DESIGN AND IMPLEMENTATION OF LOW-COST POWER INVERTER FOR THE APPLICATION OF RURAL HOUSEHOLD APPLIANCES

By

Emebet Tadesse Tamrat

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Office of Graduate Studies

Adama Science and Technology University

October, 2020

Adama, Ethiopia

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Advisor: Milkias Berhanu (PhD)

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Approval of board of examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Emebet Tadesse Tamrat have read and evaluated her thesis entitled "Design and Implementation of Sine Wave Power Inverter for Rural Household Appliance" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirement of the Degree of Master's in Power Electronics.

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Declaration

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with my approval as thesis advisor

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Advisor’s approval sheet

To: Electrical Power and Control Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled “Design and Implementation of Sine Wave Power Inverter for Rural Household Appliances” submitted in partial fulfillment of the requirements for the degree of Master’s in Power Electronics, the Graduate program of the department of Electrical Power and Control Engineering, and has been carried out by Emebet Tadesse Tamrat Id. No GSR/0032/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby she can submit the thesis to the department.

Dr. Milkias Berhanu	____________________	________________
Advisor Name	Signature	Date

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It all happened with the help of Almighty God. May all the Glory be to His Name!
I cannot thank enough for all those who are involved in this research work. I might not be able to mention everyone by name, but I am so grateful and thankful for all who have contributed in every aspect, I have put your name in the holy heart of Jesus Christ.

JESUS, I THRUST IN YOU!

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AC	Alternative Current
BJT	Bipolar Junction Transistor
CFI	Current Fed Inverter
CSI	Current Source Inverter
DC	Direct Current
GTO	Gate Turn On
HH	Household
IC	Integrated Circuit
IGBT	Insulated Gate Bipolar Transistor
LED	Light Emitter Diode
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCB	Printed Circuit Board
PI	Proportional Integral
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
THD	Total Harmonic Distortion
TV	Television
UPS	Uninterruptable Power Supply
VFI	Voltage Fed Inverter
VSI	Voltage Source Inverter

ABSTRACT

Ethiopia is the largest and most populated country in the Horn of Africa, but majority of its places lack basic infrastructure including electrical power from the national grid even regardless of the demand by the rural community. Rural households need AC power as compared with the DC at less operating cost. Thus, the objective of the study is to design and develop a low-cost sine wave power inverter which can be used for common household appliances for poor rural households of Ethiopia. The results of the study can contribute significant ideas and knowledge to the rural people, the government, and future researchers in the area. In this study, the three-design models such as with CD4047 IC based, two transistors based, and microcontroller-based inverter were presented. Each of these designs are tested for efficiency versus cost. Among the three designs, it is found that the CD4047 IC based was the lowest cost of development followed by the two-transistor and microcontroller based one. While CD4047 and microcontroller based were more efficient as compared to two transistors-based inverter designs, the Microcontroller and CD4047 IC based designs have little difference by its performance characteristics. In conclusion, designing a low-cost inverter for house appliances in the rural households who cannot buy expensive inverter is possible. There are also several low-cost inverter designing options that are simple and convenient. However, the original materials are not available in the recent market. Thus, the concerned government or regulatory bodies or private organizations can facilitate for their availability, and accessibility of genuine materials for the benefit of the rural community.

Keywords: *CD4047 Inverter, Household, Microcontroller Inverter, PROTEUS, Two Transistor Inverter.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Ethiopia, a country in the Horn of Africa lies completely within the tropical latitudes and is relatively compact, with similar north-south and east-west dimensions. The capital is Addis Ababa meaning “New Flower”, located almost at the center of the country. Ethiopia is the largest and most populated country in the Horn of Africa [1]. Most of the places in the country are not urbanized. Places near the capital are rural areas which lack basic infrastructures including road, water, and electric power.

It is well known that Electricity plays an important role in human life. Each day, people use electricity for keeping homes and businesses running smoothly, powers transportation that takes people to work, school and other places, and supplies electricity to appliances in all sectors.” [2]. In other advanced countries, the usage of electricity becomes part of their existence. Without electricity means not worth living for. For this reason, electricity plays an important role in daily life.

Rural electrification has long been topped on the development agenda of many developing countries. Nevertheless, there is no electricity for majority of the population in these countries. Studies shows that in rural areas of Ethiopia, people need electricity equally as people living in urban areas. But most places lack electric power from the grid. According to the World Bank collection of development indicators [3]; the proportion of rural population in Ethiopia have only 26.5% access of electricity. The remaining 73.5 % do not have access to electricity. Which means that there is no electricity to power lights, for cooking and heating at household level and no power for health centers, schools, or electricity to run a business.

Since the usage of electricity plays an important role for people living in rural areas, there are different ways and technologies available in the country as a temporary substitute. There are two types of electrical sources that the rural people used based on the type of appliances they are using. These are AC and DC sources. DC sources of electricity can easily be generated in different places in the country. For these reasons, people living in rural areas use solar panels to generate electricity and this generated electricity is a DC voltage. Most of the appliances available in the country use an AC source to run efficiently and DC appliances are very expensive, and they are not often available in the market. To use these generated DC voltages with the commonly available appliances in the rural places, power inverter is used to convert DC to AC. The inverter is particularly suitable for use in those rural areas where there is still no electricity supply from the main electric grid lines. Most household appliances use AC power source and hence inverter is a very essential device for rural areas. The modified inverter that exist in the current market has a very low efficiency. The electronics equipment supported by this inverter will be damaged due to the content of harmonics. In addition, it is not durable and is very expensive.

This study was conducted in two rural Kebeles in Adama and Bishoftu Cities, namely Kilinto and Arobecha, respectively. Adama and Bishofitu are two big cities in Misrak Shewa Zone of Oromia National Regional State. Adama is found at an elevation of 1,712 meters above level [4] and Bishoftu has an elevation of 1,920 meters above sea level [5].

Figure 1.1 Location of Cities from Addis Ababa

Kilinto Kebele is found at 9 km North of Adama city and Arobecha kebele is found 33km South of Bishoftu city. A total of 50 households (HH) have been reached by the study with 25 HHs from each Kebele. Based on the study conducted, this group of families living in that area does not have access to electric grid lines. But almost all of them have appliances that require electricity. The maximum required electric power was 38.8 watt but with development this can be higher in the near future. They have electric appliances like LED lamps, radio, mobile cellphones, torchlight, and TV. The torchlight and radios work by uncharged batteries, but the problem is that the battery is not durable, and the good batteries are expensive. In each HH, at least one of the family members have mobile cellphone but they do not have a charging station. For this reason, they travel from place to place to charge a mobile phone. This all makes their life difficult and challenging to get reliable information and also creates obstacles in smooth communications.

Figure 1.2 Farmland and Residence at Kilinto Kebele

Some HHs have solar panels installed on their homes. Those people having solar power in their homes, use power inverters which will convert the DC power to AC power just to power up their appliances. Most of the power inverters available in the market of certain countries are not that much efficient and hence cause damage to their appliances. There are many factors that contribute to the efficiency of this system. But most of the concerns of these people living in those areas were the cost and the reliability of the inverters. Accordingly, some inverters after few weeks of usage eventually deteriorates in powering loads or the inverter itself were being damaged. Some inverters work for a short period and operate only one of electronic equipment at a time or otherwise not working at all. Apart from that, the rating of the inverter specified by the manufacturer declines immediately because of poor quality. These and other factors cause damage to appliances and force people for unnecessary expenses. The HH load distribution is shown in the following figure.

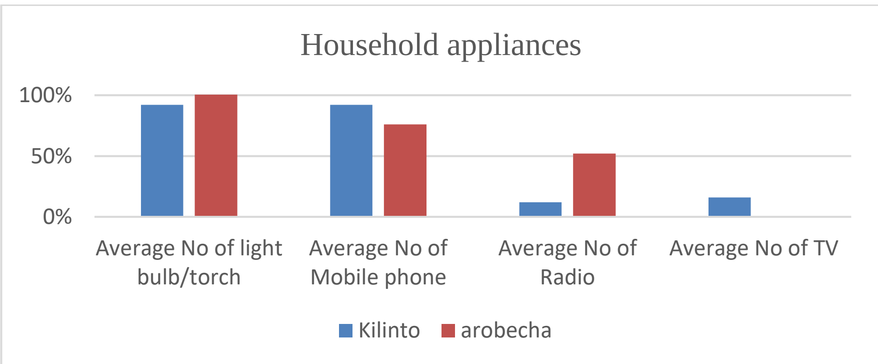


Figure 1.3 Rural Area Appliances

As shown in figure 1.3 above, majority of the households have either LED light bulb or torch. More than 80% of people have a mobile phone, quarter of the households from both kebeles have Radio and the number of TV is very few. Based on the findings, the average watt required for each of the appliances is 5, 2.9, 3 and 20 watts for LED bulb, mobile charging, radio, and Television, respectively.

This research thesis designed an appropriate household inverter based on the study of the load capacity of the rural areas. They can get a chance to charge their mobile phone, lighting, and radio charging.

1.2. Statement of the Problem

Residents of both of Kebeles share the lack of electric power in the area. These people have appliances that require access to electricity. Due to these instances, they used solar panels and batteries as their sources of electrical power. The electrical powers that were generated with solar panels were DC voltages. To use these voltages, it must be converted into AC voltages.

Figure 1.4 Problem of no Access Electricity

Inverters were commonly used to supply AC power from DC sources such as solar panels or batteries. Most people in rural areas used common household appliances and the majority of these appliances run on 220V AC. For these reasons, power inverters were required in most rural area users.

The output voltage waveform of an ideal inverters should be sinusoidal. To protect the appliances and improve the efficiency of the appliances, power inverters were used. Commercially available inverters around the country were mostly modified sine waves and the efficiency of these available inverters were much lower than what was expected by the consumer.

Using these commercially available inverters causes damages to some electronic appliances due to its harmonics. And the costs of these inverters were very high for the rural people.

1.3. Objectives

1.3.1. General Objective

The main objective of this study is to design and develop an economical sine wave power inverter that can be used for common household appliances in rural places of Ethiopia, that cannot buy an expensive inverter.

1.3.2. Specific Objectives

To obtain the general objective, the following specific objectives were developed:

- ❖ To design and simulate three models based on the gathering data from rural area load requirement
- ❖ To implement three prototypes for the required load
- ❖ To test the efficiency of the models
- ❖ To analyze the cost-effectiveness of the developed model of the power inverter

1.4. Research Question of the Study

To guide the proponent and to conduct the study effectively, the following were the research question that were developed during the study.

1. What level of loads are used in different rural areas; design parameters and mathematical tools were required based on the load requirements in rural places?
2. What different models were established based on the output analysis of load requirements and tools were used and the results of the simulation design as per load requirement?
3. What is the level of efficiency of the developed model?
4. What was the cost-effectiveness and efficiency level of modeled power inverter as compared with the existing available power inverter in the country?

1.5. Significance of the Study

The study of sine wave power inverter design for the rural community of Ethiopia can contribute some ideas and knowledge to the following:

Rural people: - The people living in a rural area can have the chance to use efficient power inverter as compared to the existing power inverter available in the market for their household appliances at a low cost. This will also serve as their input in identifying the types of power inverter suited to their budget.

The government: - The officials assigned to the rural places will have the opportunities to help and economically provide a power inverter. They can gain ideas on how to identify appropriate low-cost power inverters for the rural community.

Future researchers: - The study can be a helpful input to the researcher studying rural developmental technology. This will give them ideas based on some experiments that were conducted in this study.

1.6. Delimitations and Limitations of the Study

The scope of this study includes data gathering on the two Kebeles near Adama and Bishufto Cities. These data were used for the designing of power inverter as per the requirement of the rural community. The modeling of the power inverter circuits were included. Three model circuit designs were developed and tested based on the load requirement in rural areas. Software used for analysis and simulation were PROTEUS.

After designing and simulation analysis, developing and testing of prototype model included in the study. The parameters of the developed prototype model include 220V AC, 50 Hz, and 24W power rating. IEEE standard of THD for household is 3% percent [6]. This prototype does not have filter because the material is not available. Hence, THD is expected to be high and the efficiency to be low.

The development stages of the study were based on the resources available in the country hence big challenge to satisfy the parameter specification of the inverter quality. Specially the softwares and finding original materials was very challenging and a limitation for the study.

CHAPTER TWO
2. LITERATURE REVIEW

Alternating current dominates the power distribution as compared to direct current in the world. One of the main reasons for using AC rather than DC because it is easy to transfer with low investment costs. For these reasons, most appliances over the market use AC voltages as the primary source. Likewise, the generation of DC power is the most commonly available in the market. Even in rural areas, this DC generation can be easily achieved. With the introduction of solar technology and become commonly available everywhere in the country, it is now possible to generate DC power in the home. [7]

Since appliances are powered with AC source, the conversion of this DC to AC became necessary so that these appliances work properly. Different studies were conducted about this conversion of DC to AC, depending on the usage application of the different types of the inverter. The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

According to the shape of the generated waveform inverter classified into three types.

Square wave inverters are simple in design and implementation. The output voltage alternates between positive and negative values. The output waveform, however, has a lot of amount of THD which results in considerable power dissipation due to these harmonics. On the other hand, the square wave inverter cannot regulate its AC output voltage when the battery voltage changes significantly. This can cause some types of AC loads to fail suddenly [8].

In the modified sine wave inverters, the output signal is like a square wave except that it goes to zero for some delay time before switching positively or negatively. This may reduce the THD and gives better load compatibility. The shape of the waveform can also be controlled to allow regulation of the AC output voltage level as the battery's voltage changes. The pulses of the square wave can be made tall and narrow when the battery voltage is high and can be made short and wide when the battery voltage is low. This results in a consistent average voltage for supplying the AC loads and improves load compatibility and performance [9].

Pure sine wave inverters produce a waveform that closely matches the signal of the main power grid system. The generated waveform has very low THD and thus these inverters can run more sensitive AC loads.

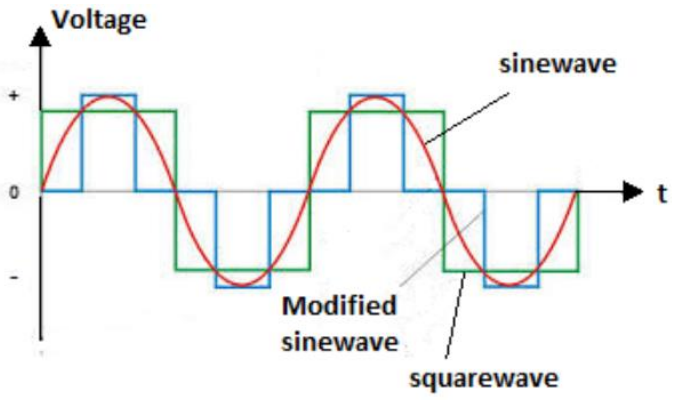


Figure 2.1 Types of the Generated Inverter Waveforms.

A pure sine wave is highly desirable because the vast majority of the electrical plug-in application is designed to run on a pure sine wave signal. The main and important issue to get this signal is the switching mechanism and control part.

One of the switching mode power conversion is an inverter and different techniques of switching strategies were implemented in the circuit designed. All switching strategies mostly concentrate in terms of reducing the power losses; reduce the total harmonic distortion and increasing the efficiencies of the inverter. For this purpose, many researchers have been studying and analyzing types of switches that can be used in an inverter. The power semiconductor devices such as the BJT, MOSFET, and IGBT are widely used in power applications as switching devices. Those switching devices are selected depending on the quality and type of power capability of the inverter.

In the very last decade, studies of complex behavior in switching power converters have gained increasingly more consideration from both the academic community and industry. The inverter generally operates in a Pulse Width Modulated (PWM) way and switch between different circuit topologies. Inverters that use PWM switching techniques have a DC input voltage that is usually constant in magnitude. The inverters' job is to take this input voltage and output AC where the magnitude and frequency can be controlled. There are many ways that pulse-width modulation can be implemented to shape the output to be AC power. There are different PWM techniques, a common one called Sinusoidal Pulse Width Modulation SPWM will be explained. Control of the switches for sinusoidal PWM output requires (1) a reference signal, sometimes called a modulating or control signal, which is a sinusoid in this case and (2) a carrier signal, which is a triangular wave that controls the switching frequency.

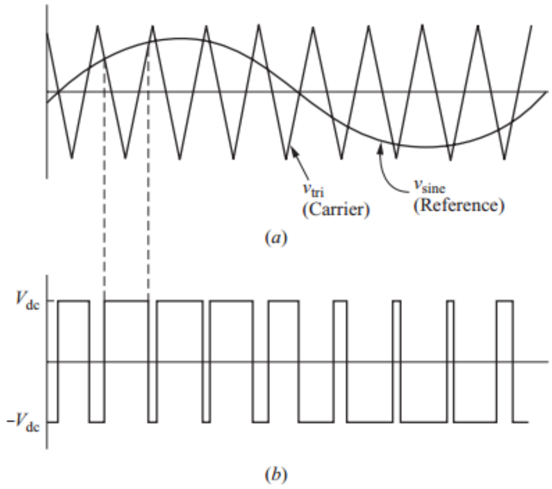


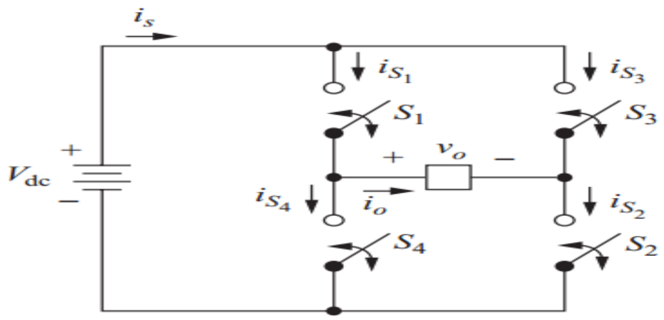
Figure 2.2 Sinusoidal Pulse Width Modulation [10]

Figure 2.2 illustrates the principle of Sinusoidal Pulse Width Modulation. Figure 2.2(a) shows a sinusoidal reference signal and a triangular carrier signal. When the instantaneous value of the sine reference is larger than the triangular carrier, the output is at +Vdc, and when the reference is less than the carrier, the output is at -Vdc

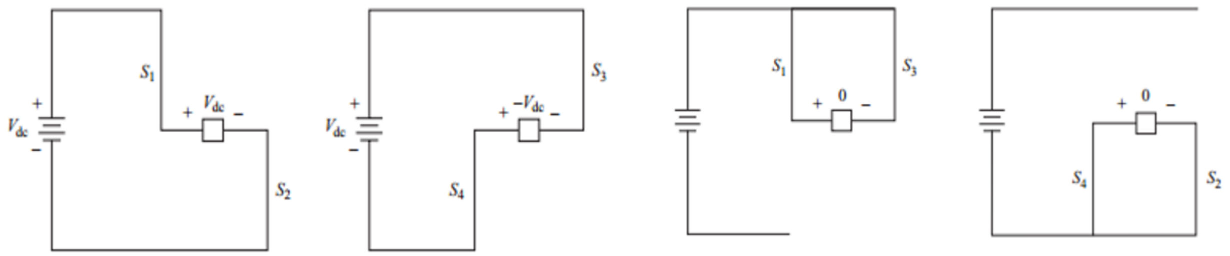
$$V_o = +V_{dc} \qquad \text{for } V_{sin} > V_{tri}$$

$$V_o = -V_{dc} \qquad \text{for } V_{sin} < V_{tri}$$

The full-bridge inverter of Fig 2.3(a) is the basic circuit used to convert DC to AC. In this application, an AC output is synthesized from a DC input by closing and opening the switches in an appropriate sequence. The output voltage Vo can be +Vdc, -Vdc, or zero, depending on which switches are closed. Figure 2.3(b to e) shows the equivalent circuits for switch combinations.



(a)



(b) (c) (d) (e)

Figure 2.3 Full Bridge Inverter and Switches Sequences [10]

(a) Full Bridge Inverter;(b) $S_1$and S_2 closed

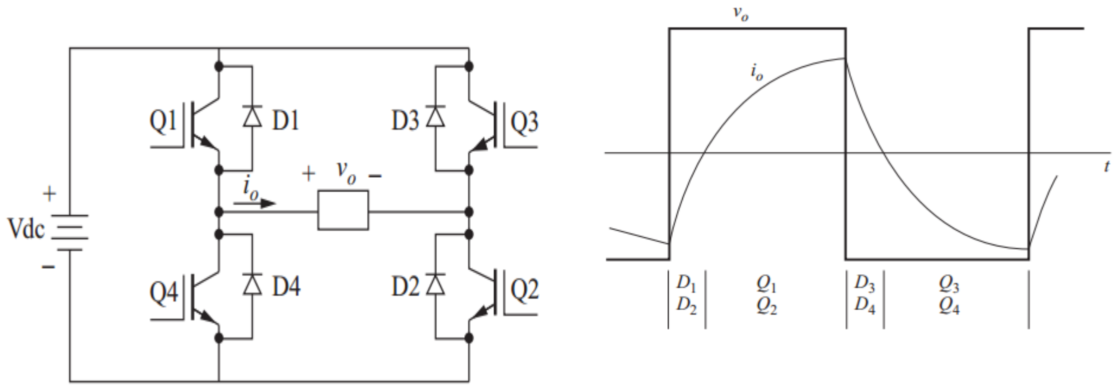
(c) $S_3$and S_4closed;(d) $S_1$and S_3 closed

(e) S_2 and S_4 closed

Table 2.1 Switches Operation

Switches Closed	**Output Voltage (V_0)**
S_1 and S_2	$+V_{dc}$
S_3 and S_4	$-V_{dc}$
S_1 and S_3	0
S_2 and S_4	0

The simplest switching scheme for the full-bridge inverter produces a square wave output voltage. The switches connect the load to $+V_{dc}$ when S_1 and S_2 are closed or to $-V_{dc}$ when S_3 and S_4 are closed. The periodic switching of the load voltage between $+V_{dc}$ and $-V_{dc}$ produces a square wave voltage across the load. Although this alternating output is non-sinusoidal, it may be an adequate AC waveform for some applications. The current waveform in the load depends on the load components. For the resistive load, the current waveform matches the shape of the output voltage. An inductive load will have a current that has more of a sinusoidal quality than the voltage because of the filtering property of the inductance. An inductive load presents some considerations in designing the switches in the full-bridge circuit because the switch currents must be bidirectional.



(a) (b)

Figure 2.4 Full Bridge inverter and Load Current [10]
(a). Full Bridge Inverter using IGBTS,

(b). Steady State current for an RL load

When IGBTs Q1 and Q2 are turned off in Fig. 2.4 (a), the load current must be continuous and will transfer to diodes D3 and D4, making the output voltage $-V_{dc}$, effectively turning on the switch paths 3 and 4 before Q3 and Q4 are turned on. IGBTs Q3 and Q4 must be turned on before the load current decays to zero.

PIC 18F4431 Micro Controller (MC) is used for generation of the PWM, PWM counting and isosceles triangular wave generation, sinusoidal reference wave, has positive and negative peaks both. The SPWM generated at the output of 20 kHz frequency must experience an LC filter attached parallel to the load, that attenuates the PWM and in-turn produces a pure sine wave.[11]

PIC 16F876 MC is used for controlling the switching pattern. To make reduced THD pure sine wave inverter has integrated a boost converter to step up the voltages produced by the Photovoltaic (PV) Panels. A low-frequency transformer has been used for better performances and an extra Aluminum shield has been used above the surface of the transformer to further reduce the eddy currents. In a ratio, MA (amplitude Modulation), between the reference sinusoidal signal and the full triangular wave has been kept around 0.8 to 0.9 for the best design of the filter used.[12]

The function of the PIC microcontroller was used to generate SPWM switching to the gate of the MOSFET to an inverter. Though controlling triggering is a bit complex. Disadvantages include more complex control circuits for the switches and increased losses due to more frequent switching.[13]

The next few pieces of literatures, the inverter is designed without any microcontroller and it has a cost-effective design architecture, designing a push-pull inverter by center tap transformer. Switching pulse generated by NE 555 timer circuit and comparator was used to provide the proper logic level pulse for triggering two MOSFET switches distinctly. The third MOSFET is used to invert the input pulse. Switching and amplifying components to minimize the cost and losses. [14]

Literature review of this paper [15] the developed system used common electronic parts such as operational amplifier (Op-Amp) gate driver DC to AC inverter and power MOSFETS. The MOSFET also use controller by gate driver circuits. The control circuit is composed of a sine wave generator and a triangle wave generator. These are implemented with the comparator and other analog circuitry they control the SPWM signals that two MOSFET drives. The SPWM signals are run into these MOSFET drivers that perform level translation to drive four N-channel MOSFETs in an H-Bridge configuration. The signal is sent through a low-pass LC filter so that the output delivers a pure sine wave.

A lot of work has been done in the field of pure sine wave inverter but to obtain a waveform with a reduced number of harmonics along with high efficiency is still an open challenge. There are techniques available to do so, but the need is to adopt a solution that is easy to implement specifically for low power applications. This thesis has discussed available techniques and tried to come up with a solution for low power applications which is easy to implement, cost-efficient, and reliable from the consumers' perspective.

Filter Circuit

The output of these inverters must be filtered out to reduce the effect of the harmonics on the appliances. Different techniques were studied by some scholars regarding this filtering method. The most common and low-cost method is passive LC filters. It uses an inductor and capacitor to filter out unwanted signals. The proper selection of inductors and capacitors is a great challenge for some designers.[16]

According to Rushija Jawale, "A square wave is rich in harmonics means it contains many sine waves. To separate the sine waves, need to pass the square wave through a low pass filter." [17]

An LC circuit can be used to convert a square wave input to pure sinusoidal output. A simple circuit can be connected as shown below in figure 2.5. In this circuit, working on low frequency such as 50 Hz may use bigger inductance and capacitance.

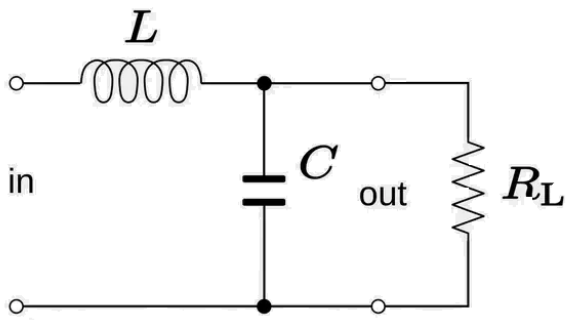


Figure 2.5 LC Filter Circuit [17]

According to Jayakumar of Delphi University, "During the ON or high state of the square wave, the capacitor and inductor begin to charge according to the LC value, if the square wave is at resonance frequency it will go to just about the peak value, now when it is in OFF or low state, the LC circuit begins to discharge to the load resistor until it gets to the value of the lower peak of the square wave. Much in the same way as a rectifier LC filter output, however, here the charging and discharging times are a bit longer." Figure 2-6 shows the improvement of the LC filter circuit which was called the PI LC filter circuit.

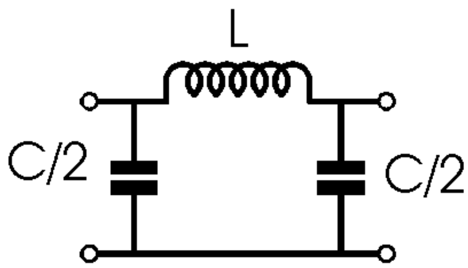


Figure 2.6 PI LC Filter Circuit [18]

According to its Fourier series, a 50% duty-cycle square wave consists of odd order harmonic sine waves with the fundamental at the same frequency as the square wave. A sine wave with the same frequency as the square wave can be gleaned by filtering out the harmonics above the fundamental. [18]

Thus, in this study, the proponent will use LC filters to filter out the harmonics and change the square wave signal to sine wave so that it can effectively use in different loads in rural areas. Likewise, different laboratory tests can be conducted to prove the different theories and techniques in converting square waves to sine waves.

CHAPTER THREE

3. MATERIALS AND METHODS

In this section the methods of conducting and the materials used are presented. This includes the data gathering, designing and development procedure, and the framework of the study.

3.1. Data Gathering

3.1.1. Questionnaire

The researcher have used customized questionnaire (see Appendix) and tools for data gathering from rural households. The type of data needed includes,

- Assessment of the type household appliances
- Assessment of the power rating of each appliance
- Market assessment of the available inverters

3.1.2. Tools

The following mathematical tools were used in analyzing the gathered data:

$$x = \sum_{i=1}^{n} w_i x_i \qquad (3.1)$$

Where:

x = the weighted mean

n = the number of data

w = the data gathered

A weighted average is an average in which each observation in the data set is assigned or multiplied by a weight before summing to a single average value. In this process, each quantity to be averaged is assigned a weight that determines the relative importance of each quantity. Weightings are the equivalent of having that many like items with the same value involved in the average. This equation was used to analyze the loads that frequently used by the rural people. In this equation the load distribution in every household were analyzed.

3.2. Designing and Development

The designing part of the study uses the waterfall process model. Throughout the development and design of the study, the said model was strictly followed. The following processes were shown in figure 3.1.

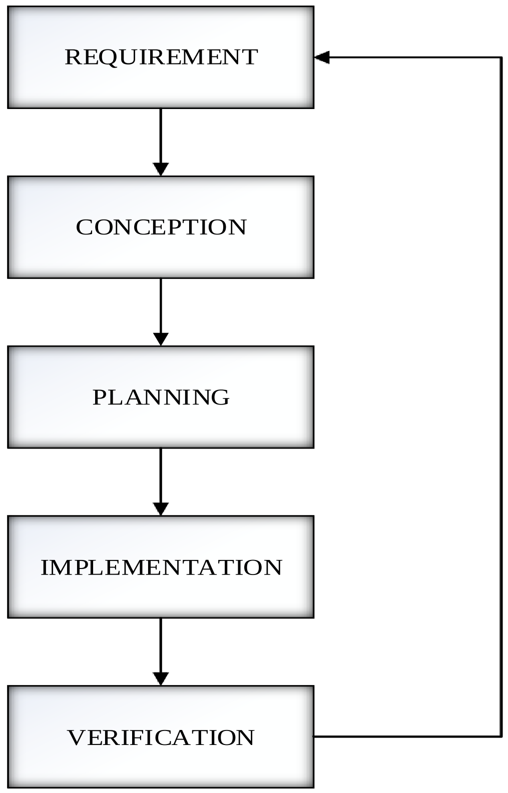


Figure 3.1 Process of Waterfall Methodology

The model shows different process as the study goes on. Using this model, the designing part became easy to conduct. This model shows 5 process that were used during the study.

Requirement stage: Ethiopia uses 220V AC supply system for commercial purpose so to design an effective inverter one must know the type of appliances used by the household and the overall load of the appliances. In addition, the climate condition has a great impact. The researcher will gather such data to decide specifications of the inverter.

Conceptualization/Designing: From the specification gathered after the assessment, the researcher formulates a mathematical model and simulates it on PROTEUS software. The cost analyses of the inverter were also conducted.

Implementation: A prototype will be developed after completing the design. This stage focuses on the hardware development to implement of the design. Every module on the different stages of the inverter was designed and developed based on the requirement.

Verification and Testing: The prototype will be verified from the output with expectation from the designing stage. A series of test were conducted with respect to the requirement specification. Laboratory test were conducted to verify the results of every module in the inverter.

The model follows the verification it was verified with the requirement stage. If during the verification stage does not conform to the requirement, the requirement stage will be reviewed and follow down to the verification stage. This flow will continue until the verification stage will conform to the requirements.

3.3. The System Block Diagram

The simplified diagram of the study is shown in figure 3.3. This block diagram was used to develop the pure sine wave inverter.

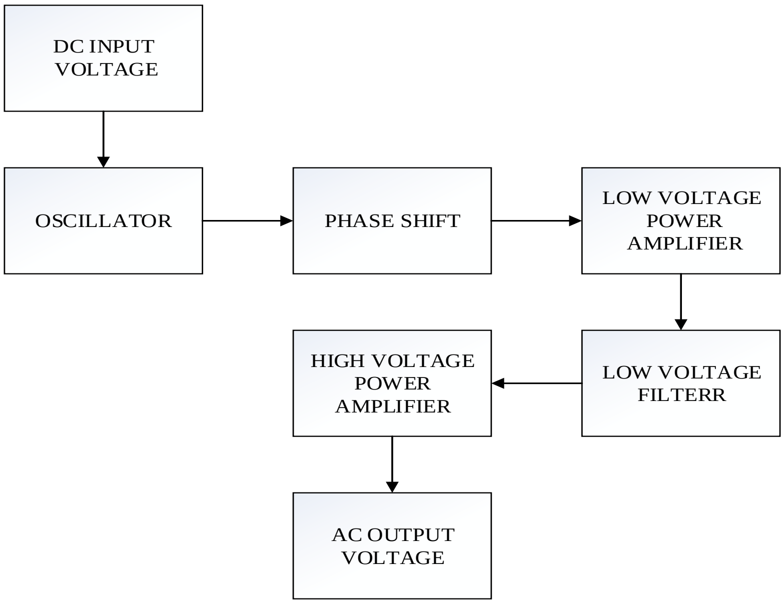


Figure 3.2 Simplified Inverter Block Diagram

The DC input voltage was used to generate a pulse using the oscillator. This oscillator was designed to generate a 50Hz frequency. Three different design models were developed in this oscillator. Then the outputs of this oscillator were sent to the phase shift module to split the generated square wave from the oscillator. Since the amplifier uses a full wave amplifier, the phase shift module was used to split up the signal into two to drive the amplifier. In this case push-pull amplifiers were used in the study. After passing the low voltage amplifier, the output of were filtered out by the low pass LC circuit. This was used to minimize the harmonics and convert the square wave signal to sine wave signal. The design of this filter circuit was simulated in the circuit lab software. The output of sine wave was 12V AC since the oscillator generates a 12V magnitude. In order that this output sine wave can be used by the appliances which were 220V AC, a high voltage amplifier was used to increase to 220V. There were different methods were tested in the high voltages power amplifier module. But the basis in the selection of this amplifier was the efficiency and the cost of development.

3.4. Materials and Equipment

Oscilloscope: This laboratory instrument was used to verify the output wave form on every stages of the power inverter. This was used also the check the correct frequency and wave shape of each stage of the inverter. By using this instrument, the design of the different module makes it easier.

Multi-meter: This instrument was used to check and test the output voltages and current of every module in the inverter. This was used also to test the different electronic component used in the design.

Computer: This equipment was used to design the system using software. PROTEUS were installed in this equipment.

Soldering Station: This equipment was used to solder the circuit connectivity on every module in the inverter. The temperature was controlled by this instrument. This was used to avoid over heating with the electronic component.

The specifications of other consumable components used in the study such as resistors, capacitors, IC, transistors, MOSFET, inductors, and transformers were identified during the designing part of the study.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

The results of the study were discussed in this section. All the HH survey results, laboratory test, simulation, design of the circuit module, and the development of the sine wave power inverters were presented in this section.

4.1. Assessment on the common loads in rural areas

The survey questionnaire was gathered from the rural Kilinto and Arobecha Kebeles near Adama and Bishoftu Towns, respectively. A total of 50 households; 25 from each kebele have been reached by the questionnaire survey. The objective of the survey was to understand what a typical household in the area use for energy and it was found out that they use electric power only for lighting, mobile phone charging, radio, and television. They use biomass energy sources for cooking which consumes lots of time and energy for rural women and it also wastes energy and pollute the environment impacting health and contributing to global warming.

It was found out that almost all 49 out of 50 households living in the area use either torch (39HH) or LED bulb (10HH) between 5 and 9 watts. It was able to understand that this wattage does not provide enough light for a room. Other than lighting loads, 84% of the households have mobile phone; 32% have small portable radio and only 4 households have television. The survey also found out that there are HHs that have solar panels.

Based on the gathered data, it was found out that the power consumption of mobile phone charger depends on the type of the phone. Figure 4.1 shows a phone charger used for charging multifunctional (touch screen) mobile phones. The power was measured using a power meter. The power consumption using this type of charger reaches up 7 watts and 10 watts when the phone was completely discharge.

Figure 4.1 Power Reading for Samsung Charger

Another type of mobile phone charger was shown in figure 4.2. This type of mobile phone charger was used for small mobile phone. Based on the reading from the power meter this type of charger has lower power consumption compared to multifunctional mobile phone charger. The survey from both kebeles show that 46 of the 50 HH have small mobile phone and use this kind of charger.

Figure 4.2 Power Reading of Small Mobile Charger

Based on the findings, the researcher has come to the conclusion that the load required for each of the appliances that is most required and appropriate for household is summarized in the table below.

Table 4.1 Summary of Loads Required for Different Appliances

Type of appliance	Load required	Minimum appliance required by a HH	Total load required (watt)
Light bulb	5 Watt	4	20
Small mobile phone charger	2.9 Watt	1	2.9
Radio	3 Watt	1	3
Television	20 Watt	0	0
TOTAL			25.9

The study shows the total power consumption based on their loads the maximum power consumption is 32.9 Watt from Kilinto Kebele. In addition, Kilinto Kebele dwellers consume more power than that of Arobecha. The table below shows summary of collected data for different type of loads in Kilinto and Arobecha Kebele.

Table 4.2 HH power usage with respective appliances

Kilinto Kebele						Arobecha Kebele					
HH	**No. of Light Bulbs**	**No of Mobile Phones**	**No. of Radio**	**No of TV**	**Total in Watt**	**HH**	**No of Light Bulbs**	**No of Mobile Phones**	**No of Radio**	**No of TV**	**Total in Watt**
1	2	1	0	1	**32.9**	1	1	1	1	0	10.9
2	1	2	0	0	10.8	2	1	1	1	0	10.9
3	1	1	0	0	7.9	3	1	0	0	0	5
4	1	1	0	0	7.9	4	1	2	2	0	**16.8**
5	1	1	0	0	7.9	5	1	1	1	0	10.9
6	1	1	0	0	7.9	6	2	0	0	0	10
7	1	1	0	1	27.9	7	1	0	0	0	5
8	1	1	0	1	27.9	8	1	1	0	0	7.9
9	1	1	0	1	27.9	9	1	1	0	0	7.9
10	1	1	0	0	7.9	10	1	0	0	0	5
11	0	1	0	0	2.9	11	1	0	1	0	8
12	1	2	0	0	10.8	12	1	1	1	0	10.9
13	1	1	0	0	7.9	13	1	0	0	0	5
14	0	0	1	0	3	14	1	1	1	0	10.9
15	0	1	0	0	2.9	15	1	0	0	0	5
16	1	1	0	0	7.9	16	1	1	0	0	7.9
17	1	2	1	0	13.8	17	1	1	1	0	10.9
18	1	1	0	0	7.9	18	1	1	1	0	10.9
19	1	0	0	0	5	19	1	1	0	0	7.9
20	1	0	0	0	5	20	1	2	0	0	10.8
21	1	0	0	0	5	21	1	0	1	0	8
22	1	0	0	0	5	22	1	0	1	0	8
23	1	1	0	0	7.9	23	1	2	1	0	13.8
24	1	0	0	0	5	24	1	0	0	0	5
25	1	2	1	0	13.8	25	1	2	0	0	10.8

It was also found out that for LED bulb that were using between 3 watts to 7 watts but majority of them use 5 watts. In Arobecha kebele, the maximum power load consumption was 16.8 watts and most of the people in this area uses LED bulb and none of them have TV. Some people in this area have solar charger for their phone while others go to other places to charge their phones and battery for their torch light.

Based on the finding in table 4.1, the maximum power demand by a household without any other additional electronic devices is 25.9 watt. This is a very least one that can survive while meeting the HH basic need.5W, 4 LED bulbs for efficient light for one room; one small mobile phone charger and one small radio for information.

Table 4.3 Cost Efficiency Comparison in Birr

NO	**LED BULB**	**12V DC**		**220v AC**	
		ILLUMINATION	**COST in ETB**	**ILLUMINATION**	**COST in ETB**
1	9 watt	22 lux	150.00	22 lux	35.00
2	5 watt	18 lux	110.00	18 lux	25.00

Table 4.3 shows the comparison of the illumination and cost of 12V DC and 220V AC LED bulb. The illumination was measured using Lux meter and the cost was based on the local market in Adama City.

It was found out that there is a cost difference for the same wattage. DC LED bulb is more expensive as compared with the 220V AC LED bulb. It was found out that using DC LED bulb gives the same illumination with the AC LED bulb. By these results, the rural people can identify which type of LED bulb they can use in their houses.

Knowing the cost difference and the illumination of both DC and AC LED was not the ultimate basis for choosing which type of LED bulb they can use.

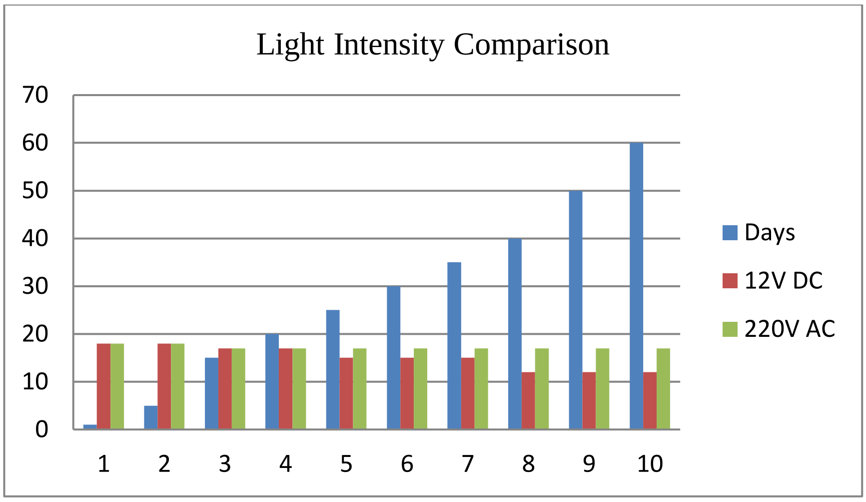


Figure 4.3 Comparison between 12V DC and 220V AC LED Bulb

A test was conducted between AC LED bulb and DC LED bulb. Both LED bulbs were connected to a power source using the 12V DC battery with a charger and the 220V AC grid line. The test lasted for 60 days continuous operation. The result was shown in figure 4.3 which shows the comparison between 12V DC and 220V AC. The test was conducted to find out the light intensity in lux for 60 days for continuous operation. The chart reveals that for continuous operation the 12V DC LED bulb illumination decreases more gradually as compared with the 220V AC LED bulb. This further shows that the efficiency of AC LED bulb in terms of its illumination was higher as compared with the DC LED bulb. On testing of the two bulbs, it was observed that there are so many factors that decrease the brightness of the light like DC lamp is very hot which attract small insects which then dies inside the bulb and cover the lamps.

4.2. Design and simulation

The power inverter design was divided into 4 different parts as follows.

4.2.1. Oscillator

The pulse generation was made by the oscillator circuit. The heart of the inverter circuit was the pulse generation module. Designing a good oscillator makes the entire circuit design easier and less expensive. There are different circuit models to generate a pulse signal. In this study, 3 different oscillator circuit models were presented. Each of this design models were compared to each other based on the cost and efficiency. The entire oscillator circuit generates a clock frequency based on the type of the design for the inverter with an amplitude of 12 V. The designs of the clock generator were tested using CD4047, Two Transistor and Microcontroller.

4.2.1.1. CD4047 IC

The first model was developed using CD4047 IC as clock generator circuit that is shown in figure 4.4. The oscillator circuit which generates square wave signal consists of two outputs shifted to each other at pin10 and pin11

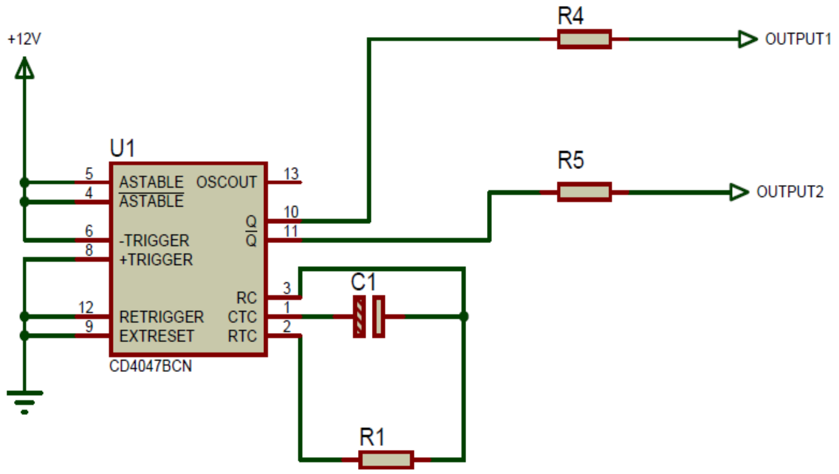


Figure 4.4 Using CD4047 IC

This square wave output frequency was being controlled by the RC circuits as shown in figure above with R_1, and C_1. The calculation design for this circuit is shown below. The frequency of the signal from those pins is given by (4.1),

$$f = \frac{1}{8.8RC} \qquad (4.1)$$

where

R is the value of the resistor and

C is the value of the capacitor.

f is the frequency requirement

The value of frequency using CD4047 IC was 50 Hz. Applying the equation, the resistor value was calculated as shown below.

$$R = \frac{1}{8.8 * f * C}$$

The capacitor value selected based on the requirement of the circuit specification and availability in the market.

C = 3.3μF,

f = 50 Hz

$$R = \frac{1}{8.8 * f * C}$$

$$R = \frac{1}{8.8 * 50 * 3.3 * 10^{-6}} = 688.7 ohm$$

But the standard resistor near to this value is 680 ohms. In real practical works, this value slightly differs because of different reason like tolerance of the component. It is expected that, the system should meet the required 50% duty cycle. For this reason, a CD4047 IC at a 50% duty cycle to operate at stable output point cannot change. This is one of the drawbacks of this IC. However, it is found to be convenient for this system.

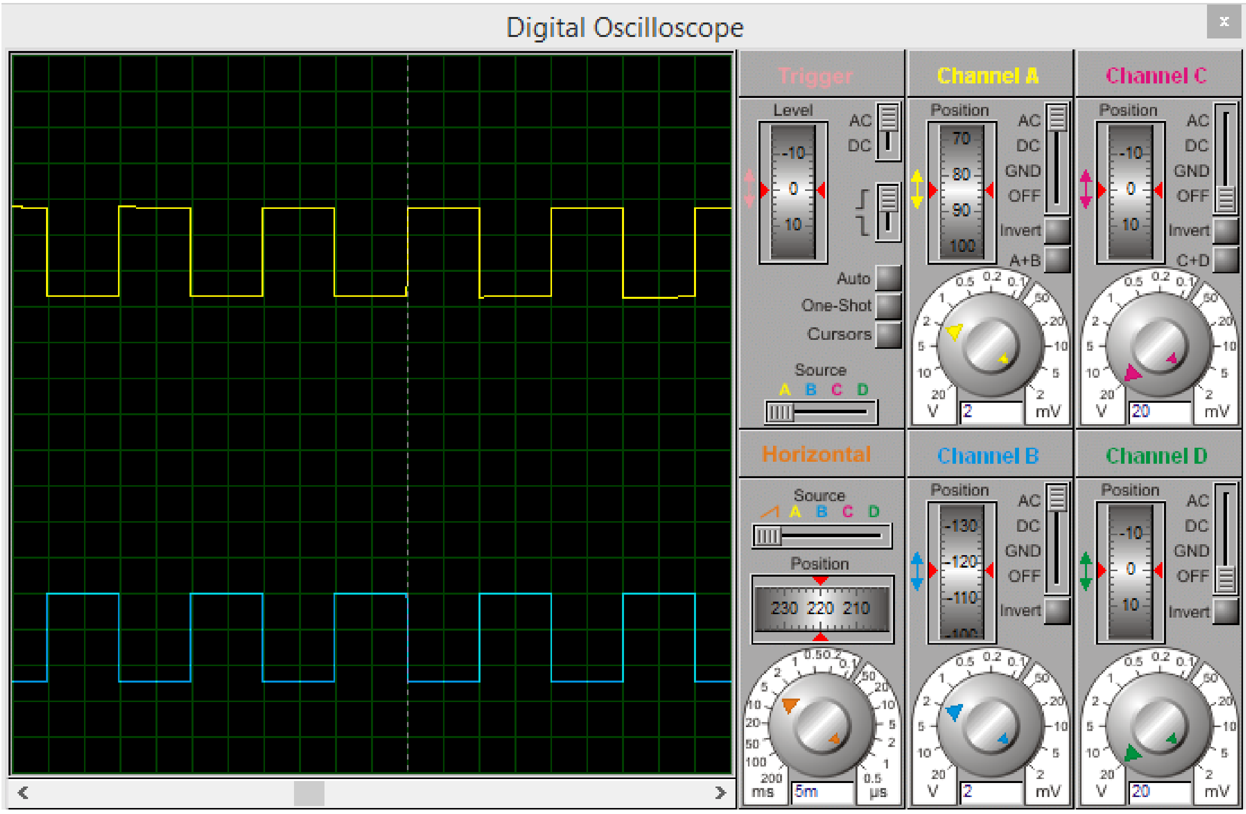


Figure 4.5 Wave Form Output

Figure 4.5 shows the output wave form of the oscillator circuit using CD4047 IC. Based on results shown in the above figure, the duty cycle was found to equals to 50%. This type of wave shape was acceptable for driving the transformer with MOSFET driver circuit.

4.2.1.2. Transistor based

The oscillator circuit that uses two transistors to generate a clock pulses for the power inverter. The two transistors switch alternately to generate the pulses needed. The frequencies of the generated pulses were based on the resistances and capacitances connected in RC circuit as shown in figure 4.6.

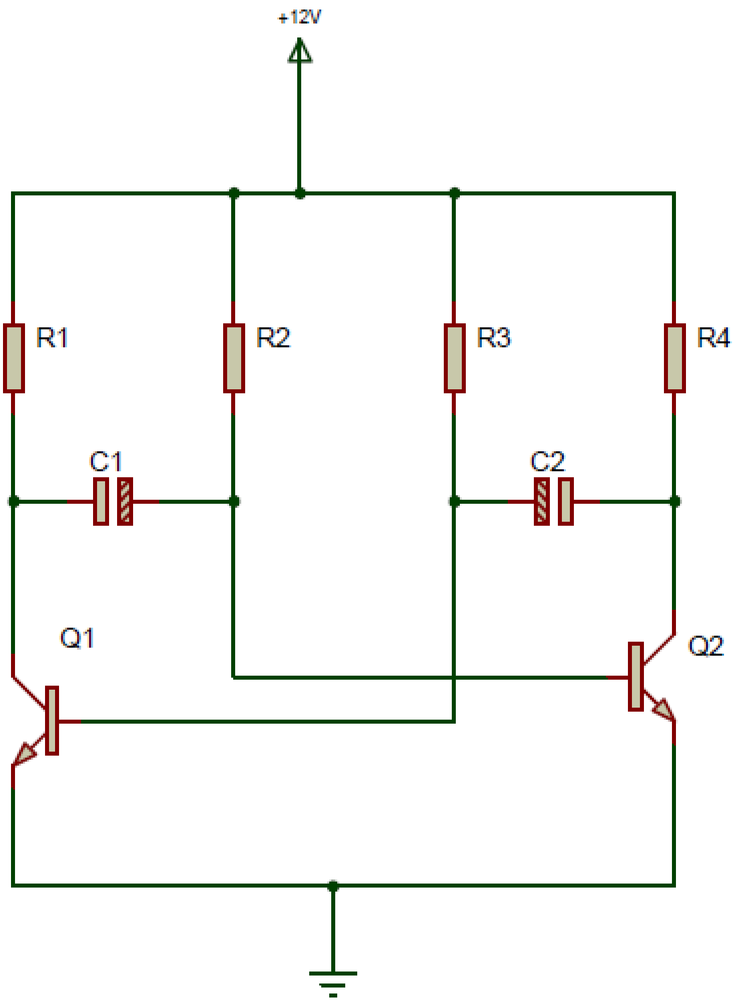


Figure 4.6 A stable Multi-vibrator using Two-Transistor

Two transistors named as Q_1 and Q_2 are connected in feedback to one another. The collector of transistor Q_1 is connected to the base of transistor Q_2 through the capacitor C_1 and vice versa. The emitters of both the transistors are connected to the ground. The collector load resistors R_1 and R_4 are of equal values and the biasing resistors, R_2 and R_3 are of equal values. The capacitors C_1 and C_2 are of equal values.

The frequency for this circuit was calculated based on the standard equation of RC circuit.

$$f = \frac{1}{T} \tag{4.2}$$

Where:

T = the period in seconds

f = the frequency in hertz

The ON time of transistor Q_1 or the OFF time of transistor Q_2 is given by

$$t_1 = 0.693 R_2 C_1 \tag{4.3}$$

Similarly, the OFF time of transistor Q1 or ON time of transistor Q2 is given by

$$t_2 = 0.693 R_3 C_2 \tag{4.4}$$

Hence, total period of square wave

$$T = t_1 + t_2 = 0.693(R_2 C_1 + R_3 C_2) \tag{4.5}$$

As $R_2 = R_3 = R$ and $C_1 = C_2 = C$, the frequency of square wave will be

$$f = \frac{1}{T} = \frac{1}{1.38RC} = 0.7RC$$

The required frequency for this circuit was known to be 50 Hz, since the circuit directly drives the transformer with center tap winding.

Using the above equations, the values of resistor and capacitor were calculated as follows:

Select the capacitor value $C = 470nF$, and $f = 50Hz$

$$R = \frac{1}{1.38 * f * C} = \frac{1}{1.38 * 50 * 470 * 10^{-9}} = 30.8K\Omega$$

Since the value of this resistor does not exist in the standard resistor table of the data sheet and in practical work is not exactly equals with that of the calculated value. Thus, a Resistor with the value of $33K\Omega$ is used.

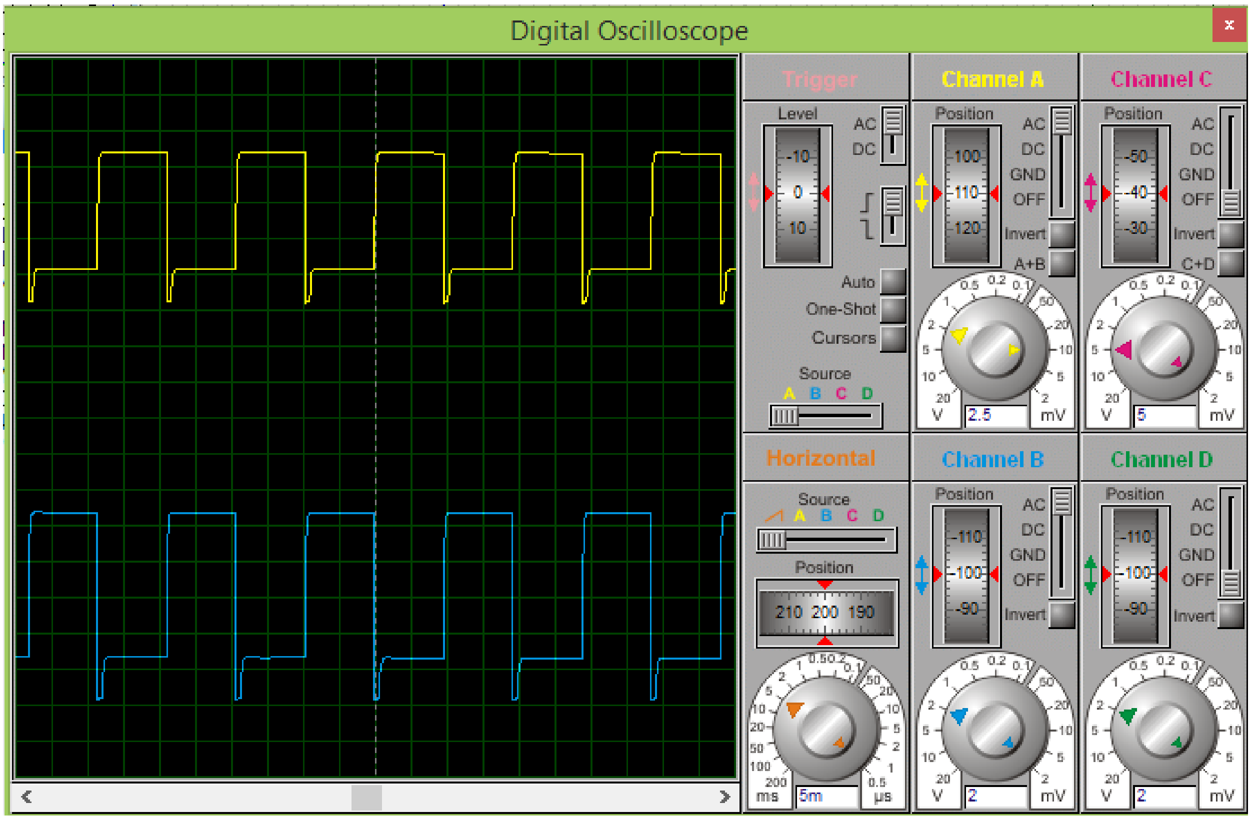


Figure 4.7 Wave Output Using Two Transistor

Figure 4.7 shows the wave shape output of the pulse generated using the two-transistor circuit. Based on the result, the shape was not perfect square wave as compared with the CD4047 IC circuit. Based on this type of wave form, harmonics were very high as shown in this waveform.

4.2.1.3. Microcontroller based

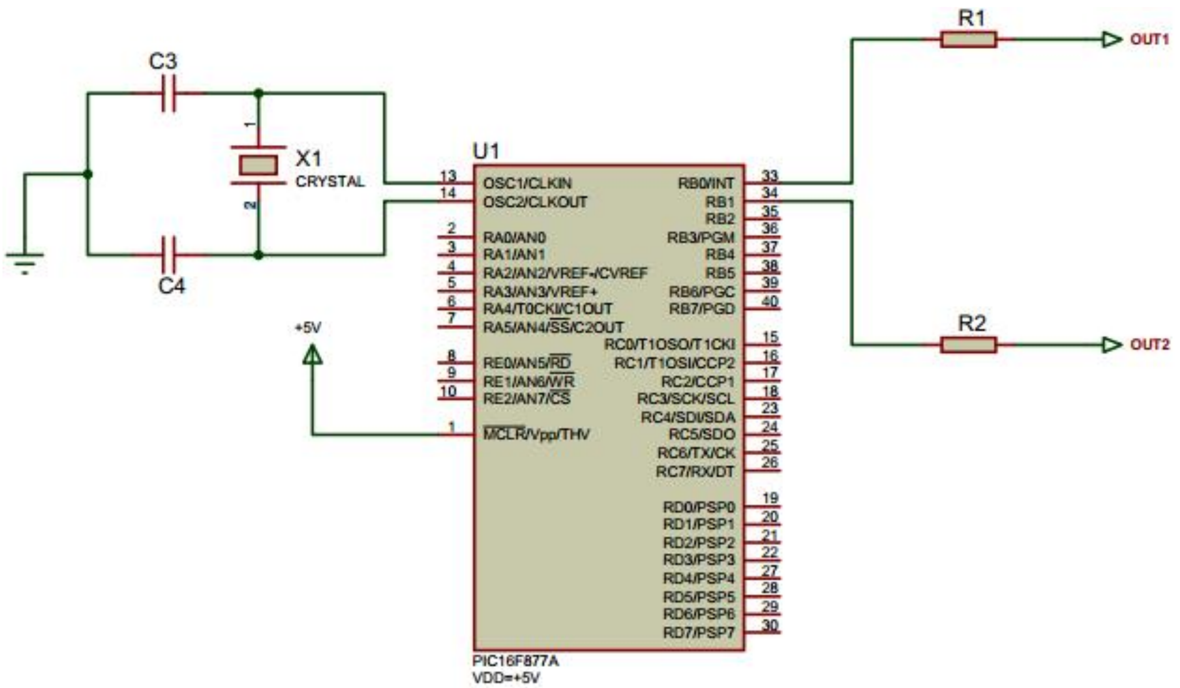


Figure 4.8 Microcontroller Based Clock Generator

Pulse Width Modulation (PWM) is a technique in which the width of a pulse is modulated keeping the period of the wave constant. The ON and OFF time can have any different values in the wave cycles, but the sum of the ON and OFF time remains same for the entire cycles. PWM is a digital wave that can be generated using digital circuits which are not capable of generating analog voltages. With the help of the modulation of the width of a pulse in a period of the wave, they can generate any required voltage with the help of a proper filter circuits. The filter circuits are used for generating the voltage corresponding to a modulated wave. Hence the PWM wave is always associated with a filter circuit.

As it was observed at figure 4.7, resistances and capacitances of RC circuit vary based on its tolerances. For this reason, the wave form that were generated using RC circuits was not perfectly square wave. To correct this, microcontroller-based circuit was also designed for oscillator circuit to drive the transformer.

Figure 4.8 shows the microcontroller-based clock generator circuit for the inverter. The circuit contains two outputs shifted to each other for driving the transistor circuit for the transformer.

R_1 and R_2 base current limiting resistors for TIP 31 transistor, in safe mode used the transistor as switch R1 and R2 equal to 1k.

4.2.2. Filters

The simplest way to convert the square wave signal to sine wave signal was to use a low pass filter. There were different studies conducted using this technique to convert square wave to sine wave. In this study of designing a sine wave inverter, this method was also adopted and modified based on the demand of the rural community.

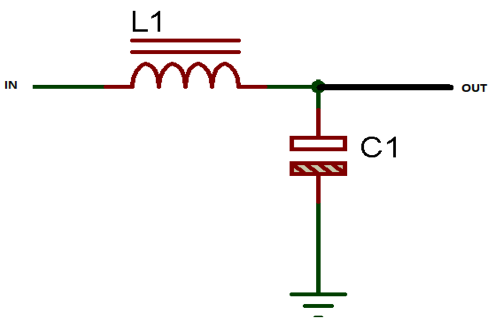


Figure 4.9 Low Pass Filter

The figure above shows the basic low pass filter that was used in the study.

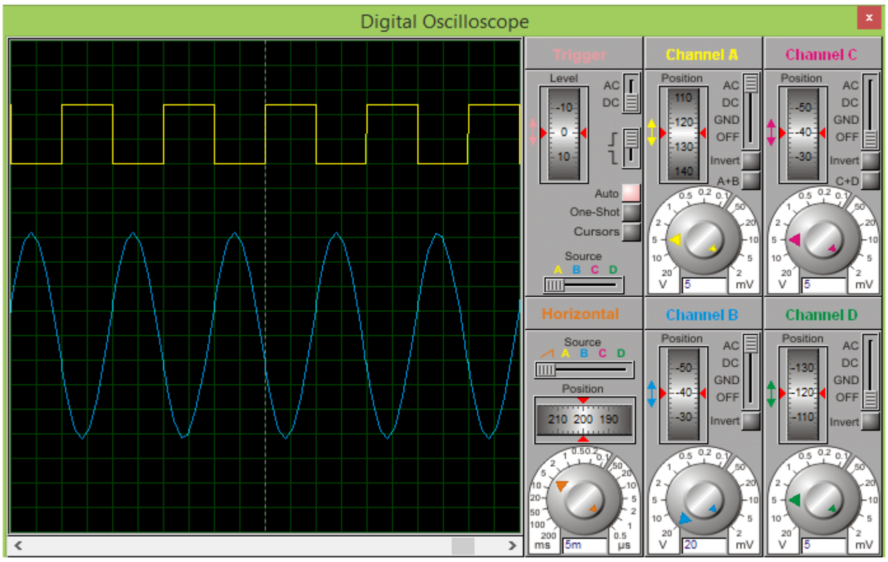


Figure 4.10 Simulation Results of Low Pass Filter Circuit

According to Charles Dawes from his book, The Electrical Engineering, a pure LC circuit has an oscillatory response, and this is due to the energy transfer that occurs between the inductor and capacitor. During one period of energy, inductor discharges energy and capacitor stores energy and the reverse occurs during the next period. This causes a sinusoidal current to be developed in the LC circuit. From the LC circuit which was shown in this study, the value of inductance and capacitance affects the sinusoidal output of the circuit.

The resonance frequency was calculated to be equal with the oscillator frequency to come up with the pure sine wave output.

$$f_c = \frac{1}{2\Pi\sqrt{LC}} \tag{4.6}$$

Where: $f_c =$ resonance frequency

$L =$ inductance

$C =$ capacitance

From this equation, the inductance was assumed to be 100mH since it can be easily being generated by winding an inductor.

Thus

$$C = \frac{1}{4\Pi^2 f^2 L} = \frac{1}{4 * \Pi^2 * (50)^2 \times 0.1} = 101.32uF$$

Standard capacitor value is 100uF since the design uses $50Hz$ frequency since a center tap transformer was used. Using this frequency, the value of capacitance in the circuit was calculated to be equals 100uF. However, a capacitor with this value is for 100 mH is not available in the market. Therefore, the researcher was able to handmade a 100mH inductor for the prototype. But it was resulted with around 3V drop on filter circuit. This is because of the high resistance of the coil. It is known that; an inductor design is highly dependent on the permeability of the coil. Thus, the researcher could not find the right core for spinning the wire.

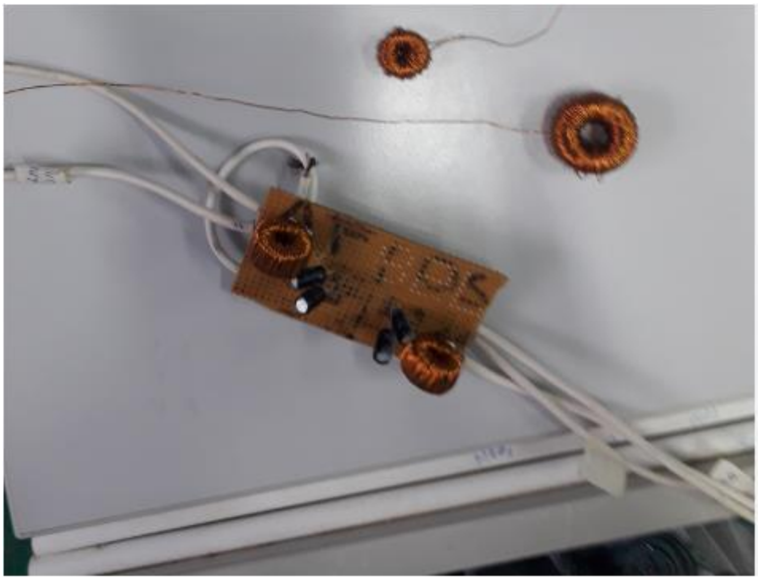


Figure 4.11 Hand made inductor

In addition to this, the filter circuit is affected by transformer coil as shown in the equivalent circuit shown below.

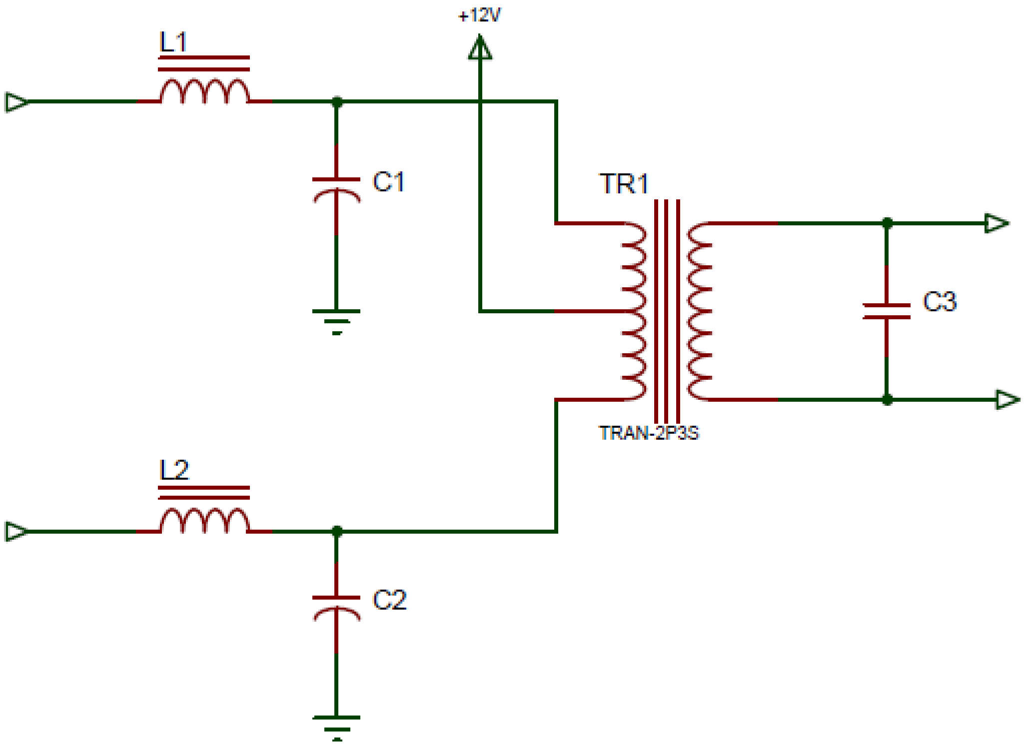


Figure 4.12 Equivalent circuit

4.2.3. Transformer

According to William Stanley, a USA scientist who uses the first transformer in 1830, it is defined that a Transformer can be used to increase and decrease the level of voltages or currents in the reverse order. In this study, the output of the oscillator was about 12 volts. This voltage was insufficient to drive AC loads in rural areas. The 220V AC was standardized by any AC appliances not only in rural areas. Throughout the country, particularly in rural areas where this study was conducted uses 220V AC. For this reason, the transformer was used to step up the voltage to 220 volts.

The transformer used in this study was commonly available in the market. It uses a two-winding transformer on the secondary side. The secondary side of this transformer has 12-0-12 output. The primary side has 220 volts. The connection and configuration of the transformer was shown in figure 4.13.

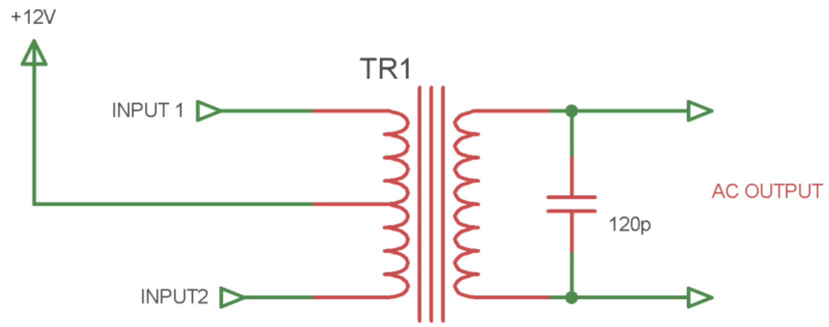


Figure 4.13 Transformer Circuit

The figure shows that the input secondary windings were driven by the oscillator and driver circuits. Then the output of the inverter was taken from primary side of the transformer. The transformer rating was chosen to cater a 100 watts load in this study. But what is available in the market is a 24W transformer which is not even new.

4.3. Development of prototype hardware

After designing and simulating the three different models of inverter circuits, the prototype was developed.

Based on the generation of oscillators; three different models were developed and tested in this study. The three models of an inverter developed are using CD4047 Inverter; Circuit Two Transistor Inverter Circuit and Microcontroller Inverter Circuit.

4.3.1. Using CD4047 Inverter Circuit

Using CD4047 IC inverter circuit generated two square wave signals inverted each other.

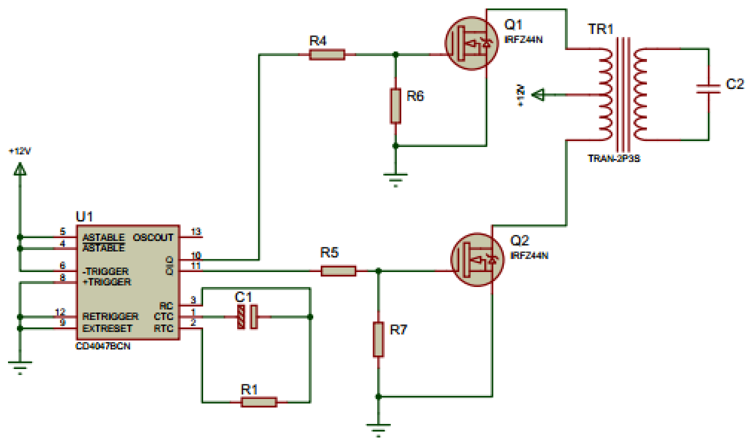


Figure 4.14 Schematic Diagram of CD4047 IC Inverter

Those signals drive two MOSFETs, Q_1 and Q_2 gates simultaneously through current limiting resistors, R_4 and R_5, other resistors R_6 and R_7 pull down resistors. MOSFET switching from coming control signal this action chopped +12V DC center tapped transformer in push-pull mode. The output of the transformer step-up 220V AC voltage.

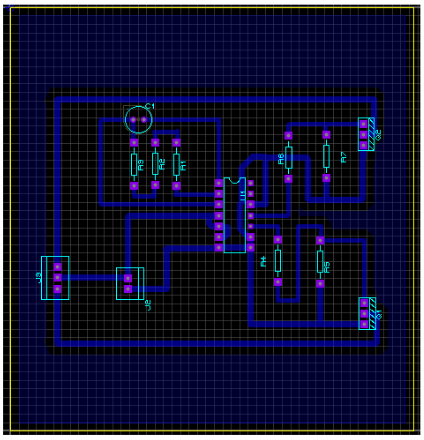


Figure 4.15 PCB Layout Design of CD4047 Inverter

Figure 4.14 shows the PCB layout of the CD4047 inverter circuit. This was design using PROTEUS software. This PCB was used for the connection of the CD4047 inverter circuit to the transformer circuit. The J1 in the layout was used for the connection of power source coming from the 12V battery. The J2 was the output of the oscillator circuit going to the filter and transformer circuit driver.

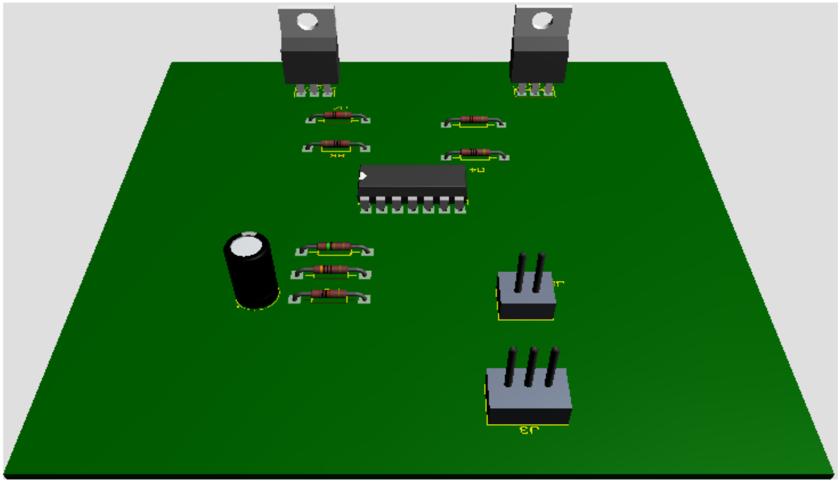


Figure 4.16 3D View of the Prototype CD4047 Inverter

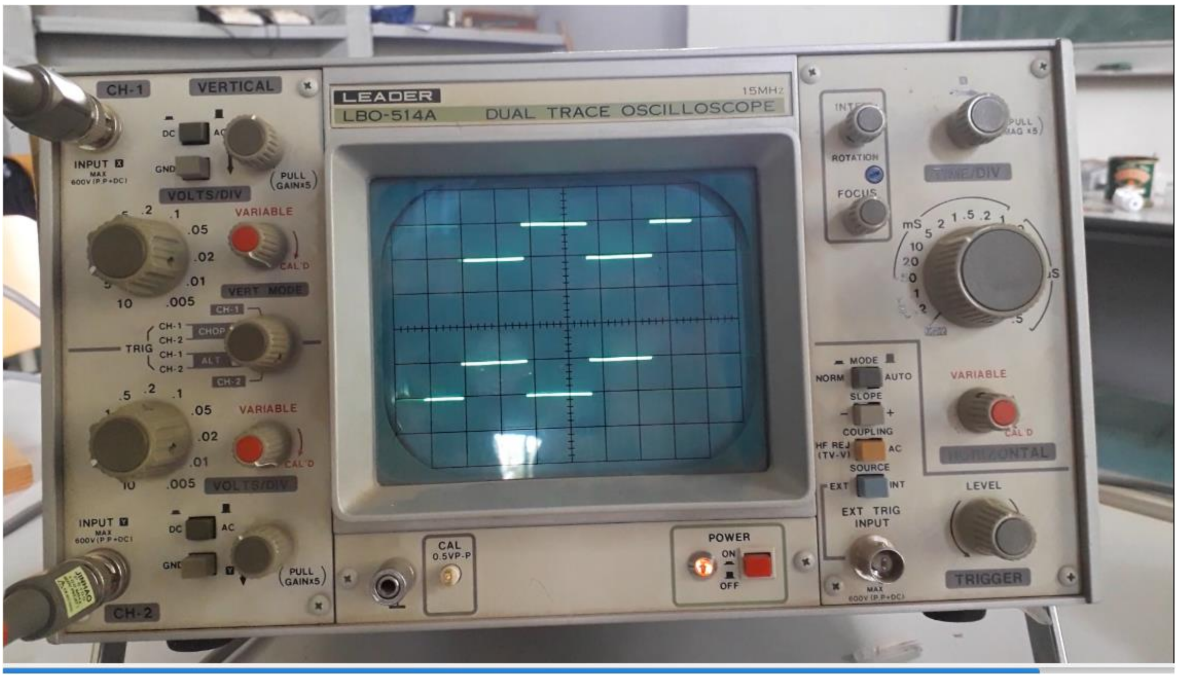


Figure 4.17 Prototype CD4047 trigger output wave shape

4.3.2. Using Two – Transistor Circuit Inverter

The second model that was developed in this study was the two-transistor inverter. The transistors were connected to form a push and pull amplifier. Each of this transistor were switching ON and OFF at a time. When the Q1 was “ON” the other transistor which was Q2 was “OFF”. The transitions from “ON” state to “OFF” state was made by the RC circuit connected to the base of each transistor. After generating two square wave reciprocal each other at collector Q1 and Q2, the circuit like CD4047 inverter.

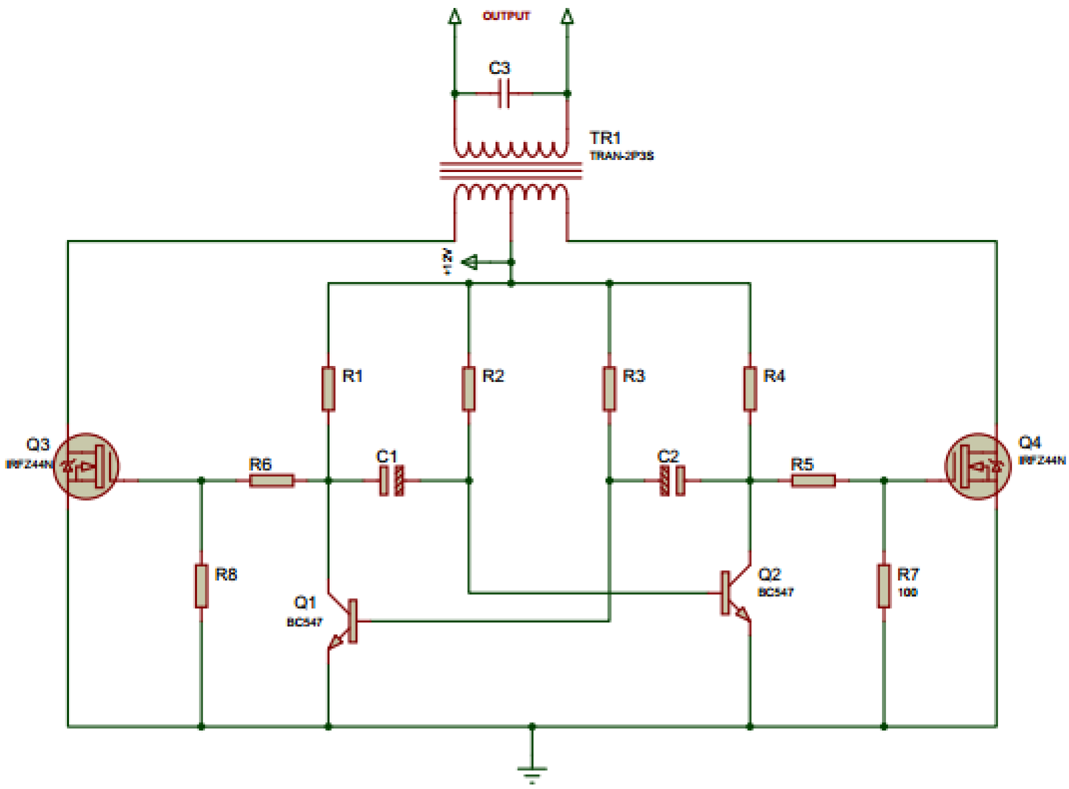


Figure 4.18 Schematic Diagram of Two Transistor Inverter

The PCB layout design of two transistor inverter is shown below. The J1 in the layout was the connection of the center tapped transformer and J2 connection of 12V source voltage coming from the battery.

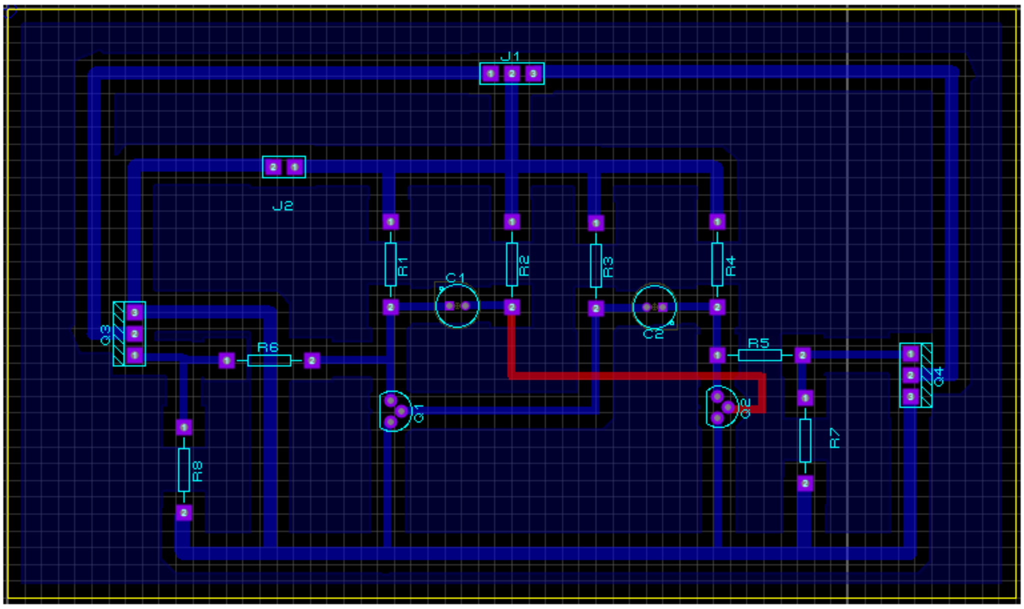


Figure 4.19 PCB Layout Design of Two Transistor Inverter

Figure 4.18 shows the 3D view of the two-transistor inverter. In this view the placement of the parts was viewed as in actual view. Through these views, it was easy to implement the actual development of the inverter. If the placement of the components were confusing, it can easily be determining in 3D views of the model.

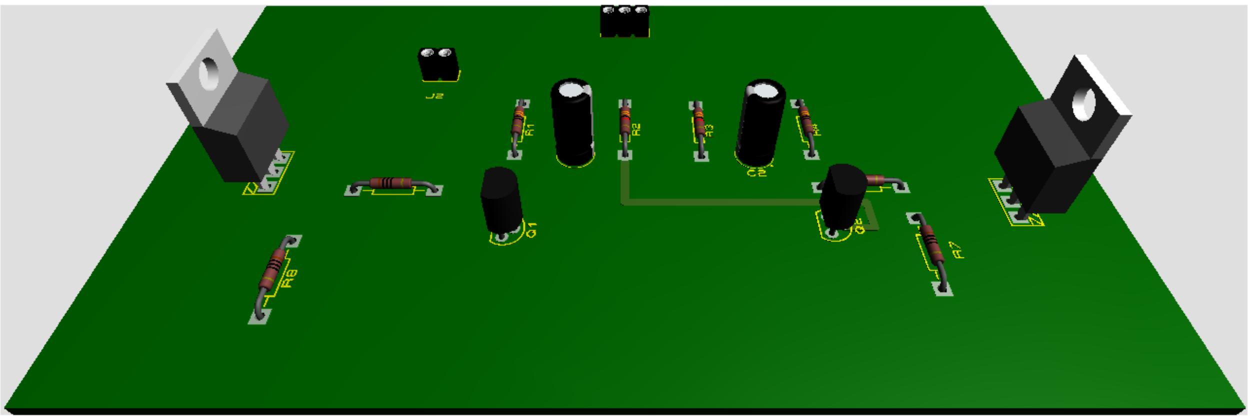


Figure 4.20 3D View of the Prototype Two Transistor Inverter

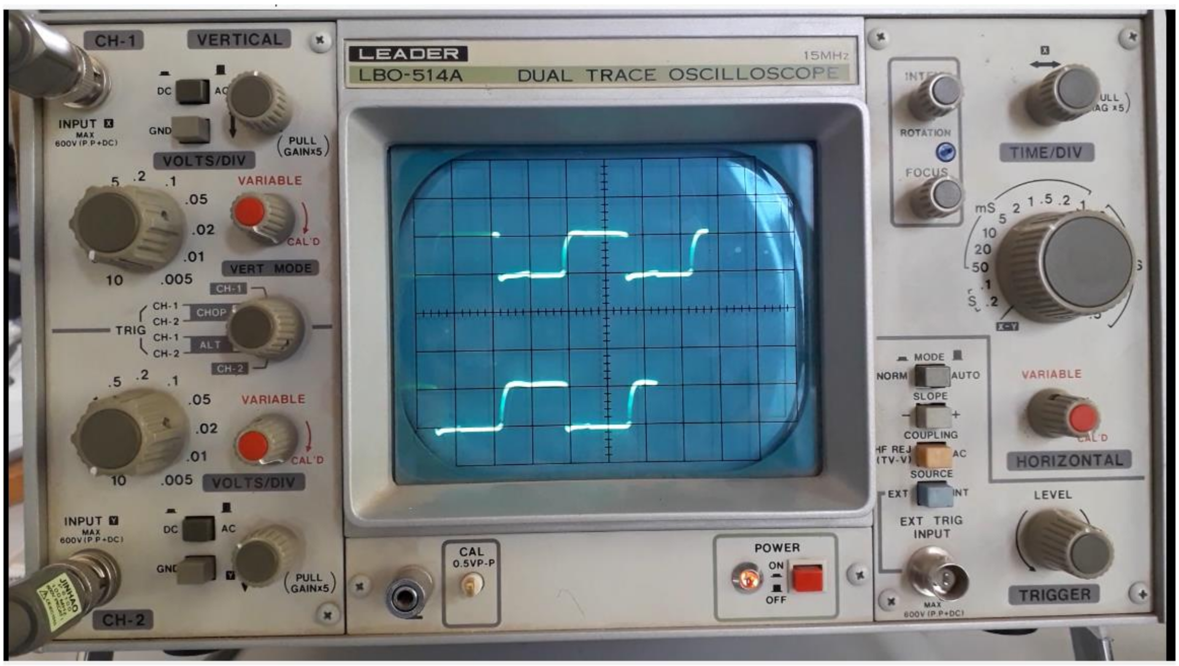


Figure 4.21 Prototype Transistor Based Inverter Trigger Output Wave Shape

4.3.3. Using microcontroller Circuit Inverter

The third model was using microcontroller as clock generator. The circuit diagram was shown in figure 4.20. The microcontroller was powered with 5V DC supply. Since the power supply used in the system was 12V DC, the LM7805 regulator was used to give a source voltage of 5V to the microcontroller. Although this LM7805 voltage regulator can be replaced with a DC-DC buck converter, but based on the experiment, the LM7805 was very easy and less expensive than the DC-DC buck converter. The transistors Q1 and Q2 were used to drive the power MOSFET Q3 and Q4. And the collector side of the MOSFET Q3 and Q4 will be transformer circuit.

The program instruction for the microcontroller was written in C language and converted into a machine language file to be loaded to the micro controller. And to execute the program inside the microcontroller, the microcontroller needs a clock frequency. This clock frequency for the microcontroller was used for its operation only of the microcontroller and not to the clock that was required in the inverter circuit. This microcontroller clock frequency ranges from 4 to 32 MHz. In this study a 4 MHz crystal oscillator was used as clock of the microcontroller.

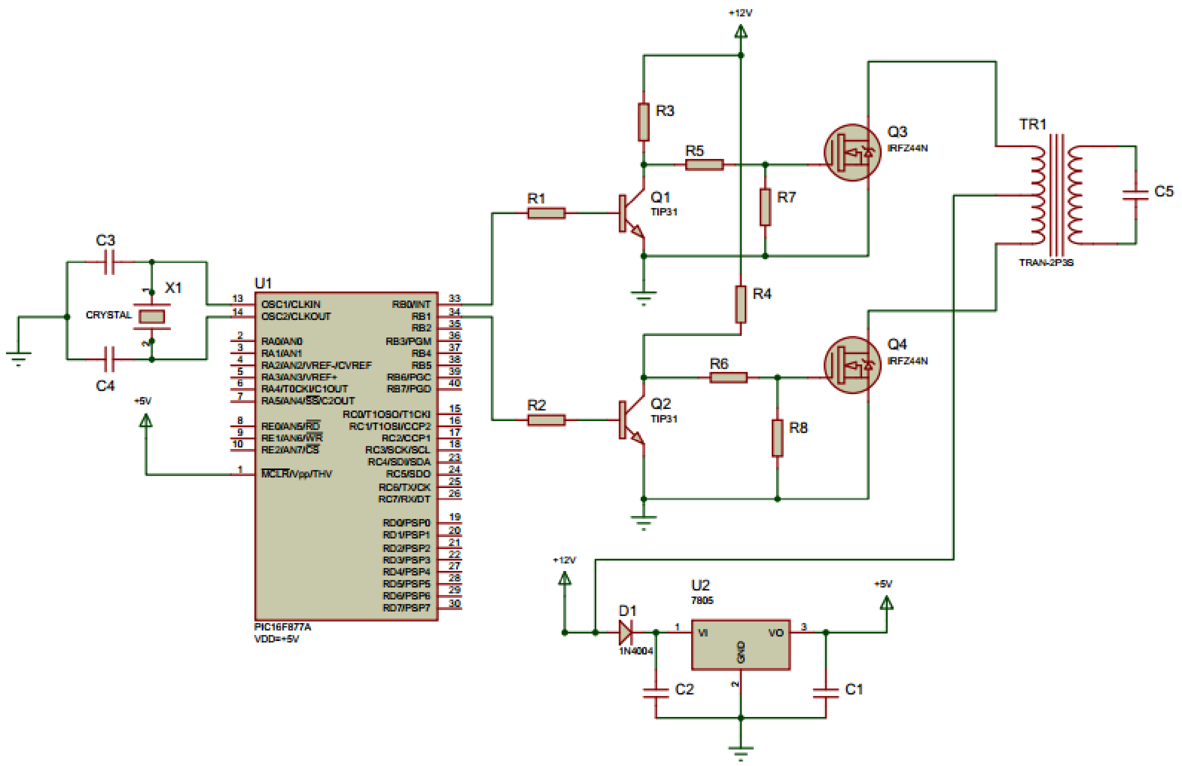


Figure 4.22 Schematic Diagram of Microcontroller Inverter

To come up a perfect 50 percent duty cycle, the "T_{ON}" and "T_{OFF}" in figure 4.20 should be equal. Since the required output frequency in the oscillator circuit was 50 Hz, from the equation

$$T = \frac{1}{f} = \frac{1}{50} = 0.02\sec = 20ms$$

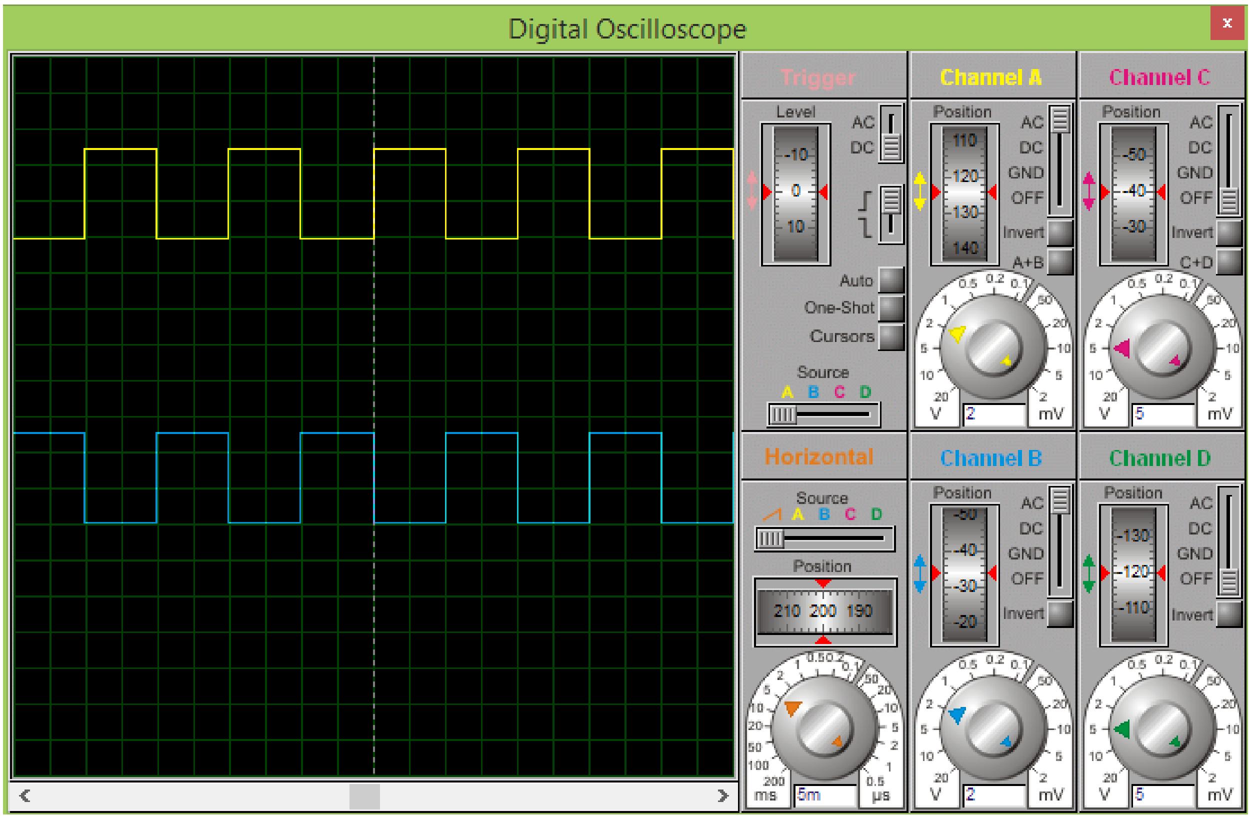


Figure 4.23 Pulse generation from Microcontroller

Thus, the program used was 20ms delay for turning 'ON' and 'OFF' of the output voltage. Through this method the design of a perfect 50% $Duty\_Cycle$ was generated for the inverter.

Figure 4.22 shows the PCB layout design of the microcontroller inverter. The PCB contains all the connection except the transformer. The power MOSFET were connected from heat sink using 1.6 mm size of wire to the PCB through Q4 and Q3. This configuration of Q3 and Q4 to Q1 and Q2 were used to increase the voltage driving capability of the MOSFET. In the actual connection Q3 and Q4 uses IRFZ44n power MOSFET. The Q1 and Q2 use TIP31 to drive the power MOSFET.

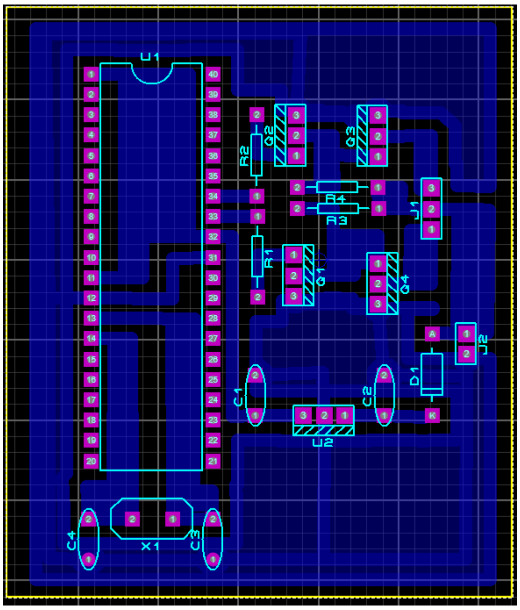


Figure 4.24 PCB Layout Design of Microcontroller Inverter

Figure 4.23 shows the 3D views of the microcontroller inverter prototype. In this view, the actual placement of every component can be seen. It also helps to simplify the arrangement of every component in the circuit.

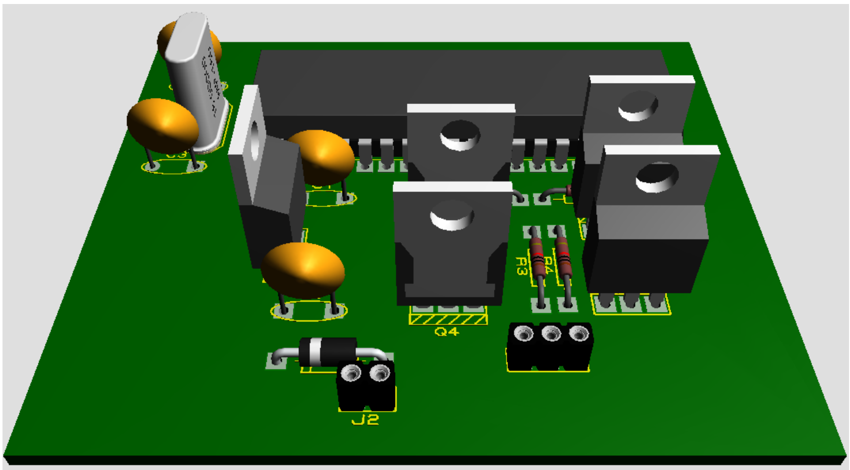


Figure 4.25 3D View of the Prototype Microcontroller Inverter

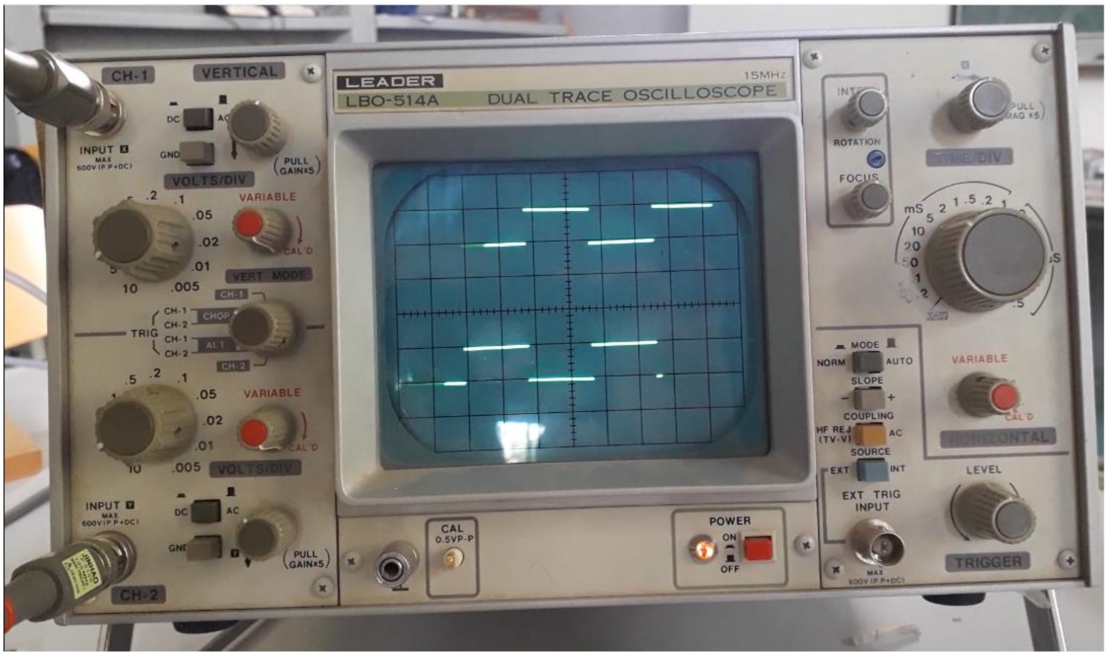


Figure 4.26 Prototype Microcontroller Trigger Output Wave Shape

4.3.4. The Filter and Transformer Circuit

Figure 4.24 shows the circuit diagram for the filter and the transformer section. In practical work LC filter is not compatible with transformer. The researcher finds out a solution that tested different value of myler capacitor at output side. This capacitor has two function one filtering and the other it gave stability for the DC source.

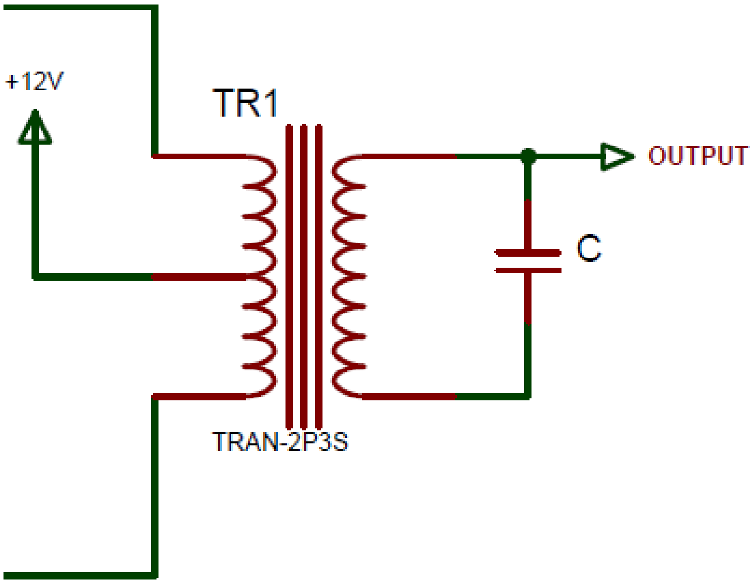


Figure 4.27 Schematic Diagram of Filter and Transformer Output

4.4. Testing of the efficiency of hardware

The efficiency of the develop inverter were tested based on the load test. The different model of inverter was tested based on the following parameters.

a. No load current
b. No load voltage
c. Full load voltage
d. Voltage regulation
e. Harmonics

The no load test was the first to consider in the design of inverter. This test was used to make sure that the inverter does not consume much power from the battery. The voltage regulation of inverter was also tested to make sure that the voltage drop at the output meets the standard. Lastly, the harmonics for sine wave inverter were also considered in the design parameters of an efficient power inverter.

Table 4.4 The Test Results of No Load and Full Load Voltages

INVERTER MODEL	NO LOAD CURRENT	NO LOAD VOLTAGE	FULL LOAD VOLTAGE
CD4047 Timer Based	-	280V	222V
Two Transistor Based	-	280V	208V
Microcontroller Based	-	272V	222V

Table 4.4 shows the test results on the different inverter model presented in the study.

The voltage regulation was calculated based on the test results on no load and full load voltages.

$$Voltage\ Regulation\ \frac{No\ Load\ Voltage - Full\ Load\ Voltage}{Full\ Load\ Voltage}\ x\ 100 \qquad (4.7)$$

Table 4.5 Functionality Test Results

FULL LOAD	FUNCTIONALITY		
	A	B	C
25 Watts LED Lamp	26.1%	34.6%	22.5%

Legend:

A – CD4047 Timer Based Inverter

B – Two Transistor Based Inverter

C – Microcontroller Based Inverter

Table 4.5 shows the results of the voltage regulation test that were conducted on each model design of power inverter.

The three-inverter has poor voltage regulation, the circuit needs additional no load cut off circuit. Because of the poor voltage regulation cannot calculate efficiency of the inverters. Since the circuit has no filter high harmonics is expected.

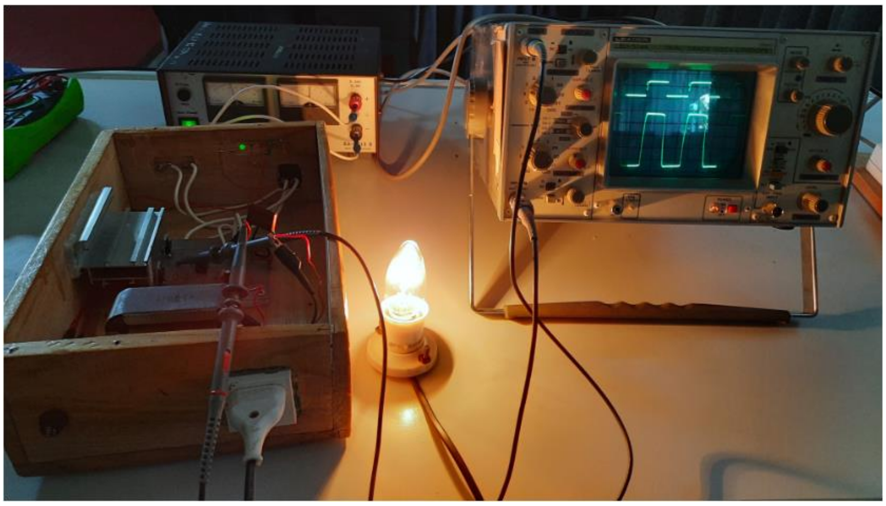


Figure 4.28 CD4047 inverter

The above figure 25W lamp and the output and trigger wave shape

4.5. Analysis of the cost effectiveness of the develop power inverters

The cost of inverter was one of the major concerns of the people living in rural places. In this section the cost effectiveness of three different models were shown. This cost estimation was based on 24 watts power inverter design.

Table 4.6, 4.7 and 4.8 shows the cost break down of the CD4047 based inverter; Two Transistor Based Inverter and, Microcontroller Based Inverter, respectively. The prices were the actual prices available in Adama City and Addis Ababa. Based on these tables the total cost for developing prototype hardware was estimated to 1,205, 1222 and 1427 ETB respectively.

Table 4.6 Cost Estimate of CD4047 Based Inverter

No.	Description	Quantity	Unit Cost	Total Cost i
1	**Resistor**			
	15ohm	1	2	2
	100ohm	2	2	4
	120ohm	1	2	2
	300ohm	1	2	2
	1K	1	2	2
	10K	2	2	4
2	**Capacitor**			
	3.3uF (Electrolytic)	1	10	10
3	**MOSFET**			
	IRFZ44n	2	40	80
4	**IC**			
	CD4047	1	40	40
	IC socket	1	35	35
5	Inductor	2	80	160
6	Transformer (12-0-12)/2A	1	400	400
7	Heat Sink	1	20	20
8	**LED**			
	Red	1	10	10
	Green	1	10	10
9	Fuse/holder	1	60	60
10	Switch	1	50	50
11	Socket Outlet	1	55	55
12	Nod	2	20	40
13	**Wire**			
	2.5cm	1	10	10
	Thin	2	5	10
14	**Screw**			
	Bolt and Nut	6	3	18
	Wood Screw	3	2	6
15	Trunking	1	15	15
16	Glass (20*30)	1	100	100
17	Box (30*20*10)	1	80	80
TOTAL				**1,225**

Table 4.7 Cost Estimate of Two Transistor Based Inverter

No.	Description	Quantity	Unit Cost	Total Cost
1	**Resistor**			
	100ohm	2	2	4
	120ohm	1	2	2
	330ohm	2	2	4
	33K	2	2	4
2	**Capacitor**			
	0.47µF	2	10	20
3	**Transistor**			
	BC547	2	30	60
4	**MOSFET**			
	IRFZ44n	2	40	80
5	Inductor	2	80	160
6	Transformer (12-0-12)/2A	1	400	400
7	Heat Sink	2	20	40
8	**LED**			
	Red	1	5	5
	Green	1	5	5
9	Fuse/holder	1	60	60
10	Switch	1	50	50
11	Socket Outlet	1	55	55
12	Nod	2	20	40
13	**Wire**			
	2.5cm	1	10	10
	Thin	2	5	10
14	**Screw**			
	Bolt and Nut	6	3	18
	Wood Screw			
15	Trunking	1	15	15
16	Glass (20*30)	1	100	100
17	Box (30*20*10)	1	80	80
TOTAL				**1,222**

Table 4.8 Cost Estimate of Microcontroller Based Inverter

No.	Description	Quantity	Unit Cost	Total Cost
1	**Resistor**			
	100ohm	2	2	4
	120ohm	1	2	2
	1K	4	2	8
	10K	2	2	4
2	**Capacitor**			
	0.01uF(Ceramic)	2	10	20
	22pF(Ceramic)	2	10	20
3	**Diode**			
	1N4004(1A)	1	2	2
4	Transistor			
	TIP31	2	12	24
	LM7805	1		
5	**MOSFET**			
	IRFZ44n	2	40	80
6	**IC**			
	PIC16F877A	1	200	200
	IC socket	1	30	30
7	Crystal Oscillator/4MHz	1	20	20
8	Inductor	2	80	160
9	Transformer (12-0-12)/2A	1	400	400
10	Heat Sink	1	20	20
11	**LED**			
	Red	1	5	5
	Green	1	5	5
12	Fuse/holder	1	60	60
13	Switch	1	50	50
14	Socket Outlet	1	55	55
15	Nod	2	20	40
16	**Wire**			
	2.5cm	1	10	10
	Hook up wire, AWG#18	2	5	10
17	**Screw**			
	Bolt and Nut	6	3	18
	Wood Screw			
18	Trunking	1	15	15
19	Glass (20*30)	1	100	100
20	Box (30*20*10)	1	80	80
TOTAL				**1,442**

Based on the three models, CD4047 and two-transistor based inverter are the cheapest with almost similar prices. The microcontroller-based inverter design was the most expensive in developing the hardware. This is because CD4047 uses less inputs than the micro-controller. Based on the design procedure the two- transistor based inverter design was not perfectly generating the oscillator square wave because transistor is not fast switching. For this reason, the inverter has more harmonics than the other circuit. Thus, microcontroller based was commonly used in many designs around the area because of its simplicity and accurateness of the signal generation.

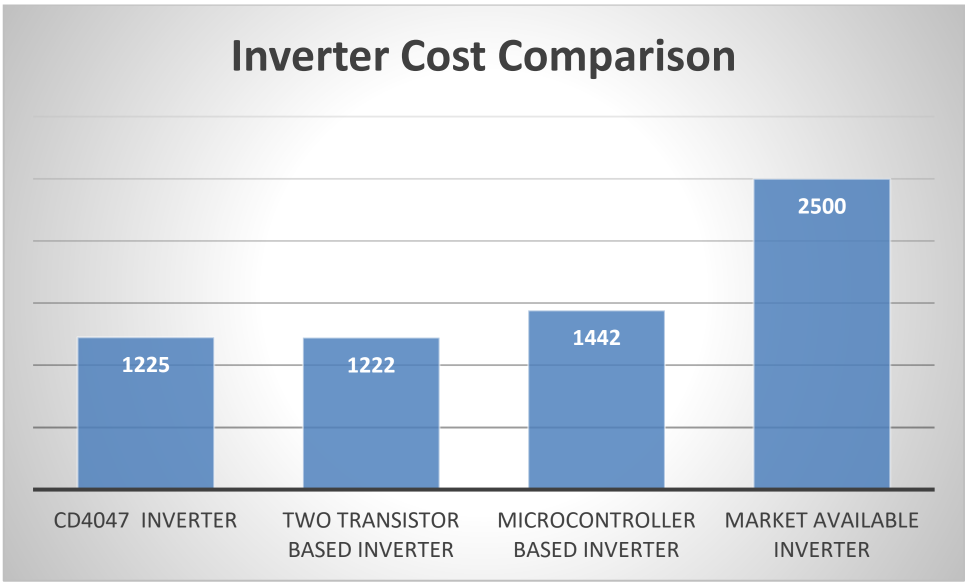


Figure 4.29 Inverter cost Analysis

Figure 4.29 shows the comparison of the three-model inverter as compared to the available price of inverter in the market. Sine wave inverter was difficult to find in the market. One of the shops informed the researcher that due to the cost of this inverter, it was made to order only from the supplier. The consumer cannot easily get it anytime they wanted.

Most of the inverters available in the market were modified and square wave inverter. The cost of investment for this inverter was ranging from 1,800.00 to 3,000.00 ETB for 100 watts inverter.

In this study it was proven that the three models were cheaper compared with the existing inverter in the country. The design limits the wattage because transformer is not available in the market for 100W inverter and the other components have the capability to handle 100W.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The invention of electricity plays important role in humans daily life activities. Technology rises and changes from time to time because of electricity that powers the needs of the people changes.

Based on the data information gathered in this study, it was concluded that in rural areas AC power was very much needed as compared with the DC power as compared at the lowest possible operating cost. The impact of AC power in rural areas was computed based on the data gathered and the result shows its greatest usefulness and need of AC power for routine activities.

It is evident that DC power is very easy to produce. However, in the rural communities and in many other applications, the use of an AC power requires the design and implementation of an appropriate power inverter for the minimization of cost of operation on the consumer side of rural areas as done in this study. Thus, it can be summarized that three different design models can be used for developing low cost power inverter. The designed models may use CD4047 IC, two-transistor type, and microcontroller-based approach. Each of these designs have their own merits and limitations when it comes to the point of cost and efficiency. Among the three-design carried out in this study, the CD4047 IC was found to be the lowest cost of development followed by the two-transistor based and microcontroller-based ones. Regarding to the consideration of an efficiency, CD4047 and microcontroller-based designs were efficient as compared with the two-transistor based inverter design. The CD4047 IC have little differences when seen from the perspectives of its performance. While comparing based on the cost issues, the CD4047 inverter design was found to be cheaper as compared with the microcontroller-based inverter design.

It was finally concluded that, simple design of an inverter can be possibly achieved using some available components in the laboratory of certain institution and a given country. It was also observed that the different components for developing a sine wave inverter were seen to be oscillator which can be designed using CD4047 IC, Two-transistor configured as a stable multi-vibrator, and microcontroller. These oscillators were fed into the driving circuit for the transformer to achieve the required AC voltage. Transformer must have the power rating to supply the load power. Since, the oscillator output was a square waveform, the output of the inverter was also a square waveform as well. To convert the output to sine waveform, a filter was used.

5.2. Recommendations

In this study, a very promising and ingesting results have been achieved. However, the researcher wants to put some points as recommendation for the consideration in the upcoming cases. Once more, it is very important to stress on that the power inverter is useful device for the rural areas with the maximum efficiency to be obtained at low price as a prime requirement for the inverter in rural community. Based on the study and the actual development of the inverter as disposed in the thesis, maximum efficiency was not easy to achieve when the actual materials are seen to be difficult which are expected to available as per the carried design steps. Therefore, the following are the recommendations where the researcher wants to bring to desk in order to achieve the maximum efficiency on the development of inverters.

- The study of the load requirement must be thoroughly being optimized. This will guide the designer to meet the requirement of the load.
- The designed circuit components must match and be in accordance with the standards available the country. If there were components not available in the country or a certain data sheet, a substitute component that will quite similarly work with the design must be used and selected. Otherwise, changing the design circuitry and its parameter should be used having greater care.
- It can be highly recommended to use the right instrument/apparatuses for the purposes they are intended for. In addition, it is also very necessary to check the correctness of the experimented data before any measurements in order to come up with an efficient design model and expected results.
- It was found to be hard to measure harmonics due to the absence of harmonic Analyzer and hence the hardware cannot be measured for this case.
- Thorough studying different design circuits will help the design to improve the voltage regulation and efficiency.
- There are also several low-cost inverter designing options that are simple and convenient. However, the original materials are not available in the current market. Thus, the concerned government or regulatory bodies or private organizations can

facilitate for their availability, and accessibility of genuine materials for the benefit of the rural community.

- Finally, anyone who is interested to further explore in the area is highly recommended to consider the aforementioned points in addition with new trends as of the changing technology.

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APPENDIX I

Questionnaire

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

PURE SINE WAVE INVERTER DESIGN FOR RULAL COMMUNITY OF ETHIOPIA

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መብራት		
የመብራት አይነቶች		
LED	--	
INCANSDENT	--	
MOBILE CHARGER	--	
TV	--	
RADIO	--	
REFRIGRATOR	--	
MITAD	--	
IRON	--	
STOVE	--	
TOTAL POWER REQUIRMENT		

APPENDIX II

Data Sheet

https://www.alldatasheet.com/datasheet-pdf/pdf/50729/FAIRCHILD/BC546.html

https://www.infineon.com/dgdl/irfz44npbf.pdf?fileId=5546d462533600a40153563b3a9f220d

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