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TITLE: A PURE SINE WAVE INVERTER FOR HOUSE BACKUP

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BY: MAINA BENARD MBURU

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SUPERVISOR: MR. OMBURA

EXAMINER: Dr. H. OUMA

Project submitted in partial fulfillment of the requirement for the award of a bachelor's degree in Electrical and Electronic Engineering at the University of Nairobi.

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DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

DECLARATION OF ORIGINALITY

FACULTY/ SCHOOL/ INSTITUTE: Engineering

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COURSE NAME: Bachelor of Science in Electrical & Electronic Engineering

TITLE OF NAME OF STUDENT: MAINA BENARD MBURU

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COLLEGE: Architecture and Engineering

WORK: A PURE SINE WAVE INVERTER FOR HOUSE BACKUP

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DEDICATION

This project is dedicated to lovers of science and technology.

ACKNOWLEDGEMENTS

First, I am grateful to Almighty God for His unconditional love and provision in the course of my studies

Secondly, I am grateful to my supervisor Mr. Ombura for his guidance during the project period.

Lastly, I would like to thank my family members, friends and colleagues for the support they accorded me in the course of my study.

ABSTRACT

The reliability of power company electricity service varies greatly due to many factors including the design of the power grid, protective features, power system maintenance practices and severe weather. This project aims to design a microcontroller based pure sine wave inverter using Pulse Width Modulation (PWM) switching scheme to supply AC utilities with emergency power. It involves generating of unipolar modulating signals from a Programmable Interface Computer (PIC16F887A) and using them to modulate a 12V dc MOSFET based full H-Bridge. The focus is on designing an inexpensive, versatile and efficient pure sine wave inverter that gives a 240V, 600W pure sine wave output.

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CHAPTER 1: INTRODUCTION

1.1: BACKGROUND OF STUDY

Electrical power exists in two main forms: alternating current (AC) and direct current (DC). The nature of alternating current is that the voltage level can be stepped up or down by use of transformers while that of direct current is that it’s possible to store in batteries. Most electrical devices in the world today are designed around AC/DC power conversion. It’s therefore necessary to convert the DC power from storage batteries to AC power to power such devices. In practice, DC/AC conversion is done by a power inverter. In today's market, there are two different types of inverters, modified sine wave and pure sine wave inverter. The modified sine wave is similar to a square wave which is less efficient in power consumption. It produces high number of harmonics which affects the devices, hence, reducing its life time. Whereas, a pure sine wave inverter reduces the harmonics to minimum, thus increasing the efficiency of power consumption and life time of AC appliances. It also reduces the audible and electrical noise in audible equipment, TV's, Fluorescent lights and allows inductive load, like fan to run faster and quieter.

1.2: STATEMENT OF THE PROBLEM

In Kenya power outage have become more frequent owing to the lack of incentives to invest in aged national grid, transmission and distribution infrastructures, as well as the fact that energy from decentralized, “volatile” renewable sources is not well aligned to work on electricity grids. With an example of April 15th 2012 fault at the Kenya Power national control center and July 2011 power rationing regime due to East Africa's drought these brings a challenge to power facilities like medical centers, households and businesses. Frequent power outages are inconvenient, expensive and difficult to mitigate without very expensive backup power systems. Some of solution to this problem is an auxiliary AC power generator and solar panels but the cost of fossil fuels continues to increase rapidly thus it will not be cost effective in the future while solar power has some aesthetic, economic and technical drawbacks. A more effective and reliable alternative is battery power back-up system.

1.3: MAIN OBJECTIVE

The major objective of this project is to design, test and implement a 600W pure sine wave inverter that converts 12V dc to 240V ac.

1.4: JUSTIFICATION OF THE PROJECT

- Pure sine AC power reduces audible noise in devices such as fluorescent lights and runs inductive loads like motors faster and quieter due to the low harmonic distortion.
- Some device like laser printers, laptop computers, digital clocks and medical equipment are not immune to harmonic distortions thus they need a power source with least harmonics
- Power outages highly experienced in the country thus power backups systems are used during power switching from line to generators and vice versa.

CHAPTER 2: LITERATURE REVIEW

2.1: INVERTER

An inverter is a device that converts the DC sources to AC sources. The purpose of a DC/AC power inverter is typically to take DC power supplied by a battery, such as a 12 volt car battery, and transform it into a 240 volt AC power source operating at 50 Hz, emulating the power available at an ordinary household electrical outlet. Inverters are used in applications such as adjustable-speed ac motor drivers, uninterruptible power supplies (UPS) and ac appliances run from an automobile battery

2.2: CLASSFICATION OF INVERTERS.

On the market today there are two different types of inverters:

- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

These inverters differ in their outputs, providing varying levels of efficiency and distortion that can affect electronic devices in different ways.

2.2.1: Modified 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 can be seen in Figure 1, which displays how a modified sine wave tries to emulate the sine wave itself. The waveform is easy to produce because it is just the product of switching between three values at set frequencies, thereby leaving out the more complicated circuitry needed for a pure sine wave hence provides a cheap and easy solution to powering devices that need AC power. However 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 Modified sine wave inverters approximate a sine wave and have low enough harmonics that do not cause problem with household equipment’s. The main disadvantage of the modified sine wave inverter is that peak voltage varies with the battery voltage.

2.2.2: Pure Sine Wave

Pure sine wave inverter represents the latest inverter technology. The waveform produced by these inverters is same as or better than the power delivered by the utility. Usually sine wave inverters are more expensive than the modified sine wave inverters due to their added circuitry.

There are two methods in which the low voltage DC power is inverted to AC power;

- The low voltage DC power is first boosted to high voltage power source using a DC-DC booster then converted to AC power using pulse width modulation.
- The low voltage DC power is first converted to AC power using pulse width modulation then boosted to high AC voltage using a boost transformer.

The second method is used in modern inverters extensively because of its ability to produce a constant output voltage compared to the first method that require additional circuit to boost the voltage.

2.3: PWM TECHNIQUES FOR PURE SINE WAVE INVERTER

Variation of duty cycle of the PWM signal provides a voltages across the load in a specific pattern will appear to the load as AC signal. A pure sin wave is obtained after passing the signal through a low pass filter. The pattern at which the duty cycle of a PWM signal varies can be implemented using simple analogue components or a digital microcontroller. Either of the two basic topologies generate sinusoidal PWM that controls the output of the inverter.

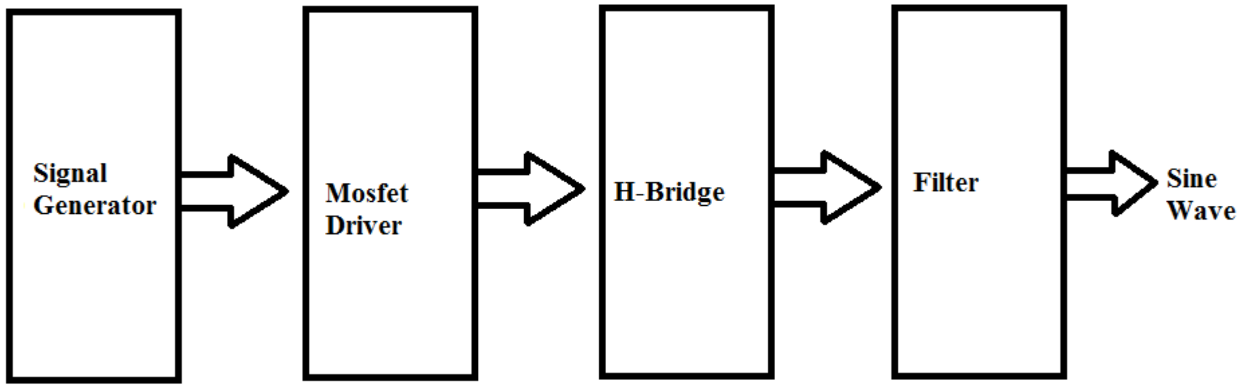


Figure 1: sine wave inverter design

From figure 1, the first step of designing a sine wave inverter is signal generation of control signals to control power switches arranged h bridge configuration to switch the DC source to AC source.

2.3.1: Pulse Width Modulation:

Pulse width modulation (PWM) is a powerful technique for controlling analogue with a processor's digital outputs. . It is also known as pulse duration modulation (PDM). The leading edge of the carrier pulse remains fixed and the occurrence of the trailing of the pulses varies. PWM signals find a wide application in modern electronics. Some of these reasons are:

- Reduced Power Loss – switched circuits tend to have lower power consumption because the switching devices are almost always off (low current means low power) or hard-on (low voltage drop means low power). Common circuits that utilize this feature include switched-mode power supplies, Class D audio power amplifiers, power inverters and motor drivers. Frequently, these circuits use semi-analogue techniques (ramps and comparators) rather than digital techniques, but the advantages still hold.

- Easy to Generate – PWM signals are quite easy to generate. Many modern microcontrollers include PWM hardware within the chip; using this hardware often takes very little attention from the microprocessor and it can run in the background without interfering with executing code. PWM signals are also quite easy to create directly from a comparator only requiring the carrier and the modulating signals input into the comparator.

- Digital to Analogue Conversion – pulse width modulation can function effectively, as a digital to analogue converter, particularly combined with appropriate filtering. The fact that the duty cycle of a PWM signal can be accurately controlled by simple counting procedures is one of the reasons why PWM signals can be used to accomplish digital-to-analogue conversion.

The desired PWM technique should have the following characteristics.

- Good utilization of DC supplies voltage possibly a high voltage gain.
- Linearity of voltage control.
- Low amplitude of low order harmonic of output voltage to minimize the harmonic content of output currents.
- Low switching losses in inverter switches.
- Sufficient time allowance for proper operation of the inverter switches and control system.

There are many types of PWM techniques used in sine wave inverters. The commonly used techniques are:

- Single or 2 level PWM; it's the simplest way of producing the PWM signal. It's through comparison of a low-power reference sine wave with a triangle wave as shown in figure 3. Using these two signals as input to a comparator the output will be a 2-level PWM signal as shown in figure 2. It's the most common and popular technique of pulse-width-modulation (PWM).

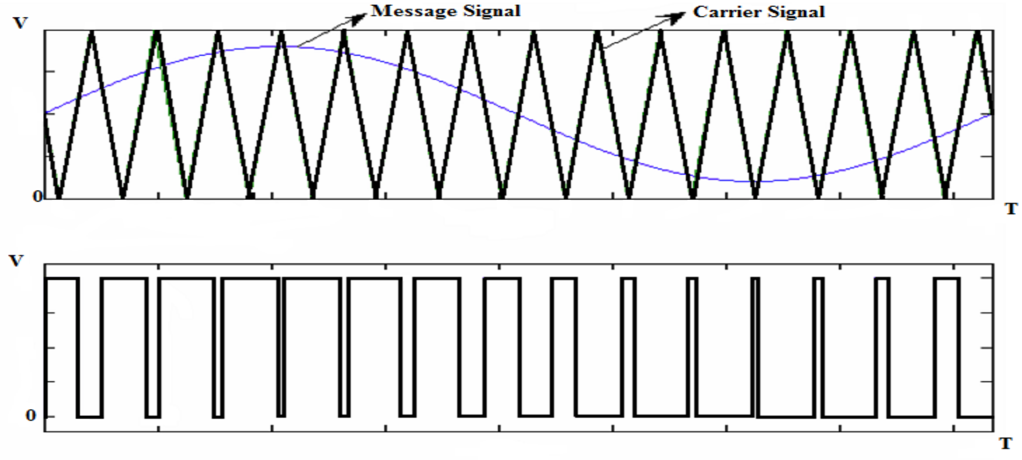


Figure 2: Two level PWM

- Multilevel PWM; The harmonic content can be reducing significantly by using several pulses in each half- cycle of the output voltage. There exist different levels of multiphase PWM producing an improved output with increase of the level of the PWM used. The most common ones are: 3 levels PWM, 5 levels PWM, 7 levels PWM and 9 levels PWM. The choice of which PWM level to use is determined by the cost of the inverter and the quality of the output. To balance between cost and quality of the inverter, a 3level PWM is commonly used.

  Figure 3 shows a 3 level PWM. Comparing the 3-level PWM to the 2-level PWM, the harmonics plot shows no higher level harmonics of significant magnitude. This represents the 3-Level signal following much more closely the desired sine wave. However, the primary frequency has a much lower voltage magnitude than that of the 2-Level design. The reason for this is the presence of other frequencies which are not harmonics of the 50Hz signal, which are caused by the switching of the signal from one polarity to the other, and back.

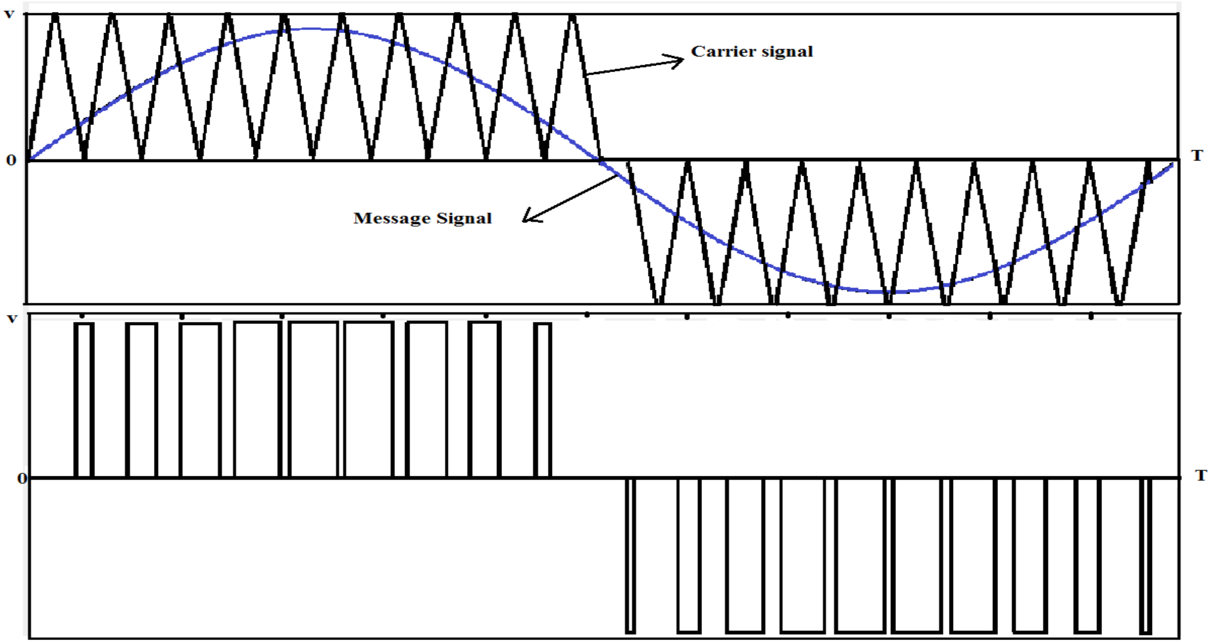


Figure 3: Three Level PWM

In electronic power converters and motors, PWM 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 PWM signal to provide a DC voltage across the load in a specific pattern will appear to the load as an AC signal, or can control the speed of motors that would otherwise run only at full speed or off. The pattern at which the duty cycle of a PWM signal varies can be created through simple analogue components, a digital microcontroller, or specific PWM integrated circuits.

Analogue PWM control requires the generation of both reference and carrier signals that feed into a comparator which creates 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 saw tooth 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. This process is shown in Figure 3 with the triangular carrier wave in black, sinusoidal reference wave in blue, and modulated and unmodulated sine pulses.

A digital microcontroller PWM requires a reference signal, sometimes called a modulating or control signal, which is a sinusoidal in this case; and a carrier signal, which is a triangular wave that controls the switching frequency. Microcontroller modules are used to compare the two to give a PWM signal.

The applications of PWM are wide variety used like ranging from measurement and communications to power control and conversion. In PWM inverter harmonics will be much higher frequencies than for a square wave, making filtering easier.

In PWM, the amplitude of the output voltage can be controlled with the modulating waveforms. Reduced filter requirements to decrease harmonics and the control of the output voltage amplitude are two distinct advantages of PWM. Disadvantages include more complex control circuits for the switches and increased losses due to more frequent switching.

2.3.2: H- Bridge Configuration

A H- Bridge or full- bridge converter is a switching configuration composed of four switches in an arrangement that resembles a 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 4.

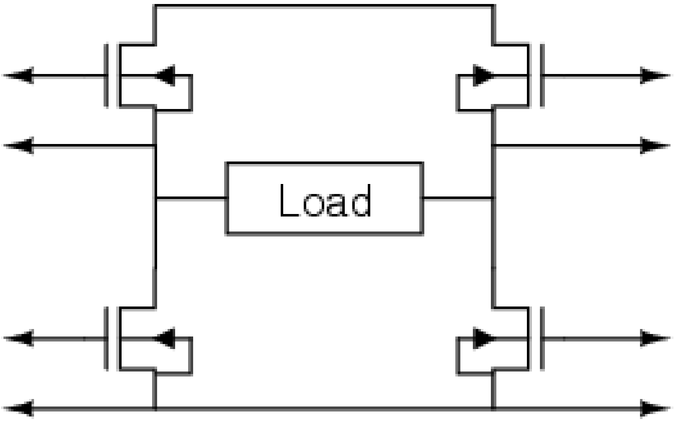


Figure 4: H- Bridge Configuration using N- Channel MOSFETs

As shown in Figure 4 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 1. 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.

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

Table 1: Valid H- Bridge Switch State

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 (in the case of a power inverter, 12V). This difficulty is often overcome by driver circuits capable of charging an external capacitor to create additional potential.

2.3.3: MOSFET Drivers

When utilizing N-Channel MOSFETs to switch a DC voltage across a load, the drain terminals of the high side MOSFETs are often connected to the highest voltage in the system. This creates a difficulty, as the gate terminal must be approximately 10V higher than the drain terminal for the MOSFET to conduct. Often, integrated circuit devices known as MOSFET drivers are utilized to achieve this difference through charge pumps or bootstrapping techniques. These chips are capable of quickly charging the input capacitance of the MOSFET (Cgiss) quickly before the potential difference is reached, causing the gate to source voltage to be the highest system voltage plus the capacitor voltage, allowing it to conduct. A diagram of an N- channel MOSFET with gate, drain, and source terminals is shown in Figure 5

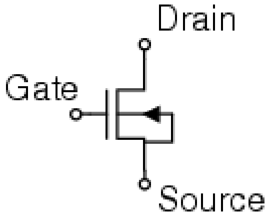


Figure 5: MOSFET symbol

There are many MOSFET drivers available to power N-Channel MOSFETs through level translation of low voltage control signals into voltages capable of supplying sufficient gate voltage. Advanced drivers contain circuitry for powering high and low side devices as well as N and P-Channel MOSFETs. In this design, all MOSFETs are N-Channel due to their increased current handling capabilities. To overcome the difficulties of driving high side N-Channel MOSFETs, the driver devices use an external source to charge a bootstrapping capacitor connected between Vcc and source terminals. The bootstrap capacitor provides gate charge to the high side MOSFET. As the switch begins to conduct, the capacitor maintains a potential difference, rapidly causing the MOSFET to further conduct, until it is fully on. The name bootstrap component refers to this process and how the MOSFET acts as if it is “pulling itself up by its own boot strap”.

2.3.4: MICRO-CONTROLLER

A microcontroller (also microcontroller unit, MCU or µC) is a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support functions such as a crystal oscillator, timers, watchdog, serial and analog I/O etc. Neither program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a, typically small, read/write memory.

Microcontrollers are designed for small applications. Thus, in contrast to the microprocessors used in personal computers and other high-performance applications, simplicity is emphasized. Some microcontrollers may operate at clock frequencies as low as 32 kHz, as this is adequate for many typical applications, enabling low power consumption (milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nanowatts, making many of them well suited for long lasting battery applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

In order to use the H-bridge properly, there are four MOSFETs that need to be controlled. This can be done either with analog circuits or a microcontroller. In this case, we chose the microcontroller over the analog system for several reasons:

- It would be simpler to adapt. With an analog system, it would be difficult to make changes for the desired output. In many cases, this is a desired trait, as it would be designed for a single purpose and therefore a single output. However, as this is something that is designed to be available all over the world, it needs to be adjustable to different standards of frequency and voltage. With an analog circuit, this would require a different circuit that it would have to switch over to, while with a micro- controller, it merely requires a change in the program's code.

- It can allow for easy feedback to control the power flowing through the load. One of the problems that can occur with systems like this is that the variances in load can cause variances in the supplied current and voltage. With a microcontroller, it is possible to have it “look” at the power output and change the duty cycle based on whether or not the load requires additional power or is being oversupplied.

2.3.5: Filter

The idea behind realizing digital-to-analog (D/A) output from a PWM signal is to analog low-pass filter the PWM output to remove most of the high frequency components, ideally leaving only the D.C. component. This is depicted in Figure 6. The bandwidth of the low-pass filter will essentially determine the bandwidth of the digital-to-analog converter.

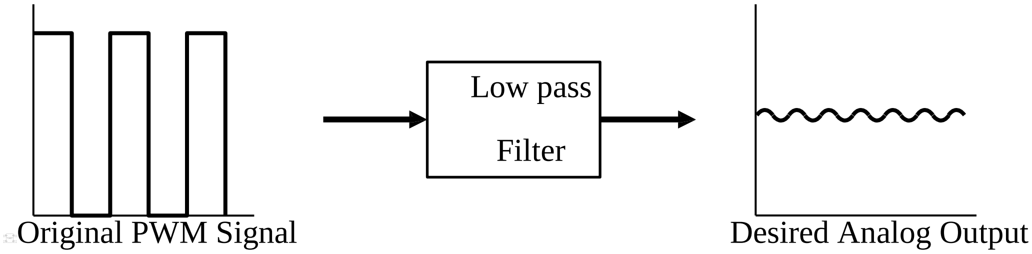


Figure 6: Analog Filtering of PWM Signal

Filters are classification is based on performance. They include:

- Active filters (built using op-amps)
- Passive filters (composed solely of resistors, inductors, and capacitors).

Active filters avoid the impedance loading issues suffered by passive filters, where the upstream or downstream impedances surrounding the filter can change the filter properties. Passive filters can offer lower cost and reduced design complexity.

With active filters, one must also consider the gain bandwidth of the op-amps used. The gain bandwidth represents the upper frequency that the op-amp can effectively handle when used in a closed-loop circuit configuration with small signal input. In terms of active low-pass filters, input signal components with frequency above the gain bandwidth will be attenuated since the op-amp will not have the ability to handle such frequencies. Op-amps with sufficient gain bandwidth to handle these frequencies are relatively expensive, and at some point one may as well just use an actual DAC chip.

Passive filters do not suffer as much from a gain bandwidth problem. The biggest drawback of passive is always impedance related. Upstream and downstream impedances can affect the performance properties of the filter. In the PWM/DAC application, upstream of the filter will be the PWM output from the DSP. This is a low output-impedance source that will not significantly affect the filter. In the downstream direction, one can use a low-cost voltage follower op-amp to create a high-impedance input. Since the op-amp is in the signal chain after the low-pass filter, an op-amp with large gain bandwidth is not needed.

Filters are further classified as

- 1st order linear time-invariant filters. The continuous-time domain transfer function for a 1st order filter is given by the equation;

  $(v_{out}/v_{in}=1/(Ts+1))$;

  Where the time constant τ is in units of seconds. It may be constructed from a single resistor and capacitor.

- 2nd order linear time-invariant filters. The transfer function is given by the equation;

  $(v_{out}/ v_{in}=\omega_n^2/(s^2+2\,\zeta\,\omega_n+\omega_n^2))$;

  where ω_n is the un-damped natural frequency in units of (rad/s)2, and ζ is the non-dimensional damping ratio. It's constructed by cascading two 1st order RC filters in series or a resister inductor and a capacitor.

2.3.6: Transformer

A transformer is an electrical device that transfers energy between two circuits through electromagnetic induction. A transformer may be used as a safe and efficient voltage converter to change the AC voltage at its input to a higher or lower voltage at its output. Other uses include current conversion, isolation with or without changing voltage and impedance conversion. A transformer consists of two windings of wire that are wound around a common core to provide tight electromagnetic coupling between the windings. The core material is often a laminated iron core. The coil that receives the electrical input energy is referred to as the primary winding, the output coil is the secondary winding.

The ideal transformer induces secondary voltage V_S as a proportion of the primary voltage V_P and respective winding turns as given by the equation

$(V_P/v_n)=(N_P/N_S)=(I_s/I_P)=a$,

Where,

a is the winding turns ratio, the value of these ratios being respectively higher and lower than unity for step-down and step-up transformers,

V_P designates source impressed voltage,

V_S designates output voltage, and,

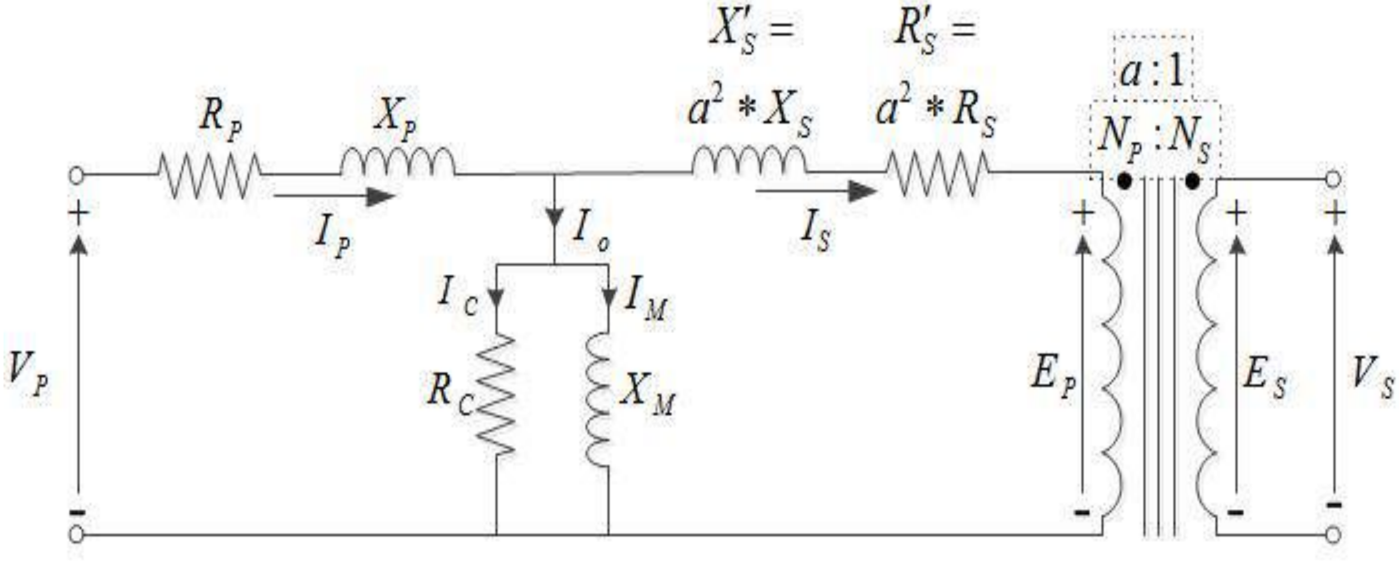


Figure 7: Transformer equivalent circuit

Core form and shell form transformers include;

- Laminated steel cores. They have cores made of high permeability silicon steel.
- Solid cores. Their cores are made from non-conductive magnetic ceramic materials called ferrites, a combination of a high magnetic permeability and high bulk electrical resistivity material.
- Toroidal cores. They are built around a ring-shaped core, which, depending on operating frequency, is made from a long strip of silicon steel or permalloy wound into a coil, powdered iron or ferrite.
- Air cores. It’s produced by simply by placing the windings near each other. The air, which comprises the magnetic circuit, is essentially lossless and so an air-core transformer eliminates loss due to hysteresis in the core material. The leakage inductance is inevitably high, resulting in very poor regulation, and hence such designs are unsuitable for use in power distribution.

CHAPTER 3: DESIGN

The construction of the pure sine wave inverter can be complex when thought of as a whole but when broken up into smaller projects and divisions it becomes a much easier to manage project. The following sections detail each specific part of the project as well as how each section is constructed and interacts with other blocks to result in the production of a 240 volt pure sine wave power inverter.

The block diagram shown in figure 8 shows the various parts of the project that will be addressed. The signal generator is simply the microcontroller. It generates both the PWM and square wave signals needed in controlling the MOSFET drivers. The signals from the drivers are then used to drive the four N-channel MOSFETs in the H-bridge configuration. The output signal from the h-bridge is then sent through a step-up transformer (Booster) and a low-pass LC filter so that the final output is a pure sine wave.

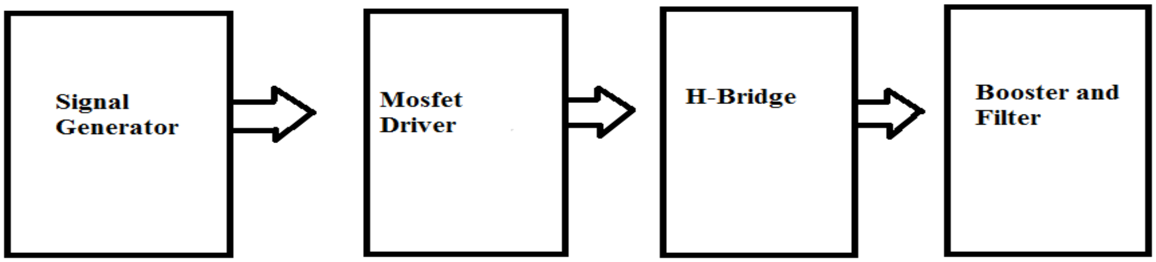


Figure 8: Inverter sections

3.1: Signal Generator

The control circuit in a pure sine wave inverter is designed using a Microcontroller. The advantages of this inverter is the use of a low cost microcontroller that has built in PWM modules. In this experiment, PIC16F877A was used that was able to store required commands to generate the necessary PWM and square waveforms. In PIC16F877A there are 40 pins each with different functions. PORT C has two output that produces PWM while PORT B is driven high and low to give a square wave.

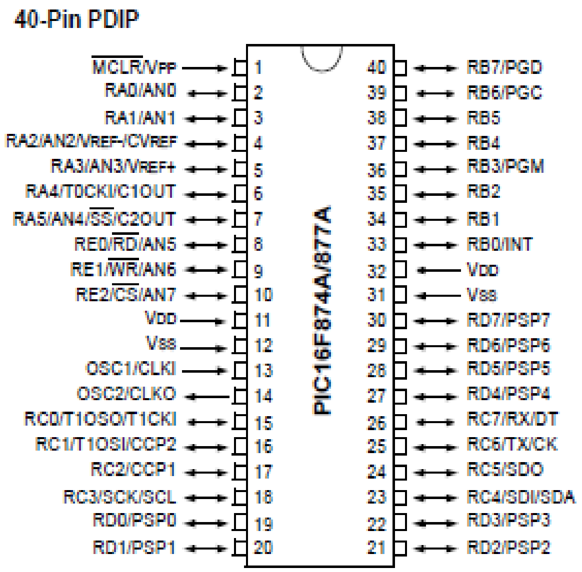


Figure 9: PIC16F8A

The microcontroller is tasked with generating the four control signals to drive two MOSFET drivers. They are two 50Hz square waves, each at 180^0 phase angle of each other, and two 2-level, 2 kHz pulse width modulation signals operating at a switching frequency of 50Hz also at 180^0 phase angle of each other.

Carrier frequency (C) =2 kHz, message frequency (M) =50Hz

Number of PWM projections per quarter cycle (P)= C/M=2000/(50*4)=10

Initial Duty (I) =50%, Overall Duty (O) =100%

Duty change for a quarter cycle= (O-I)/P= (100-50)/10=5

A delay of 305us was introduced to prevent one side of the H-Bridge switches being on at the same time.

The following steps should be taken when configuring the CCP module for PWM operation:

- Set the PWM period by writing to the PR2 register.
- Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON
- Make the CCP1 and CCP2 pins an output by clearing the TRISC

- Configure the CCP1 and CCP2 modules for PWM operation.

CCP1 Module: Capture/Compare/PWM Register 1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register controls the operation of CCP1. The special event triggers is generated by a compare match and will reset Timer.

CCP2 Module: Capture/Compare/PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer.

A Program (MIKROC PRO for PIC) was used to write the PIC code for the flowchart in figure 9. PIC code is attached in appendix (A).

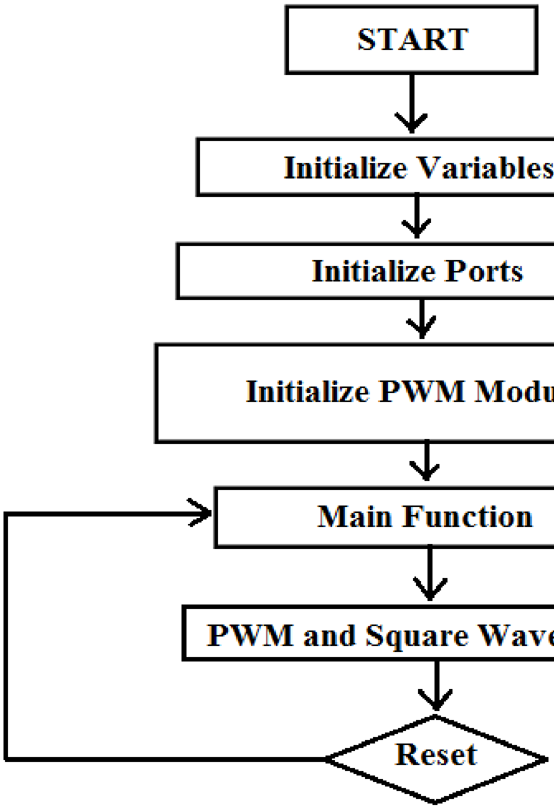
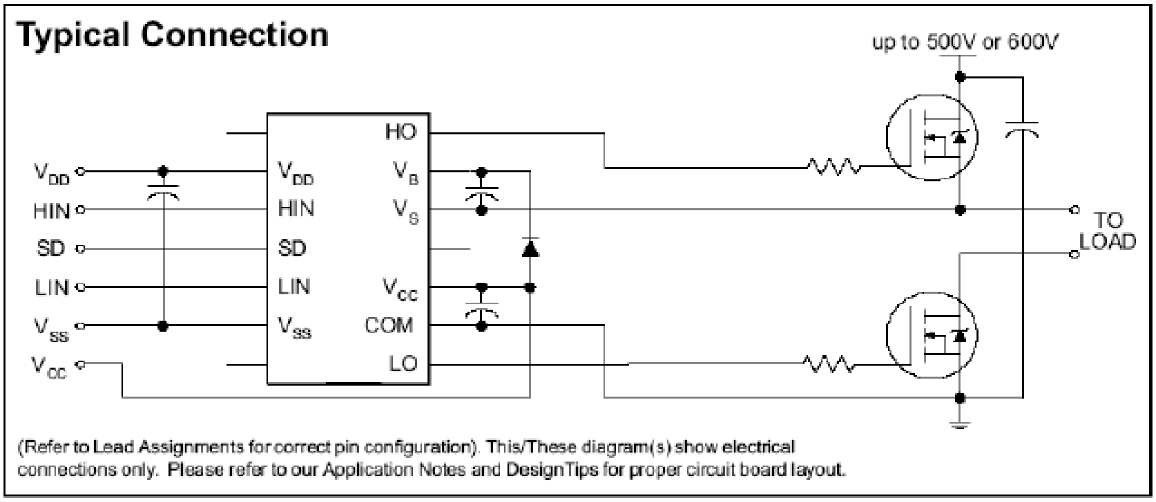


Figure 10: Control signal flowchart

3.2: MOSFET Drivers

The IR2110 High and Low Side Drive device exceeds all requirements for driving the MOSFETs in the bridge. It is capable of up to 500V at a current rating of 2A at fast switching speeds. This device is required to drive the high side MOSFETS in the circuit designated HO, due to the fact that the gate to source voltage must be higher than the drain to source voltage, which is the highest voltage in the system. This device utilizes a bootstrapping capacitor to maintain a voltage difference of approximately 10V above the drain to source voltage. With a full bridge configuration, two of these devices are utilized, as shown in figure. A typical connection of a single IR2110 device is shown in the Figure 10.



Typical Connection

(Refer to Lead Assignments for correct pin configuration). This/These diagram(s) show electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

Figure 11: connection of a single IR2110 device

Operation of the IR2110 device will be controlled through generated PWM and square signals. The PWM and square signals will be fed to the HIN and LIN pins simultaneously. If the internal logic detects a logic high, the HO pin will be driven; if a logic low is detected, the LO pin will be driven. The SD pin controls shut down of the device and will be unused and tied to ground. Additional pins that require external connections are the Vss pin which will be tied to ground, the Vcc pin which will be tied to 12V, pins requiring connections to bootstrapping components and outputs to the MOSFETS. Bootstrapping capacitors and diodes will be connected as designated. The values for these components are calculated from International Rectifier’s AN978 application note, HV Floating MOSFET Driver ICs. The formula for minimum bootstrap capacitor value obtained from this document is shown below.

$$C \geq \frac{2\left[2Q_g + \frac{I_{qbs(max)}}{f} + Q_{Is} + \frac{I_{Cbs(leak)}}{f}\right]}{V_{cc} - V_f - V_{LS} - V_{Min}}$$

Using the values determined from the data sheets of the components used, the minimum bootstrap capacitor values were calculated.

Q_g = Gate Charge of High Side FET = 220nC

I_{qbs} = Quiescent current for high side driver circuitry = 230uA

Q_{ls} = Level shift charge required per cycle = 5nC (given in application note)

I_{cbs} = Bootstrap capacitor leakage current = 210uA

F = Frequency = 50Hz

V_{cc} = Supply Voltage = 12V

$V_{f =}$ Forward voltage drop across bootstrap diode = 1 V

V_{ls} = Voltage drop across low side FET = 0.5V

V_{min} = Minimum voltage between V_B and V_S =3v

C ≥ 2[2*220nC+ (220uF/50Hz) +5nC+ (210uF/50Hz)]/ (12v-1-0.5v-3v) = 2.412uF

A safety factor of 5 is taken in consideration thus C ≥ 10.824uF.

3.4: H-Bridge

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 in the bridge. The IR2110 MOSFET driver integrated circuit was used for level translation between PWM and square signals and voltages required to forward bias high side N-Channel MOSFETS. A diagram of the H-Bridge circuit with MOSFETS and drivers is shown in below Figure

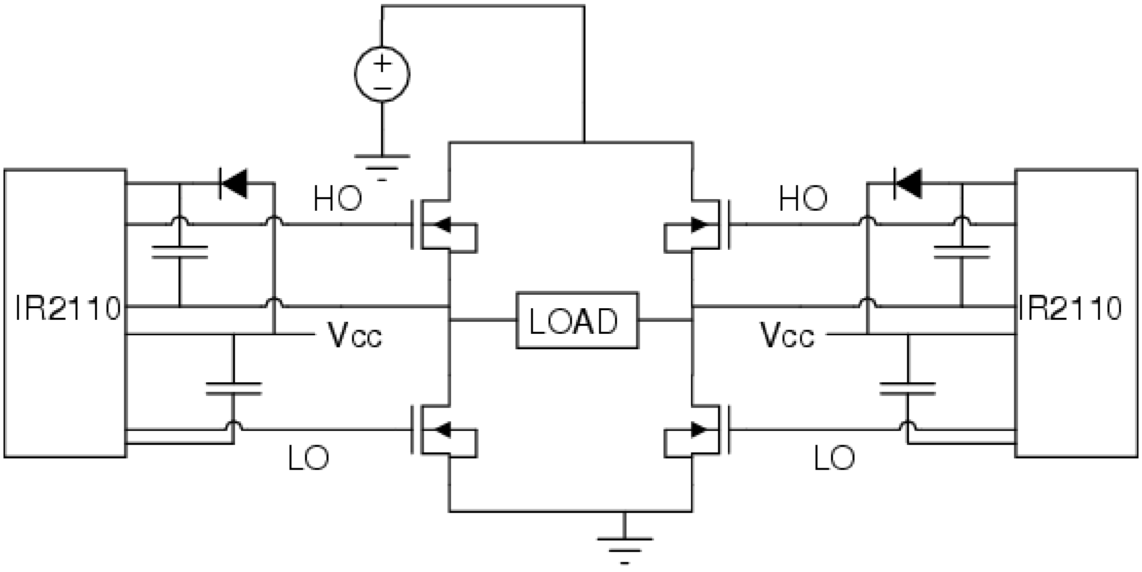


Figure 12: A full H-Bridge configuration

Driving the four MOSFETs in an H-Bridge configuration allows +12, -12, or 0 volts across the load at any time. To achieve this, the left side of the bridge is driven by the PWM signals to determine whether the output voltage is non-zero or zero while the right side of the bridge is driven by the square wave signals to determine the polarity, either positive or negative. The MOSFETs used in the design are IRF3808 Power MOSFETs rated for 75V at 140A with power handling capability of 600W

3.5: Power Loss and Heat

To determine the efficiency of the H-Bridge, and especially to determine the proper heat sink requirement for a design, the power lost through each MOSFET while conducting, and due to switching was to be determined.

The power losses through one half-bridge will be very different than that of the other half because both MOSFETs in each half-bridge are switched at different rates. The energy loss due to a single switching is found using the equation:

$$W_{on} = 0.5(V*I*T_{on})$$

V= 12V, is the maximum voltage a given MOSFET will experience which will be when it is OFF.

I= 50A, is the maximum current expected to go through the MOSFETs is ON. It is simply found with the power rating of 600Watts, with a voltage of 240Vrms, and Transformer turn ratio of 20 thus;

$$I= (600/240)20=50A.$$

Ton= 16 ns the time it takes for the switch to go from OFF to ON is found in theIRF3808 MOSFET data sheet

$$Won= 0.5 *12*50=300$$

The calculation of the OFF switching losses is identical, simply replacing Ton with Toff.

Toff=68ns

$$Woff= 0.5*12*68=408$$

$$Won + Woff=300+408uj= 708\mu j$$

Because these two values are the switching losses for each single switch from one state to the other, the total loss per cycle could be found by simply multiplying these values by the number of switches in a period. Assuming that the PWM has an average duty cycle of 50%, there will be one switch off and one switch on per switching period. The switching frequency of the PWM half-bridge is 2kHz, which means that the MOSFETs will switch, on average, 2,000 times a second each high and low. The energy lost per second of operation is;

$$2,000*(Won + Woff) = 2000(708\mu j) = 1.416W$$

The other half-bridge switches at a rate of 50Hz, thus the losses are given by:

$$50*(Won + Woff) =50*1.416=70.8W$$

On splitting the switching losses between the two bridges, it was seen that most of the heat generation was on the two MOSFETs controlled by the PWM signal compared to the other two controlled by the 50 Hz square wave.

The power loss from conduction will be the same for the two half-bridges. If the PWM has an average duty cycle of 50%, the loss due to conduction per cycle is given by the relationship:

$$W\ conduction= VDS \times I \times (DT)$$

VDS= 1.3v, is given in the MOSFET data sheet,

I= is the current previously calculated as 50,

DT= is the duty cycle is 50% and the period is 1/Fs. Because the main interest in losses per second, the T is simply dropped from the equation.

W conduction = 50*1.3*=65j per second per MOSFET.

Each MOSFET on the PWM half-bridge will have a power loss of 65+70.8=135.8W. Using the power losses calculated, the relationship $\Delta T=PR\theta$ was then used to design the correct heat sink. ΔT is the allowable range of temperatures; it’s given by difference between the maximum operating temperature given in the MOSFET data sheet and the ambient temperature. P is the power lost through the MOSFET and $R\theta$ is the thermal characteristic of the MOSFET/heat sink system.

Assuming that the ambient temperature will be 25°C, which is the high range of room temperature. The maximum operating temperature given in the MOSFET data sheet is 175°C,

$$\Delta T=175 -25=150^\circ C,$$

For our power value, the highest power loss value was taken, for which P=135.8W.

$R\theta$ can be broken down into $R\theta JC$, $R\theta CS$, and $R\theta SA$. The first two values are inherent to the MOSFET and are given by the data sheet as 0.45 and 0.24°C/W, respectively. The third value will be a property of the heat sink, and is the value for which we must solve. Using the relationship given,

$$R\theta = 150/ 65W = 2.76$$

$$A = 2.76/ (0.45)= 6.11\ cm^2$$

3.6: Output Filter and booster

The final component necessary to output a pure sine wave signal is an output filter. For our circuit we need a basic LC low pass filter with the following setup below in Figure

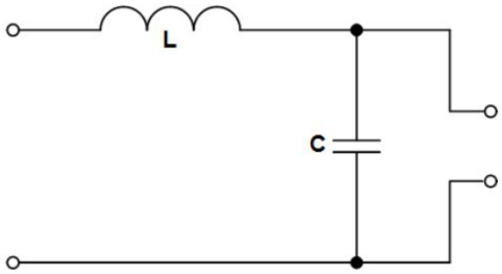


Figure 13: LC filter

This will filter out all the excess noise above the critical frequency. The goal for this was to bring the critical frequency as close as possible to the desired frequency of 50 Hz, removing other harmonics that crop up within the system. The slower the cutoff frequency, the greater the capacitance and inductance required to properly create the filter. Therefore, filter design becomes a tradeoff between the effectiveness of the filter and the cost and size of the component. The output of the H-bridge was ideally a 50Hz sine wave. Because it was encoded using a 2 kHz PWM signal it was to be filtered. Due to the high current expected to be sourced ((20*600w)/(240)=50A by the load of our output, the only option was a passive low pass filter, which is an inductor and capacitor in series, with the load connected across the capacitor designed for passing all signals under 50Hz.

$F_c=1/\ 2\prod\sqrt{(LC)}$

Using an inductor of 2.07H, requires a capacitor of 4.5µFto obtain the required cutoff frequency. The closest capacitor value was 1uF was used

The selected inductor was to be able to handle at least 50A current and the capacitor at least 50V.

A tolloidal step up transformer of 45.m14H primary inductance and 2.619H secondary inductance was used to boost 12 volts to 240 volts. A capacitor of 1uF was placed at the output of the secondary coil to filter harmonic distortions.

CHAPTER 4: IMPLIMENTATION

4.1: Signal Generator

Simulation;

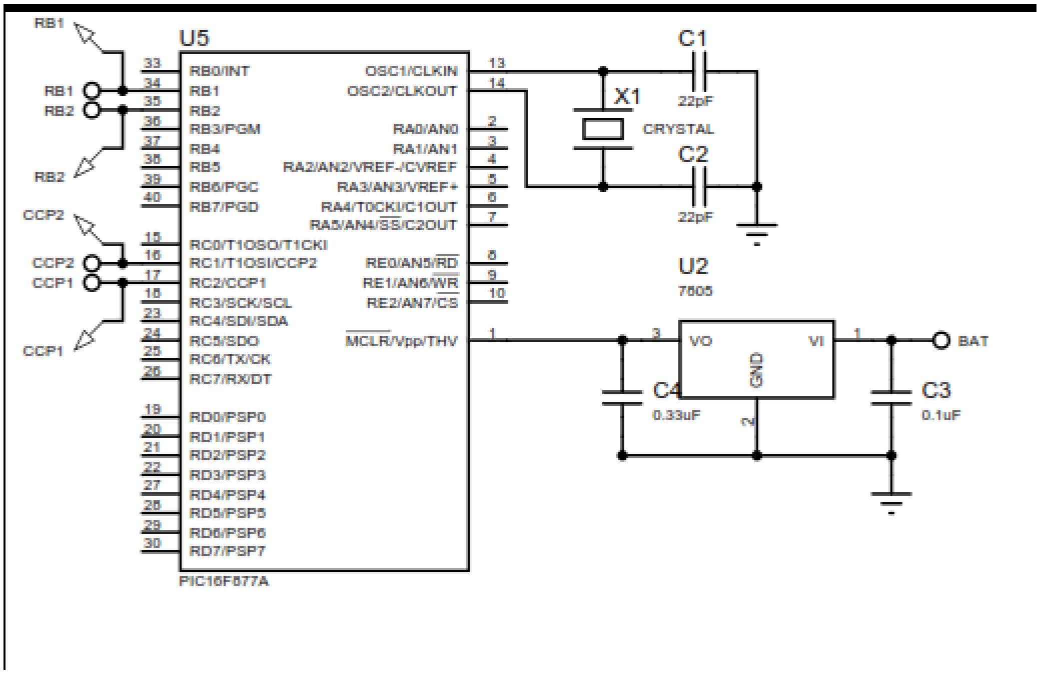


Figure 14: Signal Generator

A 12V dc from the battery was fed to the microcontroller through a 5V constant regulator with ac filter capacitors at both input and output side. The capacitor values were obtained from 7805 regulator datasheet.

The microcontroller was clocked with an external clock of 10MHz which was grounded using capacitors whose values were obtained from PIC16F877A datasheet. The High PWM and Square wave output were obtained from pins CCP1 and RB1 while Low PWM and Square wave were obtained from pin CCP2 and RB2 respectively.

4.2: MOSFET Drivers and Full H Bridge

Simulation

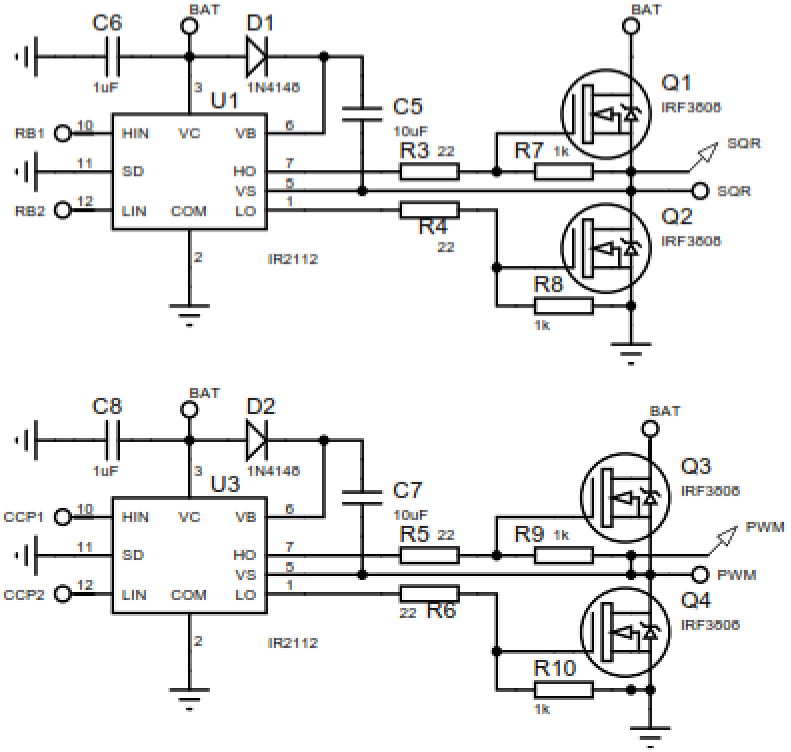


Figure 15: MOSFET Drivers controlled Full H Bridge

The microcontroller outputs were used to control the MOSFETs Full H-Bridge though MOSFET drivers U1 and U3 whose pins connection was done as shown in IR2112 datasheet. C6 and C8 are stabilizing capacitors which filters all the ac currents. Their values were obtained from the datasheet. C5 and C7 are bootstrap capacitors whose values were calculated in the design. They are charged through diodes D1 and D2. The outputs of the MOSFET drivers were fed to the MOSFET gates through resistors R3, R4, R5 and R6 which controlled the MOSFET switching speed. Their values were obtained from the IR2112 datasheet. Resister R7, R8, R9 and R10 were used for discharging the capacitance C_{GS} to allow for proper MOSFET switching. The H-Bridge was powered by a 12V dc from the battery and the output was obtained between the outputs PWM and SQR.

4.3: Filter and Boost Transformer

simulation

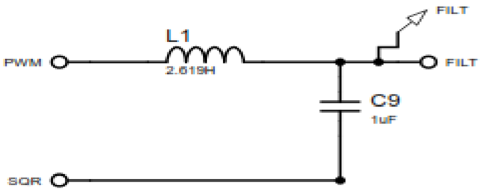


Figure 16: Passive Low pass filter

The H-Bridge output was fed to a RL Passive Filter. The values of the inductor L1 and Capacitor C9 were as calculated in the design.

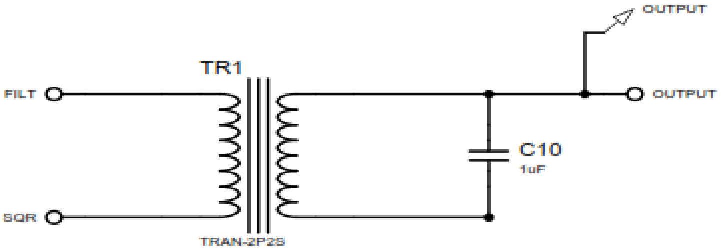


Figure 17: Step-up Transformer

The output of the Filter was boosted using a Step-up Transformer with a transformation ratio of 18.3. A capacitor C10 was placed at the output to filter the harmonics. Its value was obtained from a range given in the general transformer output stabilizers.

4.4: Sine Wave Inverter

Simulation

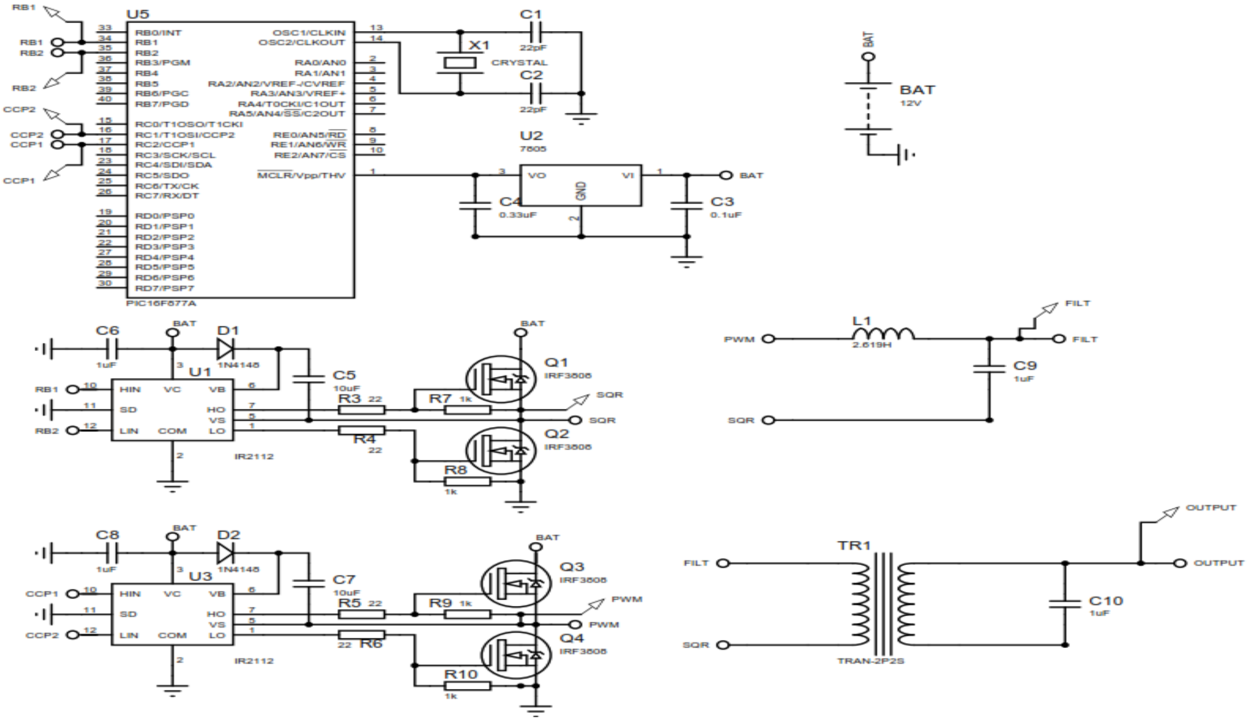


Figure 18: Sine wave Inverter

Actual

Figure 19: Sine wave Inverter

CHAPTER 5: RESULTS and ANALYSIS

The results were obtained at different levels since it made it easy to troubleshoot.

5.1: Signal Generator output

Simulation

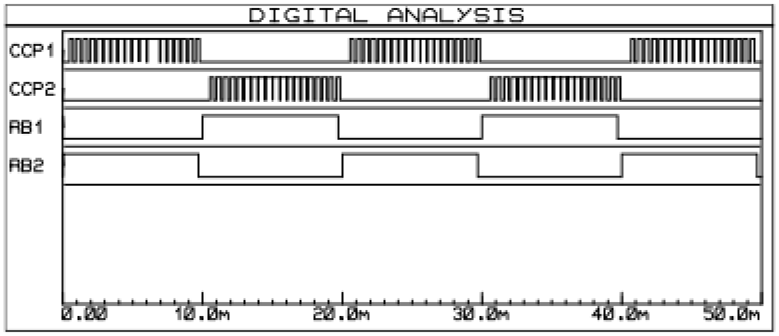


Figure 20: Microcontroller output

Switching frequency = 1/ (20ms) = 50Hz

Actual

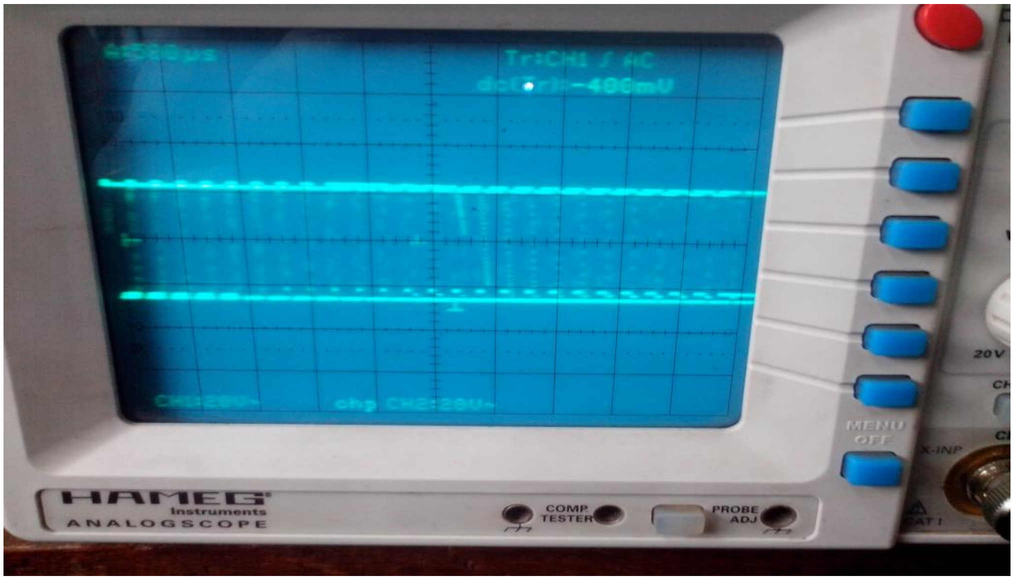


Figure 21: Microcontroller output

Peak voltage=2V*2.5=5V

5.2: MOSFET Drivers and Full H Bridge output Simulation

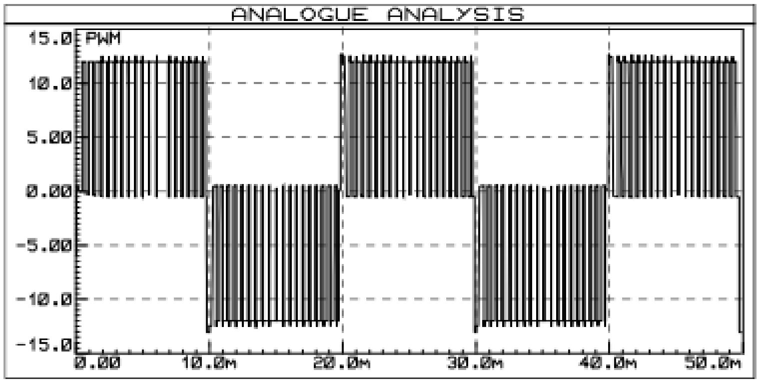


Figure 22: Bridge Output

Switching frequency = 1/ (20ms) = 50Hz

Peak voltage = 12V

Actual

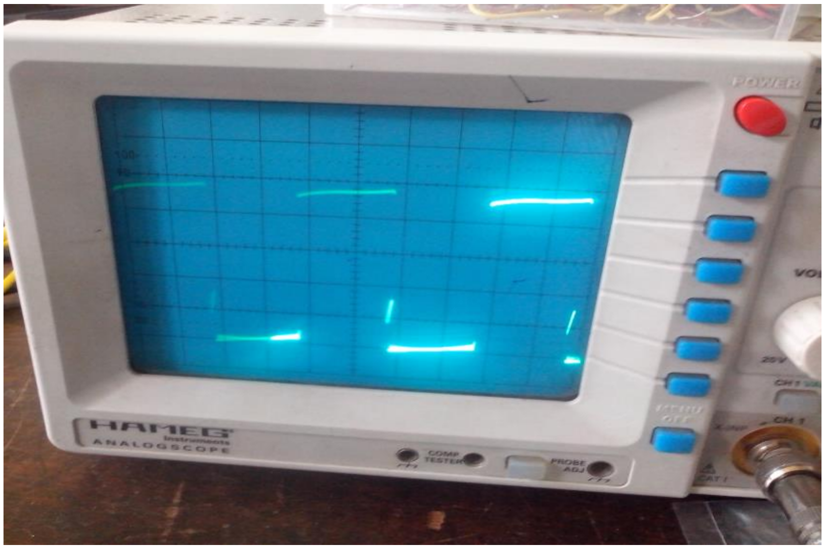


Figure 23: Bridge Output

T=5ms*4=20ms

Switching Frequency=1/T=1/(20ms)=50Hz

Peak voltage=5V*4.4=22V

5.3: Filter output simulation

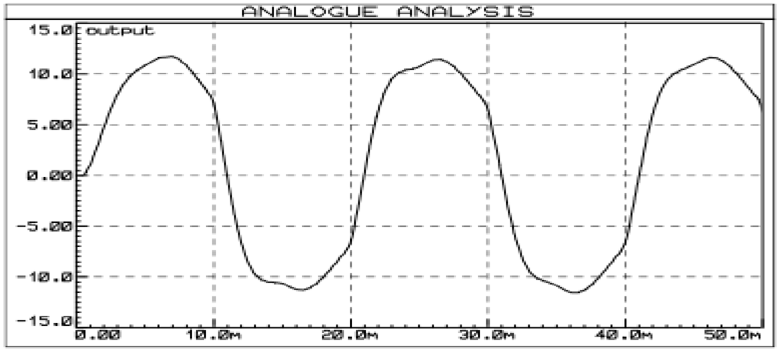


Figure 24: Filter Output

Frequency = 1/ (20ms) = 50Hz

Peak voltage=24V

Actual

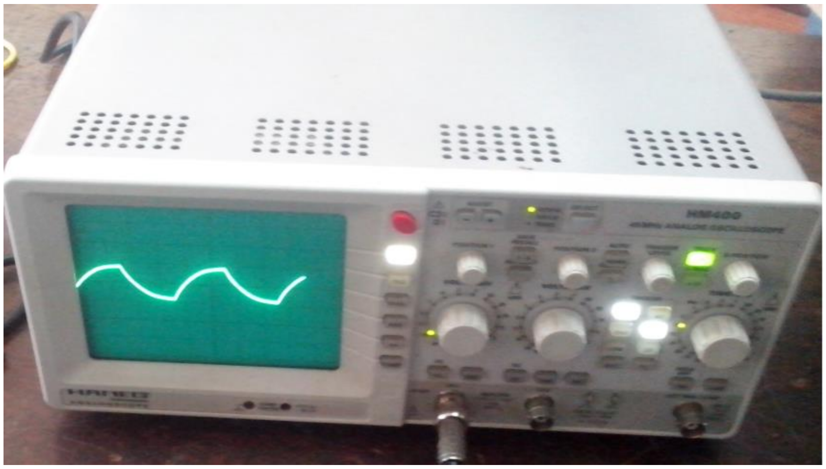


Figure 25: Filter Output

T=5ms*4=20ms

F=1/T=1/(20ms)=50Hz

CONCLUSION

The basic goal of this project, which is designing and implementing a working DC-AC sine wave inverter that could efficiently provide 600watt of power using 3-level PWM, has been achieved. Different signals were generated to control MOSFET switches arranged in an H-bridge. The aim was to modulate the bridge with a 2 level PWM and obtain a 3 level PWM and filter the bridge output to get a pure sine wave. Although the final output waveform was not the desired waveform, the design went along in trying to design an affordable sine wave inverter.

This project provides a good building block that can be added in to many general-use high-power applications, as well as a base to work off for a self-regulating power supply

RECOMMENDATIONS

An improvement that can be made is a feedback system which would give the microcontroller a view of the output across the load so that the signals controlling the system could be adjusted according to certain parameters in the programming. As different loads are connected and disconnected, the efficiency and output of the system will change. In order to keep the system running at $240V_{rms}$ and 50Hz, it has to be able to adapt to changes in its load and battery levels. Implementing a voltage booster at the bridge input is one recommended method as it would minimize the effect battery voltage drop on the output.

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APPENDIX

```
void main()
  {
int duty=50;                    // initial value for duty
TRISB=0;                        // designate PORTB pins as output
TRISC=0;                        // designate PORTC pins as output
PORTB=0;                         // set PORTB Low
PWM1_start();                    // start PWM1
PWM2_start();                    // start PWM2
PWM1_init(2000);                   // Initialize PWM1 module at 2KHz
PWM2_init(2000);                   // Initialize PWM2 module at 2KHz
RB4_bit=1;                      // Set port RB4 High
while(1){                       // endless loop
RB2_bit=1;                      // set PORT RB2 to High
for(duty=50;duty<100;duty+=5){     // increment duty
pwm1_set_Duty(duty*2.55);        // set duty
delay_us(130);}
for(duty=100;duty>50;duty-=5){     // decrement duty
pwm1_set_Duty(duty*2.55);        // set duty
delay_us(130);}
pwm1_set_Duty(0);
```

```
RB2_bit=0;                  // reset PORT RB2 Low

delay_us(305);

RB1_bit=1;                  // set PORT RB1 High

for(duty=50;duty<100;duty+=5){

pwm2_set_Duty(duty*2.55);        // set duty

delay_us(130);}

for(duty=100;duty>50;duty-=5){     // decrement duty

pwm2_set_Duty(duty*2.55);        // set duty

delay_us(130); }

pwm2_set_Duty(0);

RB1_bit=0;                  // reset PORT RB1 Low

delay_us(305);}

  }
```