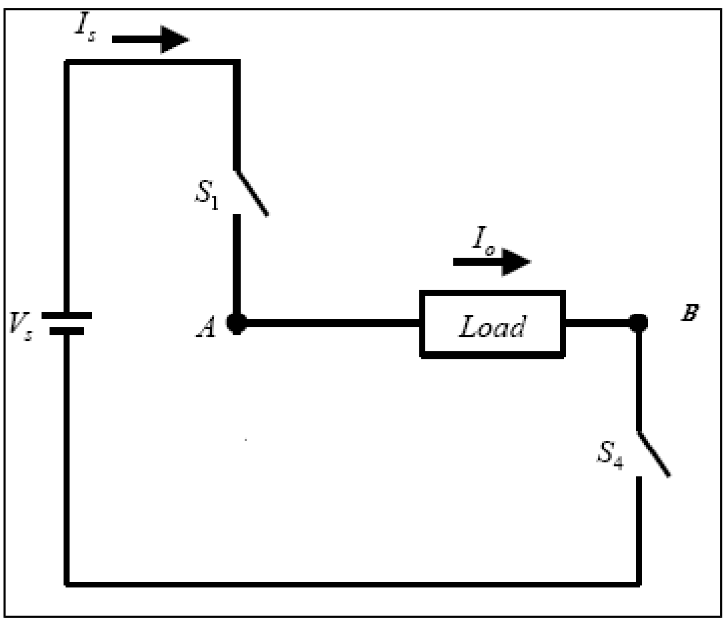
Single H- Bridge

INPUT	HIGH SIDE LEFT	LOW SIDE LEFT	HIGH SIDE RIGHT	LOW SIDE RIGHT
HIGH (POSITIVE)	ON	OFF	OFF	ON
LOW (NEGATIVE)	OFF	ON	ON	OFF

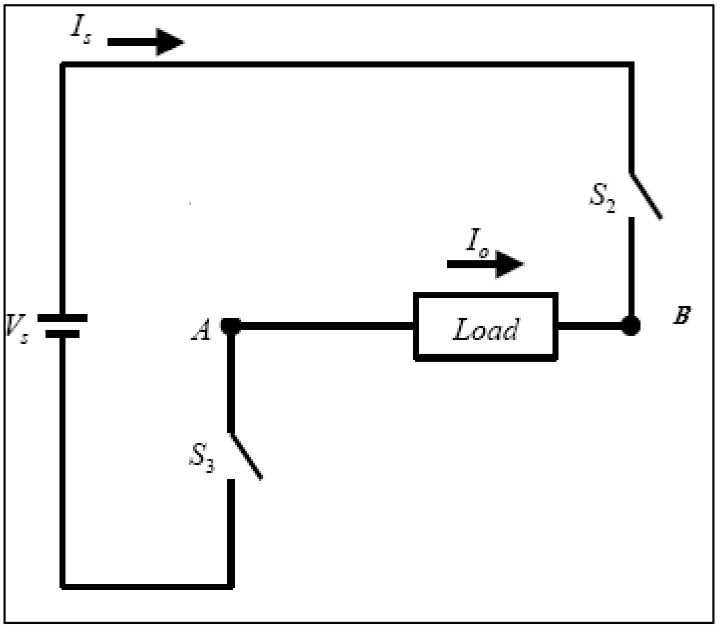
Power MOSFETs were chosen for switching purpose in this project work because they have high switching frequency capability that is, they can be switched at frequencies higher than $200\,kHz$ .They do not have as much capability for high voltage and high current applications as other transistors. Power MOSFETs do not have current tail power losses and they have body diode for protection.

MOSFETs conduct for the duration its gate pulse is present and is commutated as soon as the pulse is removed. So we do not need any extra commutating circuitry.

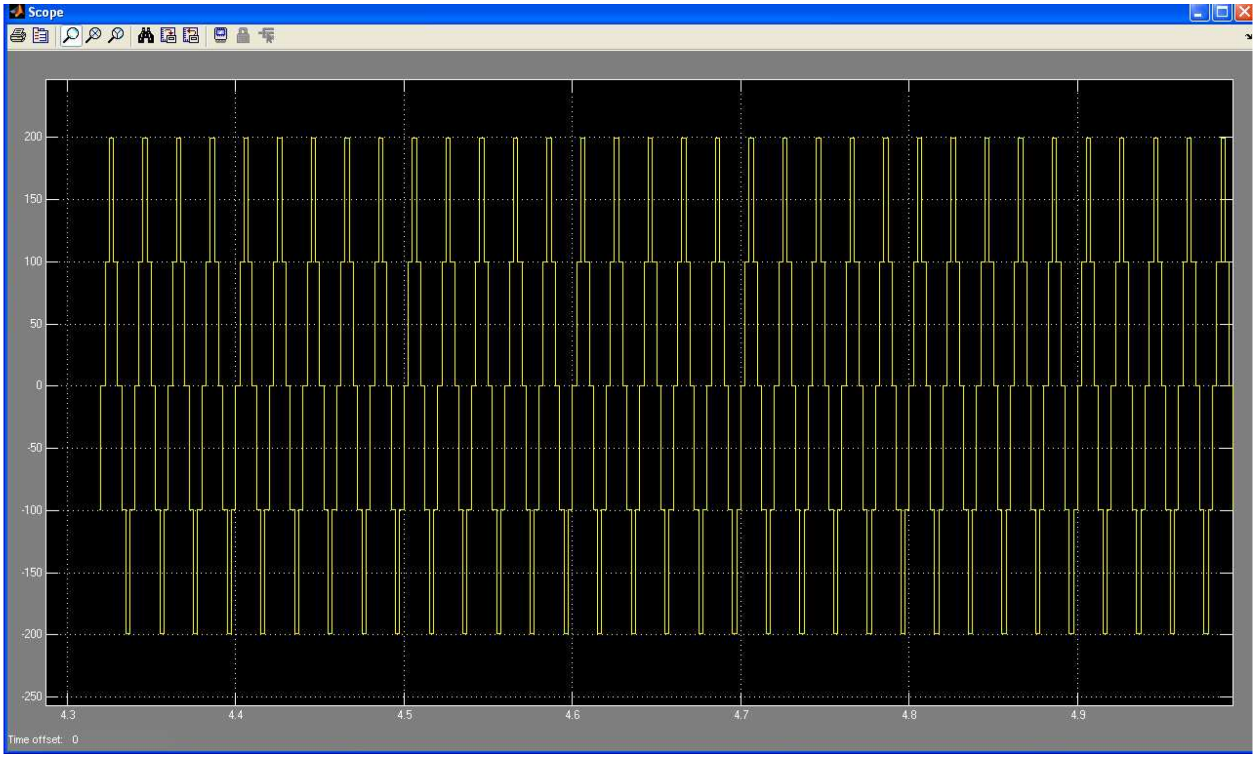
During the first half cycle i.e., during which the MOSFETs 1&2 are fed with voltage, across the output is positive and the equivalent circuit is as shown.



During the other half cycle i.e., during which MOSFETs 3&4 conducts, voltage across the load is negative (opposite to that assumed) and the equivalent circuit is as shown



Now to practically obtain such a gate signals we make use of NOT gate IC whose operation was discuss earlier. MOSFETs 1&2 are fed voltage from the comparator and MOSFETs 3&4 are fed from the NOT gate whose input is taken from the same comparator generator. When a 15V voltage source and a resistive load of 1000 ohms are applied to the H-bridge the following waveform is observed in the oscilloscope, which is connected across the load.



Scope
200
150
100
50
0
-50
-100
-150
-200
-250
4.3
4.4
4.5
4.6
4.7
4.8
4.9
Time offset: 0

2.3.6GATE DRIVER

A gate driver is a power amplifier that accepts a low power input from a pulse width modulation circuit and produces the appropriate high-current gate drive for a power MOSFET.A gate driver is used when a pulse width modulation controller cannot provide the output current required to drive the gate capacitance of the associated MOSFET. It is also responsible for providing dead time to ensure that bridge MOSFETs are not ON at the same time. Figure 20 shows a gate driver.

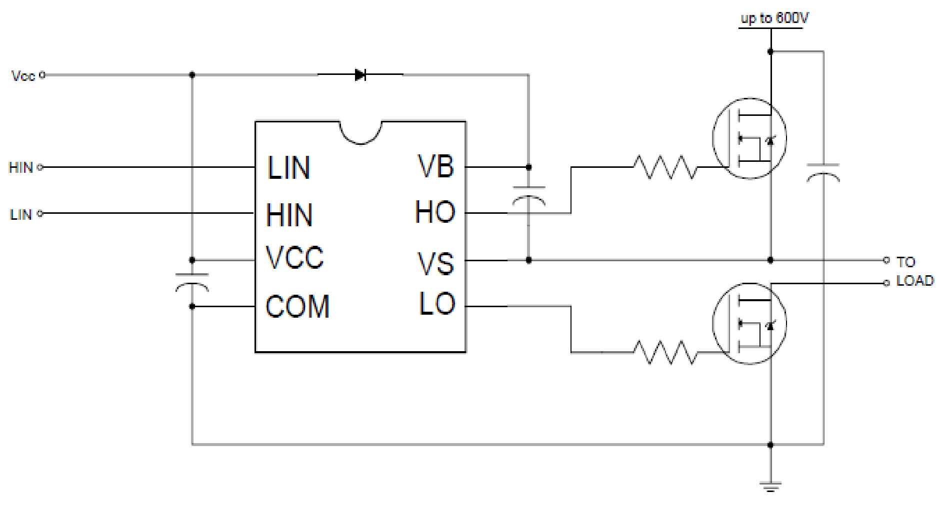


Fig 15: A gate driver IC

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 a bootstrap capacitor using an external source to create additional potential since the gate terminal of the MOSFET must be approximately 10V higher than the drain terminal for the MOSFET to conduct. In other words, the bootstrap capacitor ensures that the voltage difference of approximately 10V above the drain to source voltage is maintained. In this project work, IR2112 is used as the gate driver.

2.3.7 THE INPUT AND OUTPUT PINS OF IR2112 GATE DRIVER AND THEIR FUNCTION

HIN and LIN are the logic inputs. A high signal to HIN means that you want to drive the high-side MOSFET, meaning a high output is provided on HO. A high signal to LIN means you want to turn off the low-side MOSFET, meaning a high output is provided on LO.

A low signal to LIN means that you want to drive the low-side MOSFET, meaning a low output is provided on LO. A low signal to HIN means that you want to turn off the high-side MOSFET, meaning a low output is provided on HO.

V_S is the high side floating supply offset voltage. When it goes below V_{DD}, the low side MOSFET is turned ON and the high side MOSFET is turned off.

V_B is the high side floating supply voltage.

SD is used as shutdown control.

CHAPTER 3

CIRCUIT DESIGN AND ANALYSIS

This Cascaded H Bridge inverter consists of $12\,VDC$ power supply (lead acid accumulator), sine wave generator unit, triangle wave generator, pulse width modulation controller, MOSFET switches. Therefore, in designing, a number of factors were taken into consideration. The analysis follows:

3.1 THE CHOICE OF SINE WAVE GENERATOR

Different attempts were made to generate a $50\,Hz$ reference sine wave, though several attempts were based on filtering a Schmitt-trigger oscillator (a square -wave generator). Initially a bubba oscillator was considered the best choice because of some essential features which it does offers that other oscillators does not; the richest factor considered was its frequency stability which holds while still maintaining a low distortion output. But after designing and simulating using Proteus Software, a pure sine wave was not achieved due to RC loading effect. Rather a modified triangle wave was obtained. Therefore, to generate a sinusoidal wave, a Wien bridge oscillator and a first order low pass filter were used. Figure 3.1 shows the circuit diagram of the sine wave generator.

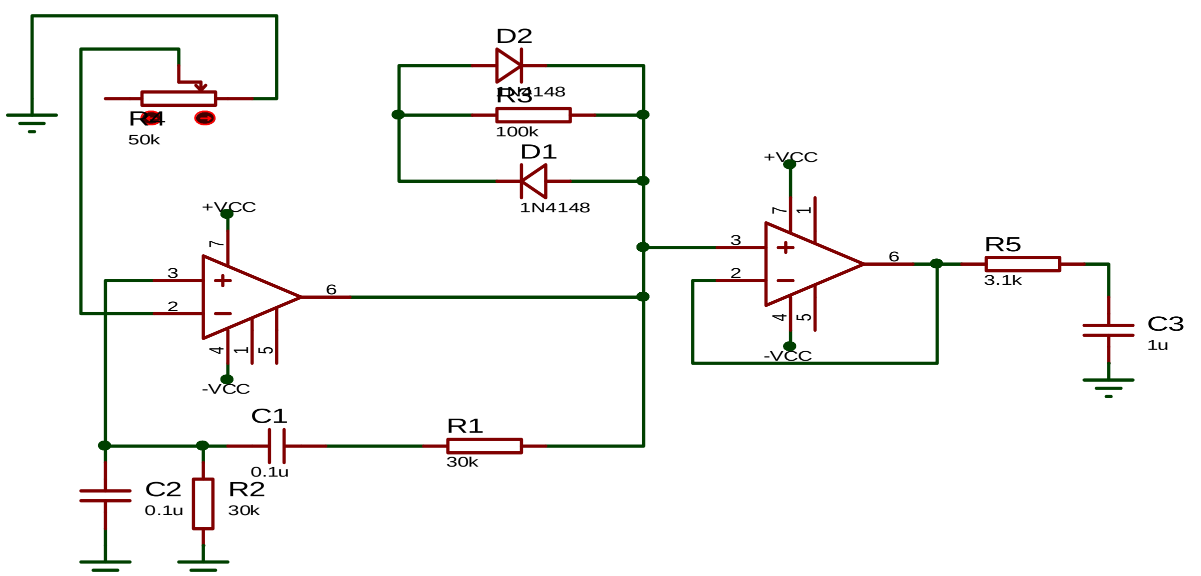


Fig 3.1: Sine wave generator (Wien bridge oscillator with low pass filter)

Considering the circuit diagram in figure 3.1, the voltages seen at the inputs of the operational amplifier are $V_{+¿¿}$and $V_{-¿¿}$. We know that a Wien bridge oscillator has two feedbacks which are the positive feedback or the regenerative feedback and the negative feedback or the degenerative feedback.

The regenerative or positive feedback is given by:

$$V_{+¿=V_o\frac{Z_1}{Z_1+Z_2}¿} \quad 3.10$$

Where $Z_1=R_1/¿\frac{1}{jwC_1}=\frac{\frac{R_1}{j\omega C_1}}{R_1+\frac{1}{j\omega C_1}}$

$$Z_1=\frac{R_1}{j\omega C_1R_1+1} \quad 3.11$$

and

$$Z_2=R_2+\frac{1}{j\omega C_2} \qquad 3.12$$

.

Substituting equation 3.11 and equation 3.12 into equation 3.10 gives

$$V_{+¿=V_o\frac{\frac{R_1}{j\omega C_1R_1+1}}{\frac{R_1}{j\omega C_1R_1+1}+R_2+\frac{1}{j\omega C_2}}¿} \qquad 3.13$$

$$V_{+¿=V_o\frac{R_1}{R_1+R_2+j\omega C_1R_1R_2+\frac{C_1R_1}{C_2}+\frac{1}{j\omega C_2}}¿} \qquad 3.14$$

Also, the degenerative or negative feedback is given by

$$V_{-¿=V_o\frac{Z_4}{Z_3+Z_4}¿} \qquad 3.15$$

Where $Z_3=R_3$ and $Z_4=R_4$

But, we know that amplifier gain, A, is defined as the ratio of output to input i.e.

$$A=\frac{V_o}{V_{¿}}$$

$$V_o = A\,V_{¿} \qquad 3.16$$

But, $V_{¿}=V_{+¿-V_{-¿¿}¿}$ 3.17

$$V_o = A\,¿ \qquad 3.18$$

Substituting equation 3.10 and equation 3.15 into equation 3.18 yields

$$V_o = A\left(V_o\frac{Z_1}{Z_1+Z_2}-V_o\frac{Z_4}{Z_3+Z_4}\right)=A\,V_o\left(\frac{Z_1}{Z_1+Z_2}-\frac{Z_4}{Z_3+Z_4}\right) \qquad 3.19$$

$$\frac{1}{A}=\frac{Z_1}{Z_1+Z_2}-\frac{Z_4}{Z_3+Z_4} \qquad 3.20$$

$$\frac{1}{A}=\frac{R_1}{R_1+R_2+j\omega C_1 R_1 R_2+\frac{C_1 R_1}{C_2}+\frac{1}{j\omega C_2}}-\frac{R_4}{R_3+R_4}$$

3.21

For real A, the regenerative (positive) feedback must be real i.e.

$$\frac{Z_1}{Z_1+Z_2}=\frac{R_1}{R_1+R_2+j\omega C_1 R_1 R_2+\frac{C_1 R_1}{C_2}+\frac{1}{j\omega C_2}}=\frac{R_1}{R_1+R_2+\frac{C_1 R_1}{C_2}+j\left(\omega C_1 R_1 R_2-\frac{1}{\omega C_2}\right)}$$

3.22

For equation 3.22 to be real, then,

$$\omega C_1 R_1 R_2-\frac{1}{\omega C_2}=0$$

$$\omega C_1 R_1 R_2=\frac{1}{\omega C_2}$$

$$\omega^2 = \frac{1}{C_1 C_2 R_1 R_2}$$

$$\omega = \left(\frac{1}{C_1 C_2 R_1 R_2}\right)^{\frac{1}{2}} \qquad 3.23$$

For simplicity of design,

Let $C_1 = C_2 = C$ and $R_1 = R_2 = R$

Equation 3.23 becomes

$$\omega = \left(\frac{1}{R^2 C^2}\right)^{\frac{1}{2}} = \frac{1}{RC} \qquad 3.24$$

But $\omega = 2\pi f$ 3.25

Substituting equation 3.25 into equation 3.24 gives

$$2\pi f = \frac{1}{RC}$$

$$f = \frac{1}{2\pi RC} \qquad 3.26$$

For $f = 50\ Hz$,

$$50 = \frac{1}{2\pi RC}$$

$$RC = \frac{1}{100\pi}$$

$$RC = 0.00318$$

Let $C = 1\,\mu F$

Then,

$$R = \frac{0.00318}{1 \times 10^{-6}} = 3.18\,K$$

At this frequency and this condition, equation 3.22 becomes,

$$\frac{R}{R+R+R}=\frac{R}{3R}=\frac{1}{3}$$

Considering the amplifier as a non-inverting amplifier, the amplifier gain A will be

$$A=\frac{V_o}{V_{-¿}=\frac{R_3+R_4}{R_4}=1+\frac{R_3}{R_4}¿} \qquad 3.27$$

And the transfer function of the feedback network is

$$\beta=\frac{V_{+¿}}{V_o}=\frac{Z_1}{Z_1+Z_2}=\frac{1}{3}¿$$

3.28

Hence, the overall gain of the network is given by

$$A\beta=\left(1+\frac{R_3}{R_4}\right)\left(\frac{1}{3}\right) \qquad 3.29$$

But according to BARKHAUSEN criterion, the product of A and β must be unity (one) i.e.

$$A\beta=1$$

$$1=\left(1+\frac{R_3}{R_4}\right)\left(\frac{1}{3}\right)$$

$$3=1+\frac{R_3}{R_4}$$

$$\frac{R_3}{R_4}=3-1=2$$

$$R_3=2R_4 \qquad 3.30$$

Equation 3.30 implies that R_3 should be at least twice R_4.It should not be far below $2R_4$ and should not be far above $2R_4$ either, because if it does, amplifier gain will be affected and this will result in frequency instability.

Now let $R_4 = 50\,K$

Then, $R_3 = 2 \times 50 = 100\,K$

A first order filter was thereafter added to remove harmonic distortion. The design is as follows:

$$f = \frac{1}{2\pi R_5 C_3} \qquad 3.31$$

A cut off frequency of 50Hz was chosen and C_3 was chosen as $1\,\mu F$ while R_5 was calculated from equation 3.31

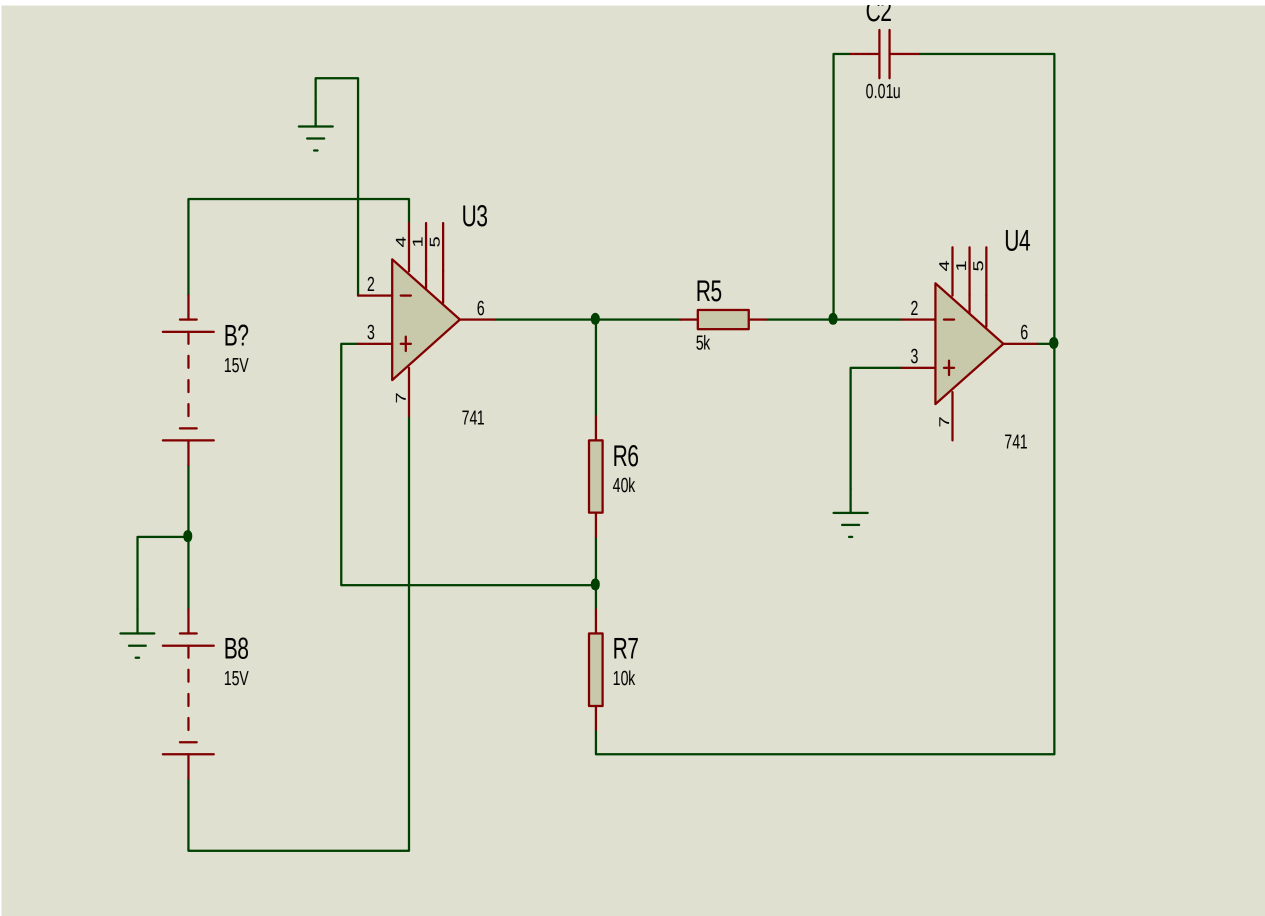
$$50 = \frac{1}{2\pi \times R_5 \times 1 \times 10^{-6}}$$

$$R_5 = \frac{1}{100\,\pi \times 1 \times 10^{-6}}$$

$$R_5 = 3.18\,K$$

Note that D_1 and D_2 are just clipping diodes to ensure the amplitude of the sine wave is stable

3.2 DESIGN OF THE TRIANGLE WAVE GENERATOR



The output of the first op Amp generates a square wave whereas the output of the second op Amp generates a triangle wave. To get a triangle wave, we need to charge the capacitor with a current source. We use an integrator to achieve that. $V_B$has only two states because of the positive feedback V_+ and V- of the operational amplifier.

The design steps for the triangle wave are given as follows:

When V_A is equal to $V_{+,}$ then the capacitor is charged at the negative direction of V_o. The process stops when$V_A = 0$.

From the circuit shown in figure 22, we deduce that

$$V_A = V_o \frac{R_6}{R_6 + R_7} + V_B \frac{R_7}{R_6 + R_7} \qquad 3.20$$

$$¿\, V_o + \frac{\left(V_B - V_o\right) R_7}{R_6 + R_7} \qquad 3.21$$

When $V_B = V_{+¿=V\,¿}$,

$$V_A = V_o + \frac{\left(V - V_o\right) R_7}{R_6 + R_7} \qquad 3.22$$

When $V_A = 0$

$$V_o = \frac{-V \,.\, R_7}{R_6} \qquad 3.23$$

When the capacitor is charged to the other direction of V_o(positive direction)

$$V_o = \frac{V \,.\, R_7}{R_6} \qquad 3.24$$

For one period of charging the capacitor voltage change is given as

$$\Delta V_o = V_o - \left(-V_o\right) = 2 V_o = \frac{2 V R_7}{R_6} \qquad 3.25$$

Considering the integrator circuit of the triangle wave generator shown in figure 1, we know that

$$I = C_4 \frac{dV_o}{dt} \qquad 3.26$$

$$dV_o = \frac{I}{C_4} dt$$

$$\Delta V_o = \frac{I}{C_4} \Delta t$$

$$t = \frac{\Delta V_o C_4}{I} \qquad 3.27$$

But $I = \frac{V_B}{R_5} = \frac{V}{R_5}$ 3.28

Substituting equation 3.28 into equation 3.27 yields

$$t=\frac{\Delta V_o\times C_4}{\frac{V}{R_5}}=\frac{R_5\times\Delta V\times C_4}{V}=\frac{R_5\times 2V\,\frac{R_7}{R_6}\times C_4}{V}$$

$$t=\frac{2\times R_7\times R_5\times C_4}{R_6}$$

$$T=2t=\frac{4\times R_7\times R_5\times C_4}{R_6}$$

$$f=\frac{1}{T}=\frac{R_6}{4\times R_7\times R_5\times C_4}\quad 3.29$$

In designing the triangle wave generator, we chose $f=20\,kHz$, $R_6=4\,R_7$, $R_7=10\,k\,\Omega\,C_4=0.1\,\mu F\,,V_{o(p-p)}=5V$ and then calculated the values of $R_6$and R_5 respectively as follows

$$R_6=¿4R_7=4\times 10=40\,k\,\Omega$$

$$f=\frac{R_6}{4\,R_7R_5C}\qquad 3.30$$

$$R_5=\frac{R_6}{4fR_7C_4}=\frac{40}{4\times 20\times 10^3\times 10\times 0.1\times 10^{-6}}$$

$$R_5=5000\,\Omega=5\,k\,\Omega$$

$$t=\frac{2\times R_7\times R_5\times C}{R_6}=\frac{2\times 10\times 5\times 0.01\times 10^{-6}}{40}$$

$$t=25\,nS$$

$$T=2t=2\times 25=50\,nS$$

3.3 DESIGN OF THE OUTPUT UNIT (CHOICE OF MOSFET)

The output unit of the cascaded H bridge inverter comprises H-bridge MOSFETs.

The switching MOSFETs to be chosen must be able to withstand high current. Therefore, a fast switching MOSFET with extremely low $R_{DS(ON)}$was chosen. We chose IRF1407 rated at $75\,V$, $130\,A\,@\,25\,℃, 330\,W$.

The gate resistance(R_g), the gate drive current (I_g) and the overall power dissipation of the switching MOSFETs are determined are follows:

The gate current, $I_g = \frac{Q_{gd}}{t_{switching}}$ 3.34

Where $Q_{gd} = Total\,gate\,charge = 150\,nC$ from the datasheet of the MOSFET

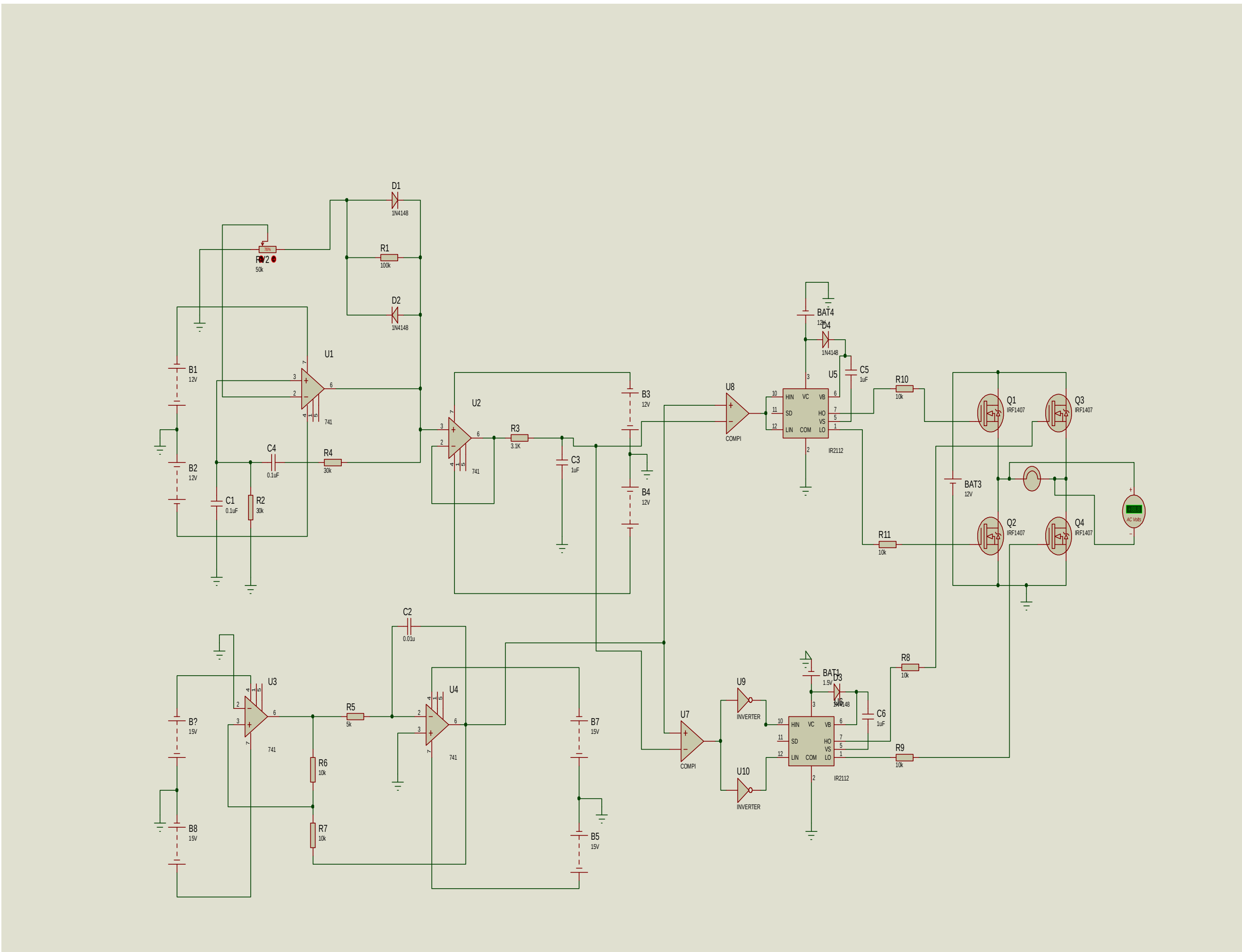
$t_{switching} = switching\,time\,of\,the\,MOSFET = 150\,nS$Also from the datasheet of the MOSFET

Therefore, $I_g = \frac{150\,nC}{150\,nC} = 1\,A$

The gate resistance, $R_g = \frac{V_{DD} - V_{gs(th)}}{I_g} = \frac{12-2}{1} = 10\,\Omega$ 3.35

Where $V_{DD} = 12\,V$ and $V_{gs(th)} = 2\,V$

Note: other MOSFETs with higher current rating can also be chosen for switching.



D1
1N4148
RV2
50k
R1
100k
D2
1N4148
U1
741
B1
12V
B2
12V
C4
0.1uF
R4
30k
C1
0.1uF
R2
30k
U2
741
R3
3.1K
C3
1uF
B3
12V
B4
12V
U8
COMPI
BAT4
D4
1N4148
C5
1uF
U5
IR2112
R10
10k
R11
10k
Q1
IRF1407
Q3
IRF1407
Q2
IRF1407
Q4
IRF1407
BAT3
12V
AC Volts
C2
0.01u
U3
741
B?
15V
B8
15V
R5
5k
R6
10k
R7
10k
U4
741
B7
15V
B5
15V
U7
COMPI
U9
INVERTER
U10
INVERTER
BAT1
1.5V
D3
C6
1uF
R8
10k
R9
10k
IR2112