Active Front End Inverter

A Project report submitted in partial fulfilment
of the requirements for the degree of B. Tech in Electrical Engineering

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Full Signature of the Student

Place:

Date:

CERTIFICATE

To whom it may concern

This is to certify that the project work entitled **Active Front End Inverter** is the bona fide work carried out by

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TABLE OF CONTENTS

CONTENT	PAGE

❖ ABSTRACT

Use of Photovoltaic systems to generate electricity in house and business is becoming increasingly popular, as the cost of conventional electric energy increases while the cost-effectiveness of solar power systems improves. While much attention is paid to gradual improvements in the efficiency of solar cells, steps must be taken to improve the efficiency of the power conversion electronics of the system. Solar electric systems incorporate inverters or power control units that transform the DC electricity generated by the solar cells into AC to run appliance or sell to a utility grid.

Inverter converts DC battery power to standard AC power. The AC power produces can run regular AC appliances, including TVs, computer, microwaves and power tools.

This Project presents a design that will attempt to convert 12V DC power to a three phase 440V AC power at 50Hz. The design is based on CMOS logic inverters made up of power MOSFETS and a microcontroller. Simulation is carried out and actual implementation done.

From the laboratory measurements, the inverter is seen to generate a Three Phase 118V AC at 47Hz. The discrepancy in frequency of oscillation from the design value can be attributed to the execution time and propagation delays of the microcontroller and others components.

1.0 INTRODUCTION

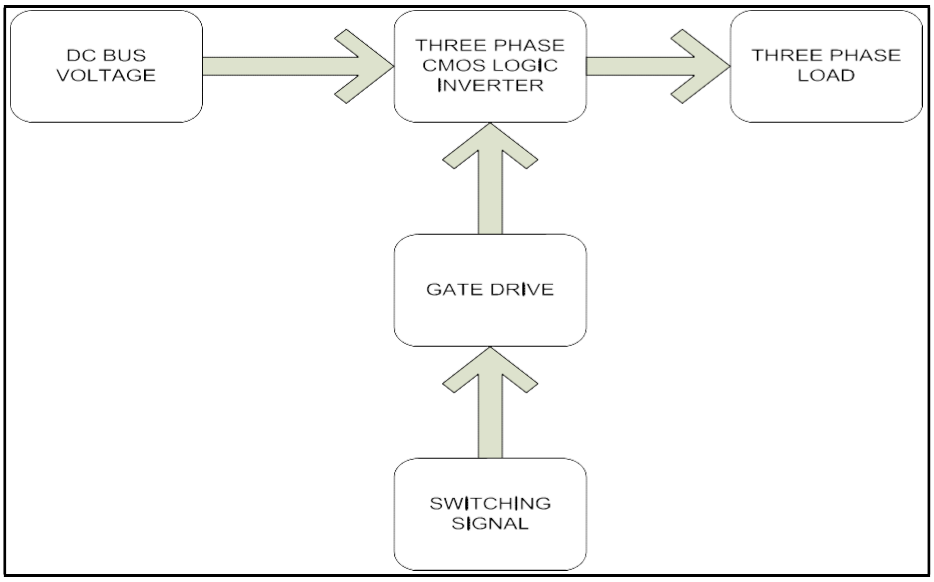
1.1 Objective:

The project aimed to come up with specification, design and implementation of a Arduino based three phase inverter. In this design proposed, 12V DC from the power supply is used as the input.

1.2 The need for inverter circuit:

When it is required to provide AC power for a load from a DC supply as the only sources of power for example in the case of solar power, there is need for conversion of the available DC energy to AC most industrial and domestic application utilize AC energy hence the need for the conversions.

The design proposed in this project can be described by the block diagram of figure. The switching signals are generated by the Arduino while CMOS logic inverters are used for switching.



Block diagram of the proposed design of the Inverter.

1.3 Recognition of previous work

Most power inverter available in the market for domestic purposes are single phase. This means only single phase machine can be run on such inverters. To cater for low power three phase machines, there is need for design of three phase inverters. This project tries to solve this problem by converting DC voltage to three phases AC.

This project is organized in six chapters.
Chapter one gives a general introduction, project objective and the need for power inverter.

Chapter two gives the theory and background information concerning power inverter. The principles of operation of both single phase and three phase inverters are outlined here. The performances are also described.

Chapter three describes the system design. Operation of CMOS logic inverter and how it is used to realize a power inverter is described in this chapter. A single phase simulation of an inverter is described and the results explained.

Chapter four explains the actual implementation of the three phase inverter using CMOS logic inverters. The gate drive circuit used in implementation is described in this chapter.

Chapter five gives the Software Implementation.

Chapter six gives the Hardware Implementation.

Chapter seven gives the knowledge about Arduino.

Chapter eight gives the Result obtained and Analysis

Chapter Nine gives the list of Conclusion and Future Work.

Chapter: 2

2.0 LITERATURE SURVEY

An inverter circuit is used to convert DC power to AC power. This conversion is achieved either by transistors or by SCRs. For Low power and medium power output, common MOSFETs and BJTs transistors are suitable but for high power transistors such as IGBT are used. For low power self-oscillating, transistorized inverters are suitable but for high power output, driven inverter is more common than self-oscillating ones. Moreover for multiphase ac output, driven inverter must be used.

The driven inverters have better frequency stability because a separate master oscillator is used for the purpose. For inverter applications, transistors have the following advantages over SCRs:

- Higher switching speed
- Simplicity in control circuit
- Higher efficiency and greater reliability

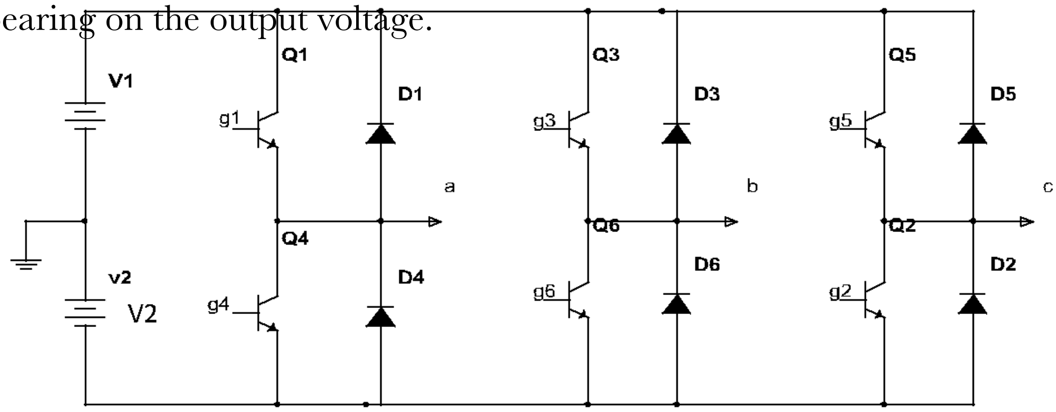
This is mainly due to the fact that SCR inverters require extra circuit to turn SCRs off, moreover additional complex logic circuits may be required to prevent false triggering and provide proper commutation timing. SCRs can handle much higher load current than BJTs and MOSFETs thus, for high power output, SCRs becomes more desirable than the transistor.

2.1 Amplifier type sine-wave inverter

Transistor is used as amplifiers operating in a non-saturated condition. The efficiency of this type of inverter is generally low because of high power dissipation in the transistors. Another problem is the crossover distortion in class B and C push-pull circuit. This circuit are suitable for low power outputs where load power factor and load regulation are not important and efficiency is not a criterion.

2.2 THREE PHASE INVERTER

A three phase inverter may be regarded as three single phase inverters and the output of each single phase is shifted by 120⁰ with respect to each other. The three phase inverter can be connected in parallel to form the configuration of a three phase inverter. The transformer primary winding may be connected in Y or delta. The transformer secondary is normally connected in Y or delta. The transformer secondary is normally connected in Y to elimated triple harmonics appearing on the output voltage.



A three phase inverter formed by the three single-phase inverters.

The type of control signals can be applied to the transistor:

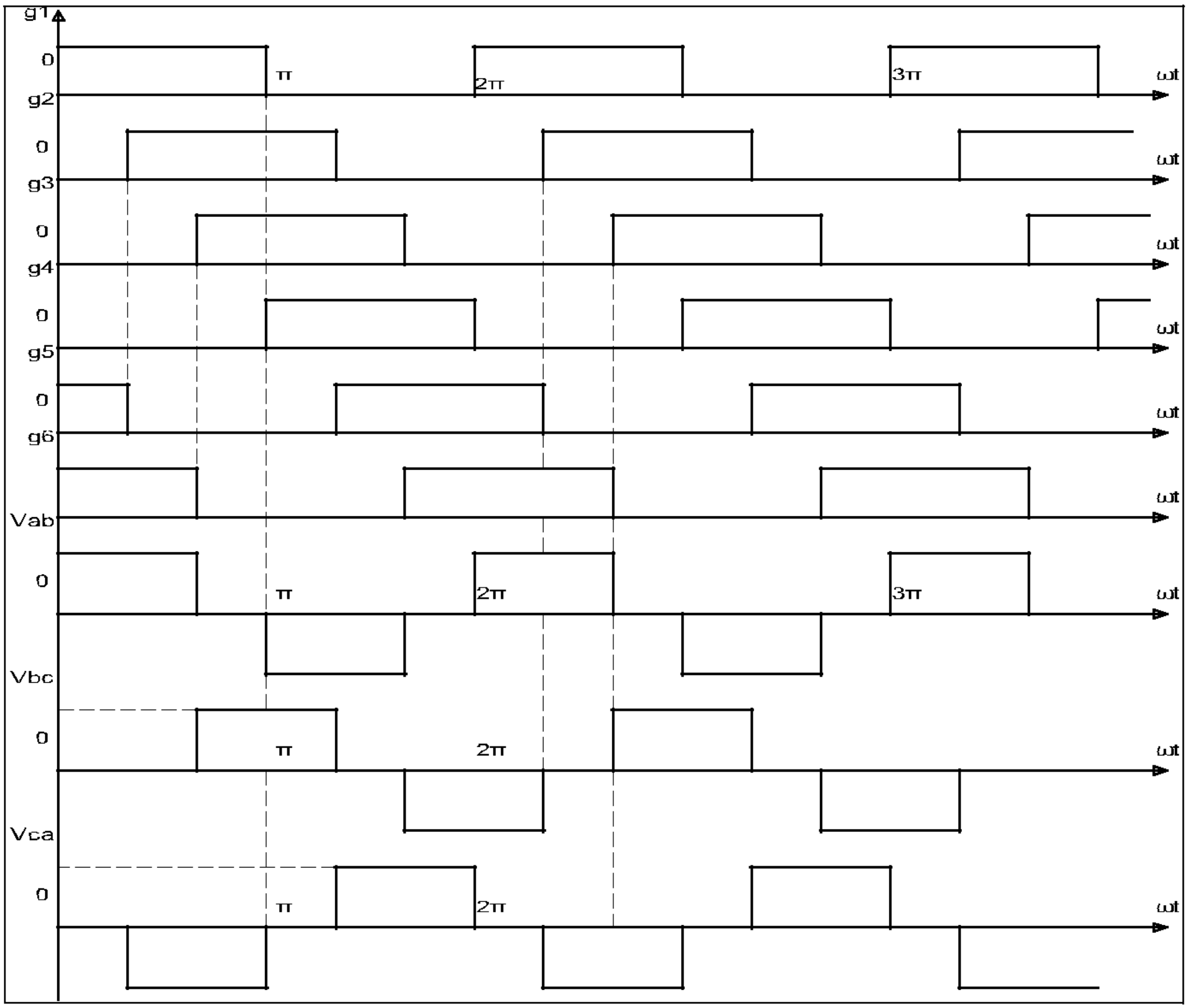
- 180⁰ conduction mode
- 120⁰ conduction mode.

2.2.1 180 Conduction

Each Transistor conduct for 180. Three transistors remain on at any instance of time. When transistor Q1 is switched on, terminal a of fig. is connected to the positive terminal of the DC source. When transistor Q4 is switched on, terminal a is connected to the negative terminal of the DC source. There are six mode of operation in a cycle and the duration of each is 60 . The transistors are numbered in the sequence of gating the transistor. That is 123,234,345, 456,561, and 612. The signals are sifted from each other by 60 to obtain three phase balance voltages.

The load may be connected in Y or delta. For a delta connected load, the phase currents can be obtained directly from line to line voltages. Line current is determined from phase currents.

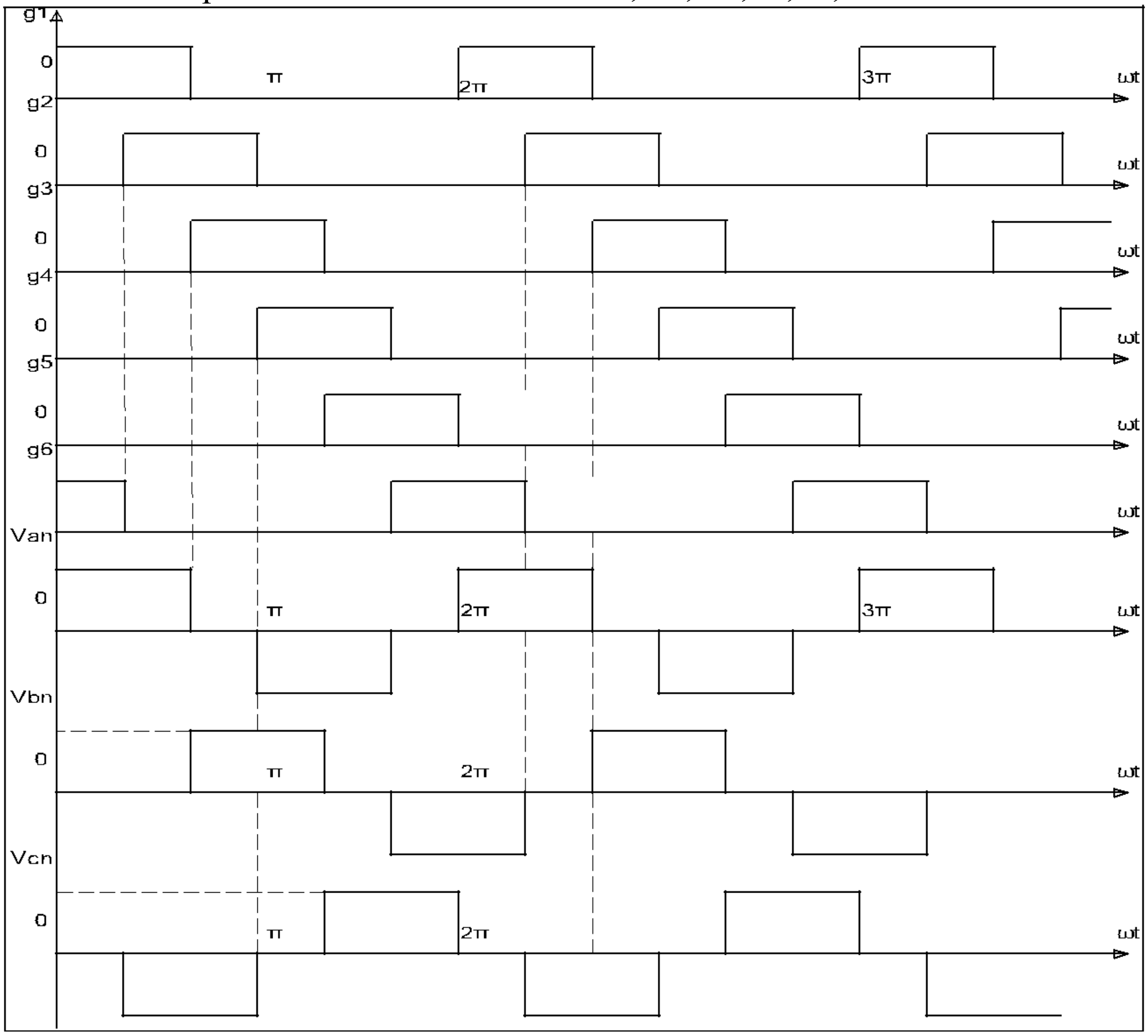
For a Y-connected load, the line-to-neutral voltages must be determined to find the line currents.



Getting signal waveforms for 180   conduction

2.2.2 120 Conduction

In this type of control the, each transistor conducts for 120 . Only 2 transistors remain ON at any instance of time. The gating signals are shown in fig. The conduction sequence of the transistors is 61, 12, 23,34,45,56 and 61.



Getting signals for 120 conduction

2.3 Control of Inverter output voltage

There are many applications in which it is necessary to control the output voltage of the inverter. Two much application are a stabilized AC or DC voltage source from a battery whose voltage varies during discharge, and AC motor control system, in which a constant voltage-to-frequency ratio has to be maintained to avoid saturation of the motor. In both cases, control of inverter output voltage is necessary.

The output voltage of the single-phase inverter is roughly square wave with amplitude approximately equal to the DC supply voltage. Therefore the output is proportional to the input voltage.

The common methods of output control are:

- Controlling DC input voltage
- Controlling AC output voltage
- Pulse width modulation

If inverter is supplied from an AC source through a rectifier, the input to the inverter can be regulated by means of an induction regulator, variac or a controlled rectifier.
If the supply DC, it can be regulated by shunt or series regulated or chopper using time-ratio control method. The pulse width modulation can be applied for both types of inputs.

2.4 Reducing of Harmonics of the inverter output

The inverter output waveform may vary depending on the application and the circuit used. In most cases an AC load requires sinusoidal output but the majority of the inverter produces square wave voltages. Therefore appropriate means are used to alter the waveforms of the inverter output to a more or less sinusoidal wave shape. Harmonic attention can be achieved by the following methods.

- Resonating the load.
- Using LC filter
- Using pulse width modulation
- Using Polyphase inverter

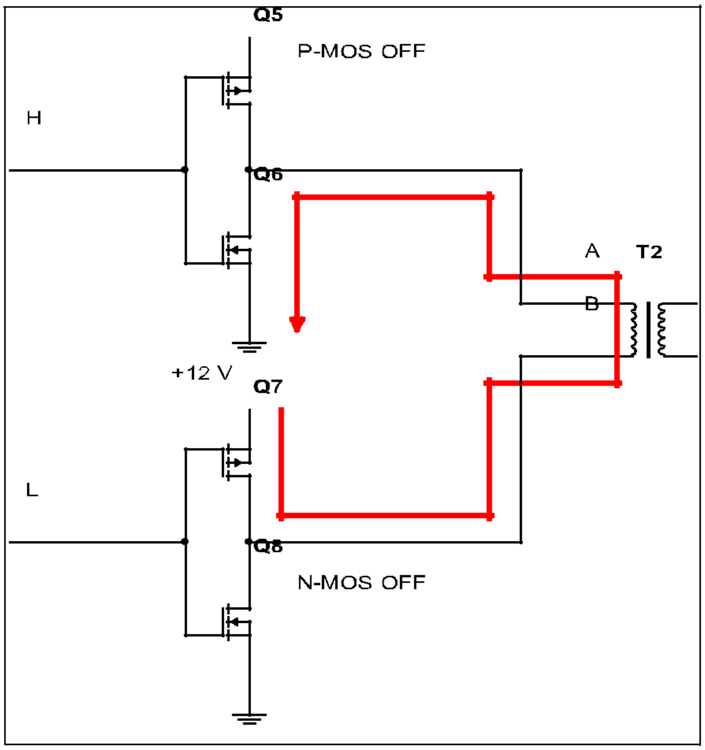
Chapter: 3

3.0 INVERTER DESIGN

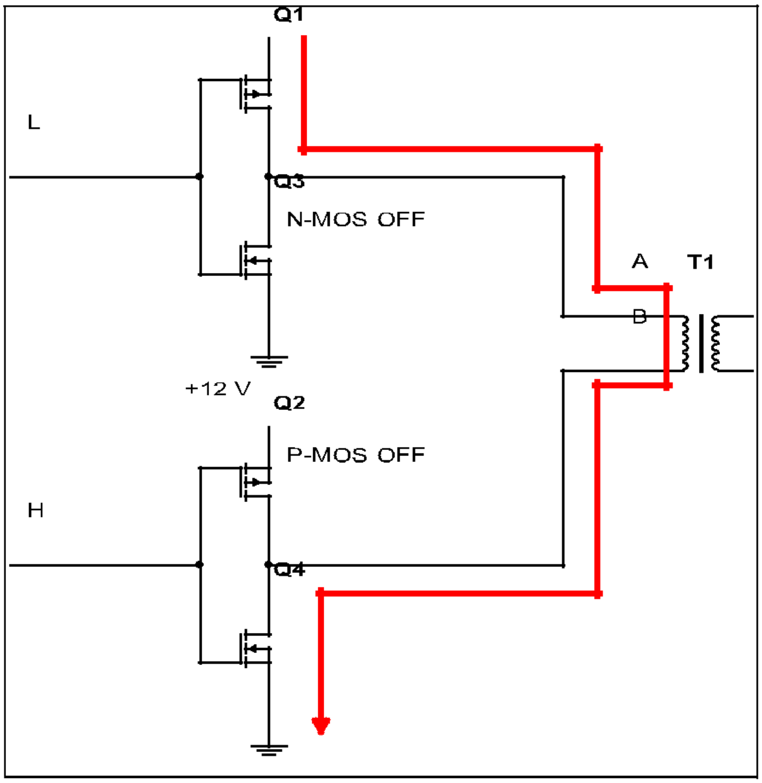
3.1 power MOSFET Switching Circuit

A power MOSFET is a voltage controlled device and requires little input current. It has a high switching speed and time on the order of nanoseconds and is used for low power high frequency converters.

Fig shows the switching circuit used in the DC to AC inverter designed. A CMOS switch was implemented using power MOSFETs. Two sets CMOS MOSFET circuits are used and are controlled by the anti-phase signals generated by the Arduino.



In the case when the gate inputs of transistors Q1 and Q3 are L level signifying 0 volts, and the inputs of transistors Q2 and Q4 are H levels signifying 5 volts, transistors Q1 and Q4 are turned ON while transistors Q2 and Q3 are OFF. Therefore, the electric current flows through the direction of A to B on the primary coil of the transformer.



Considering when the input of transistor Q5 and Q6 are H level and the input of transistors Q7 and Q8 are L level. Transistors Q6 and Q7 are ON while transistors Q5 and Q8 are OFF. Therefore, the electric current flows through the direction of B to A on the primary coil of the transformer as shown in below fig.

To produce an AC signal, current is made to flow in one direction for half a period then reversed in the next half period. The duration of the period determine the output frequency.

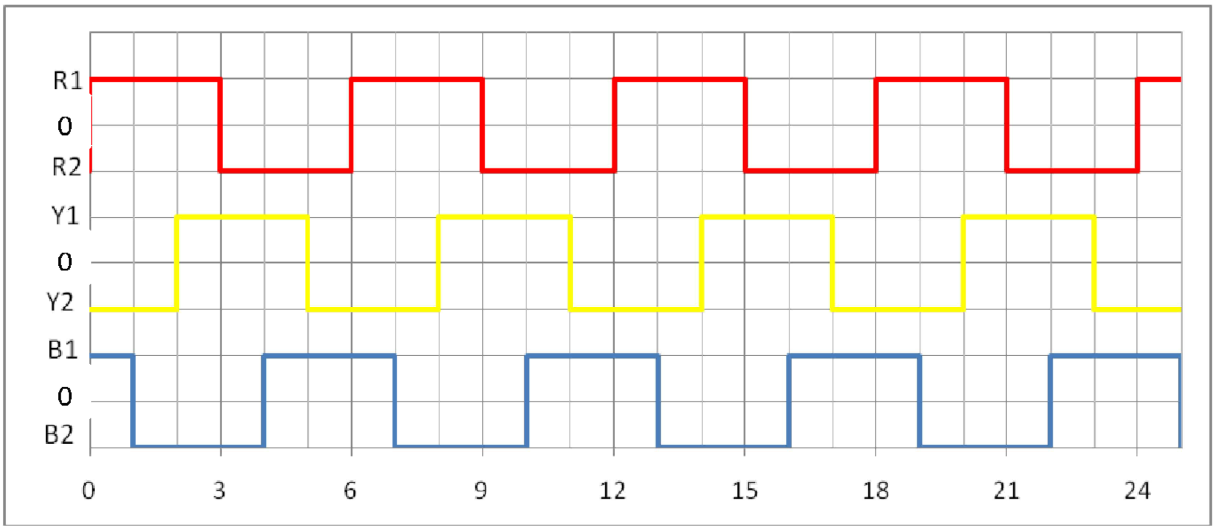
3.2 Gate drive signal

The gate drive signal is generated by Arduino UNO.

The Arduino UNO was chosen as the most appropriate source of getting signal because it has the following characteristics:

- ✓ Microcontroller: ATmega328
- ✓ Operating voltage: 5V
- ✓ Input voltage: 7-12V
- ✓ DC current per I/O pin: 40mA
- ✓ Flash Memory: 32 KB of which 0.5KB used by boot loader
- ✓ SRAM: 2KB
- ✓ EEPROM: 1KB
- ✓ Clock speed: 16MHz

The desired output is 50Hz hence a period of 0.02 seconds is equivalent to 20,000 microseconds. To obtain the three phase square wave AC signal, the three phases must be 120 out of phase as shown in fig.



From the three phase waveforms drawn, it can be observed that for every one sixth of the period, one of the three waveforms will either be changing from high to low or low to high.

The sequence of switching ON and OFF various pins is of the Arduino to achieve a three phase square-wave waveform.

Chapter: 4

4.0 IMPLIMENTATION

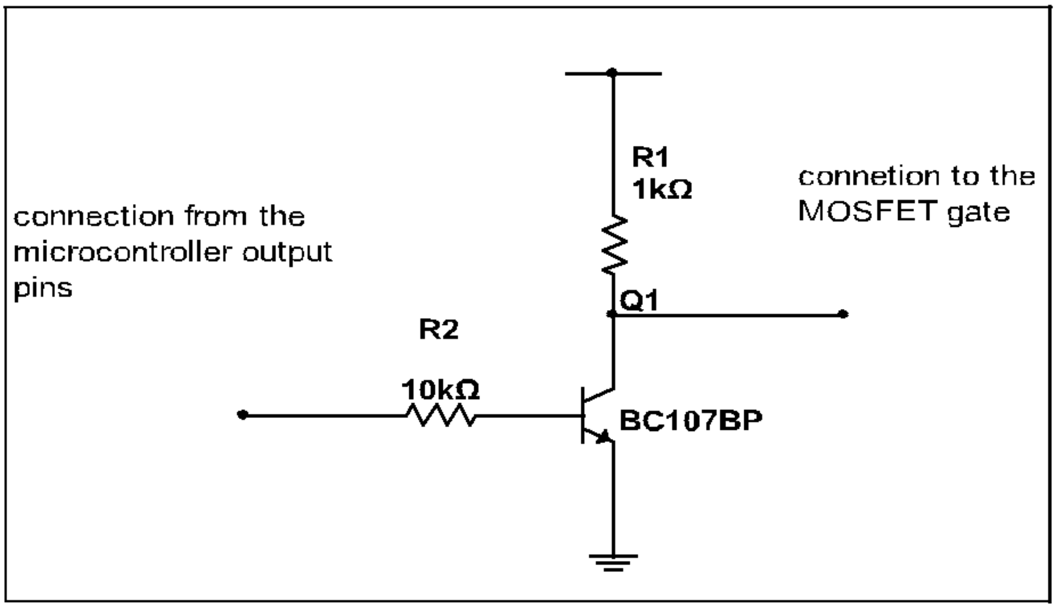
A Arduino based three phase inverter was implemented using CMOS logic inverter. IRF540 NMOS and IRF9540 PMOS power MOSFET were used in actual implementation of CMOS logic inverter. These set of power MOSFET were chosen because of the following reasons:

- ✓ They have freewheeling diodes internally connected between their drain and source.
- ✓ They are also affordable.
- ✓ They are locally available.

4.1 Gate drive circuit

The output of the Arduino was a square wave of voltage 2.2V. This voltage could not drive the gates for the CMOS logic inverter because the threshold voltage for the MOSFETs is 4.5V. Power MOSFET has large stray capacitance between the gate and source.

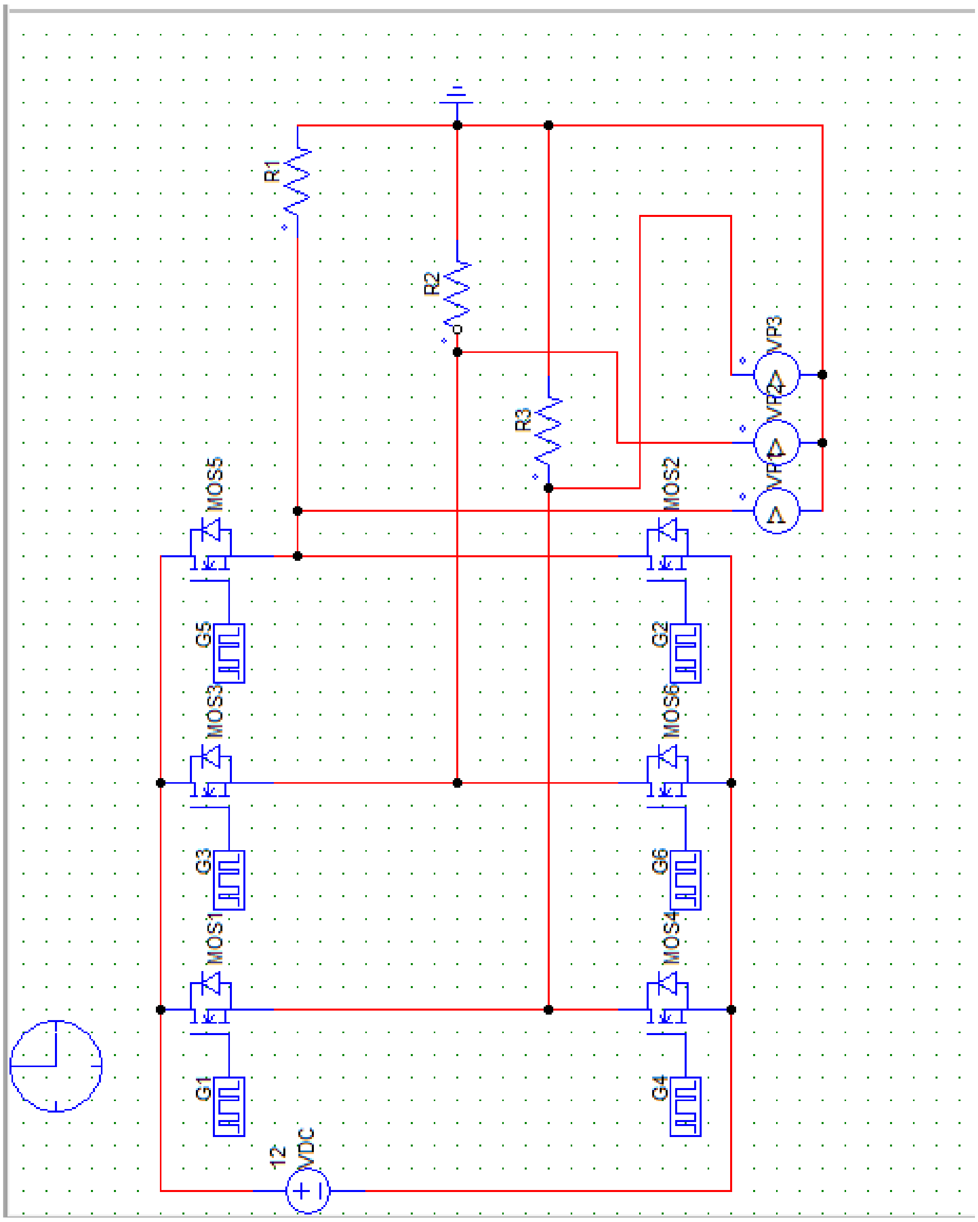
The effect of this is that the gate voltage must first charge the capacitance before the gate is turned on. For efficient switching of the MOSFETs, the gate drive voltage need to be range of 10-20V depending on the device rating. A simple BJT buffer shown in fig. was used for the gate drive.



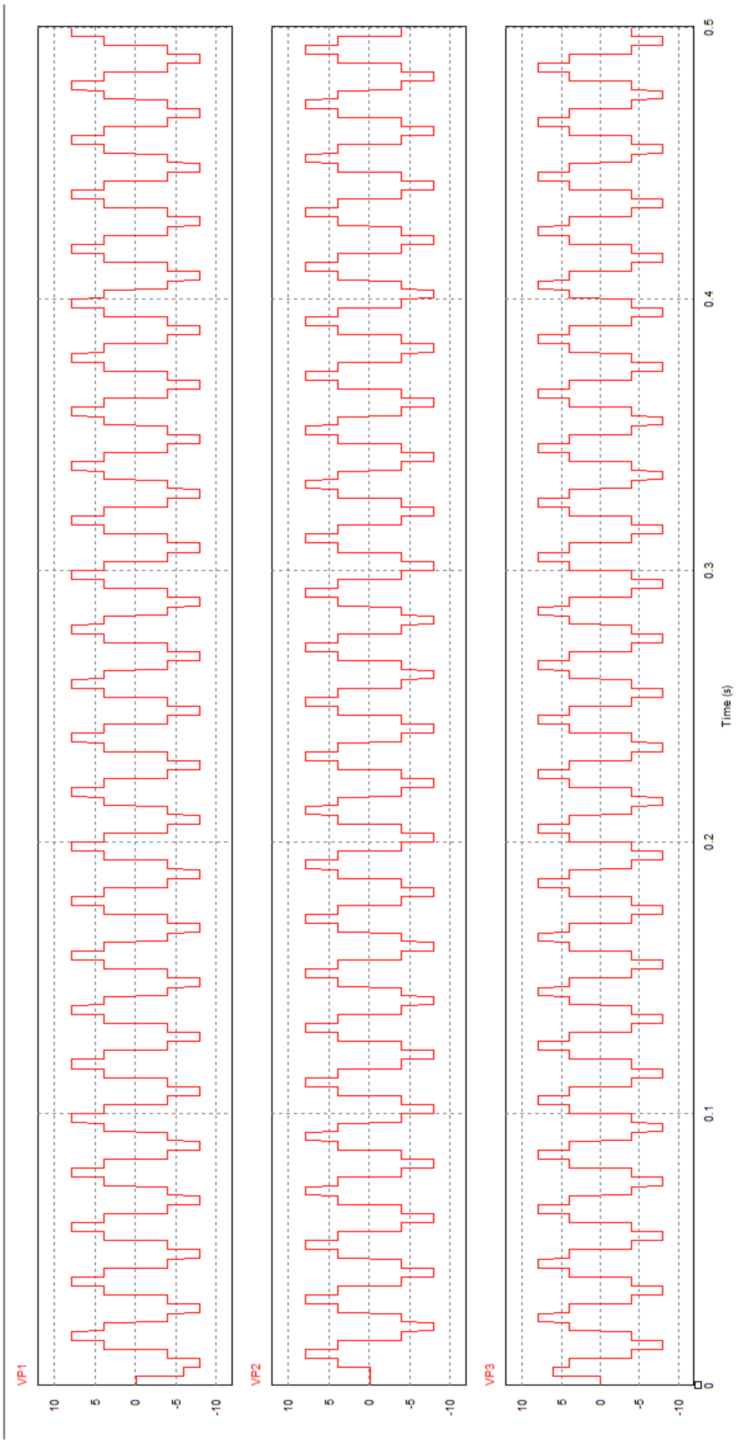
Chapter: 5

5.0 SOFTWARE IMPLIMENTATION

5.1 SIMULATION CIRCUIT



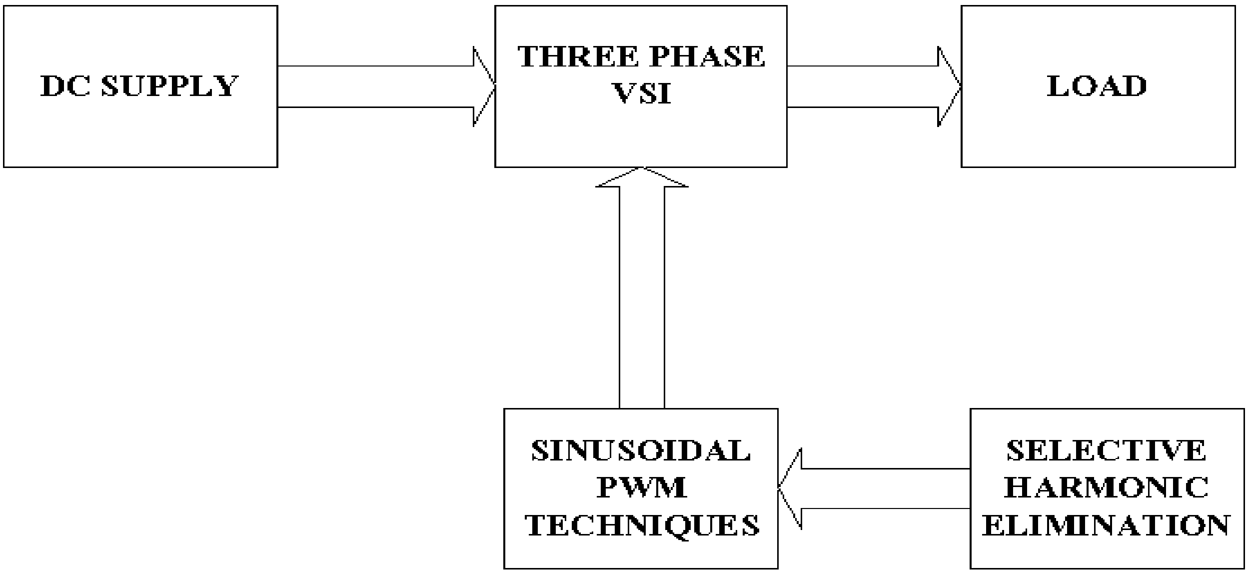
5.2 SIMULATION OUTPUT



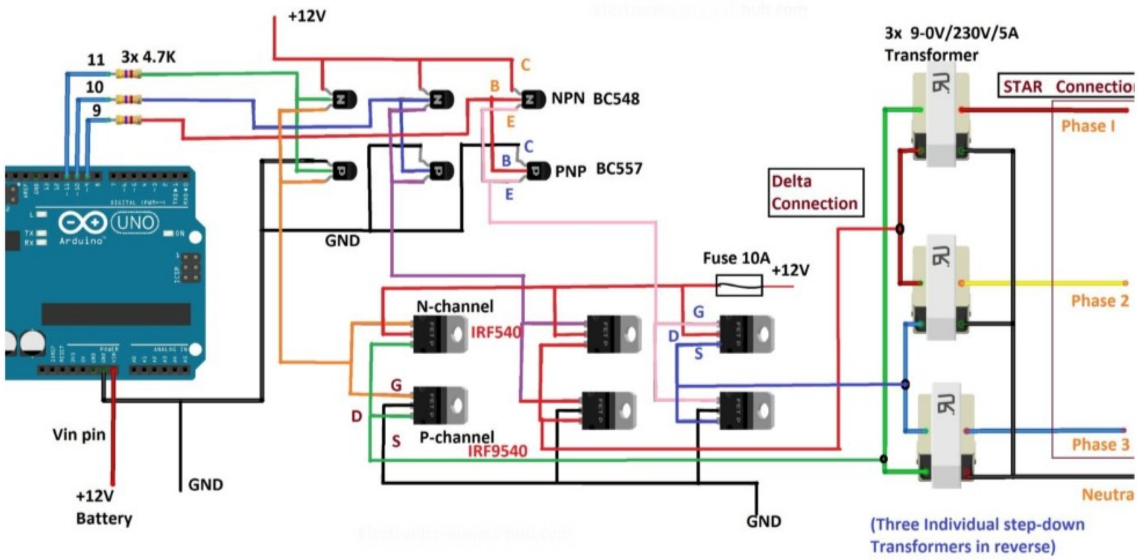
Chapter: 6

6.0 HARDWARE IMPLIMENTATION

6.1 BLOCK DIAGRAM



6.2 CIRCUIT DIAGRAM



6.3 CIRCUIT DESCRIPTION

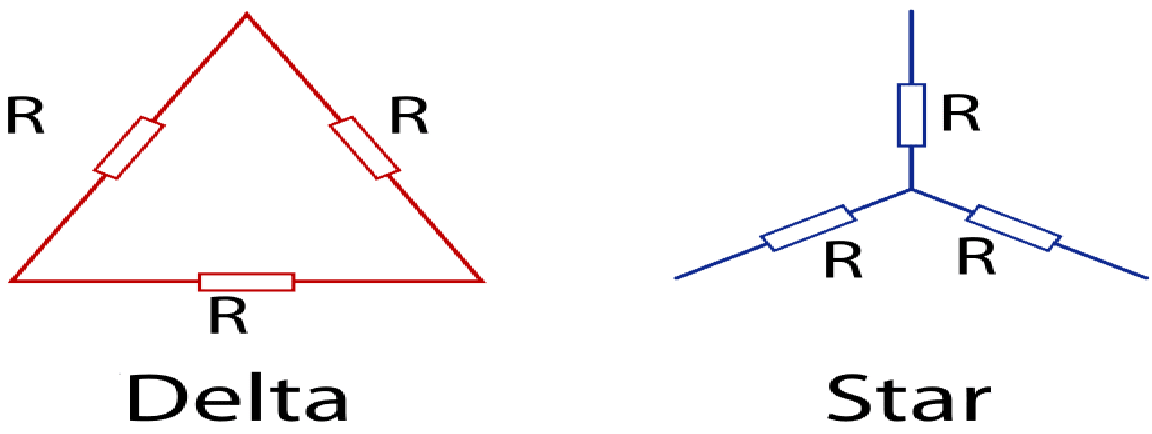
- ✓ The circuit consists of an Arduino which generates the 3 phase waveform with 120degree electrical phase difference between each individual waveform. You may use your favourite Arduino board.
- ✓ The BJTs and MOSFETs are configured in push-pull configuration; three push-pull stages are utilized for three individual phases.
- ✓ Three single phase step-down transformers (used in reverse) are connected in delta and star connection at primary and secondary winding respectively; this will replicate a three phase transformer.
- ✓ At the output we have three phases and one neutral line derived by using star connection at secondary side.
- ✓ We have used three 0-9V transformer and all must be at-least 5A rated to get a decent power output.
- ✓ A fuse is included in the circuit to prevent short-circuit due to some unfortunate situations that may occur.

6.4 PUSH-PULL MOSFET DRIVE STAGE

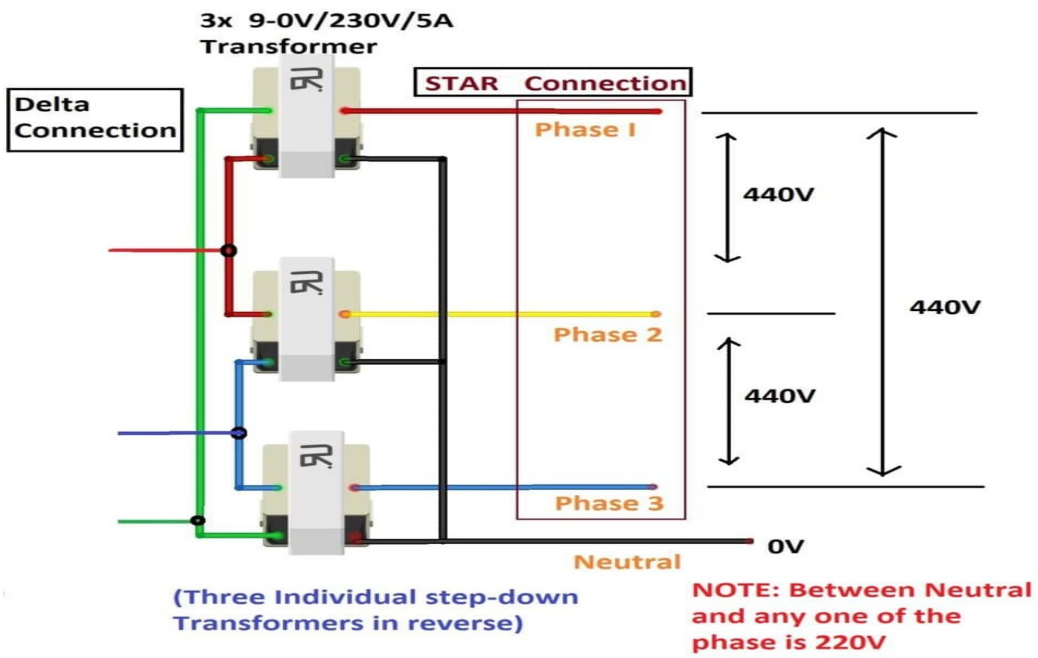
- ✓ The feeble three phase signals are pre-amplified by a couple of low power BJTs per phase signal. The BJT is configured in push-pull configuration so that it can amplify both LOW and HIGH signals; now three such push-pull stages are implemented in the circuit.
- ✓ The output signal from BJT is inverted by 180 degree from the applied signal (for all three phases). The 5V signal from Arduino is now amplified to 12V signal which is sufficient for a MOSFETs to turn ON and OFF (fully). If we directly apply the 5V signal from Arduino to gate of the MOSFET, the MOSFET will still switch ON and OFF (partially) but there will be huge resistance between source and drain terminal which will not allow maximum current to flow and cause MOSFETs to overheat.
- ✓ Now the 12V (from BJTs) signal is applied to MOSFETs which is also configured in push-pull. The output at the MOSFET is now a strong which can drive the three phase transformer. The output signal from the MOSFET is 180 degree inverted (again) from the BJT’s output, now we got zero degree phase shift with respect to Arduino’s output. The weak signal from the Arduino is now on the steroid with exactly same phase difference etc.

6.5 CONSTRUCTION OF 3 PHASE TRANSFORMER BY USING 3 SINGLE PHASE TRANSFORMERS

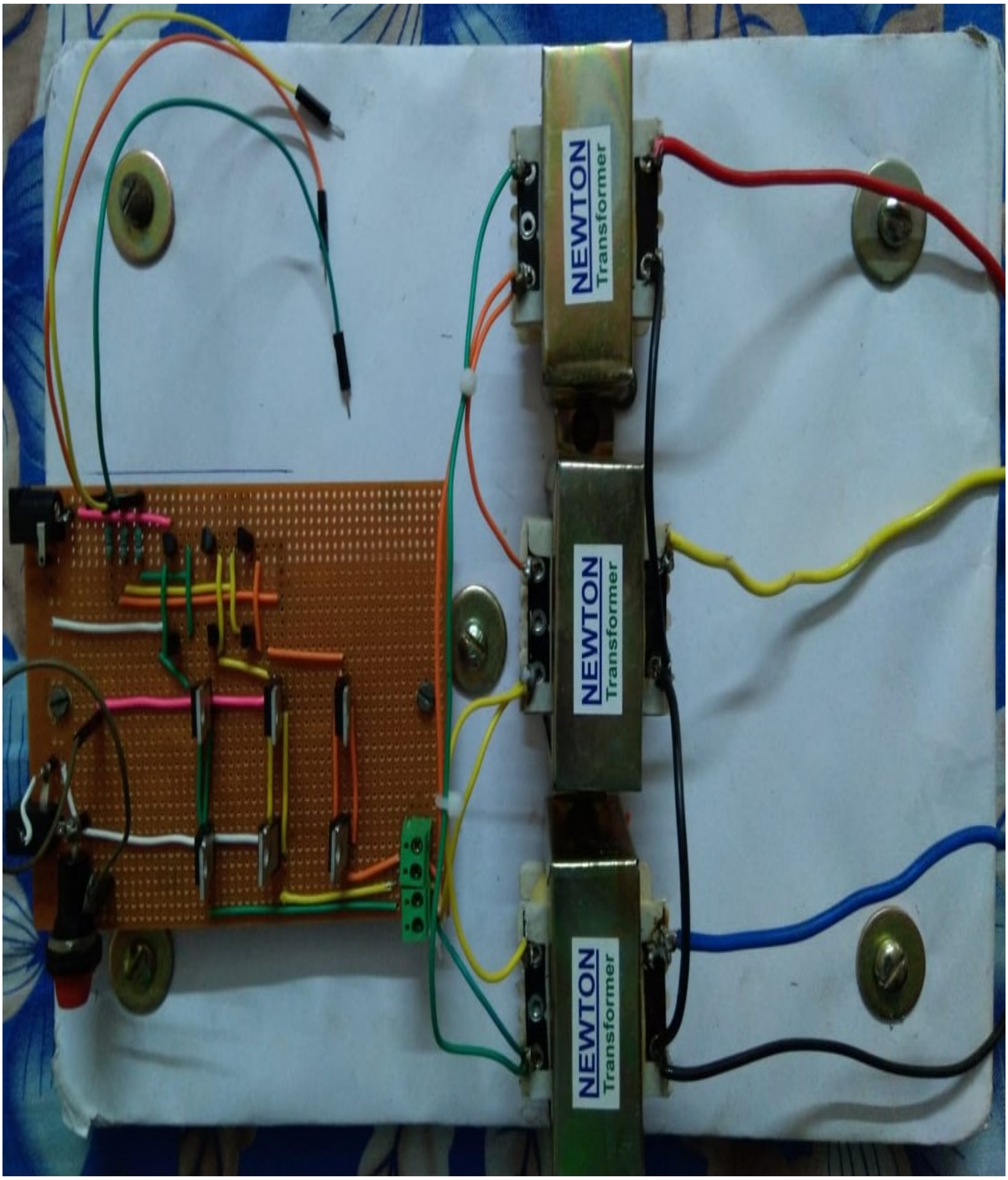
- ✓ Now here is the most interesting part of the project, we are going to construct a three phase transformer using three individual ordinary step-down transformers.
- ✓ We can take three single phase transformers and connect their primary windings each other and secondary windings each other in star or delta configuration or one of the windings in star and other in delta configuration, now we can use it with three phase supply.



- ✓ In this case the output is configured in "star" with a neutral point taken from the centre of the star connection, while the other side of transformer is connected in delta configuration as illustrated below:



6.6 HARDWARE MODEL



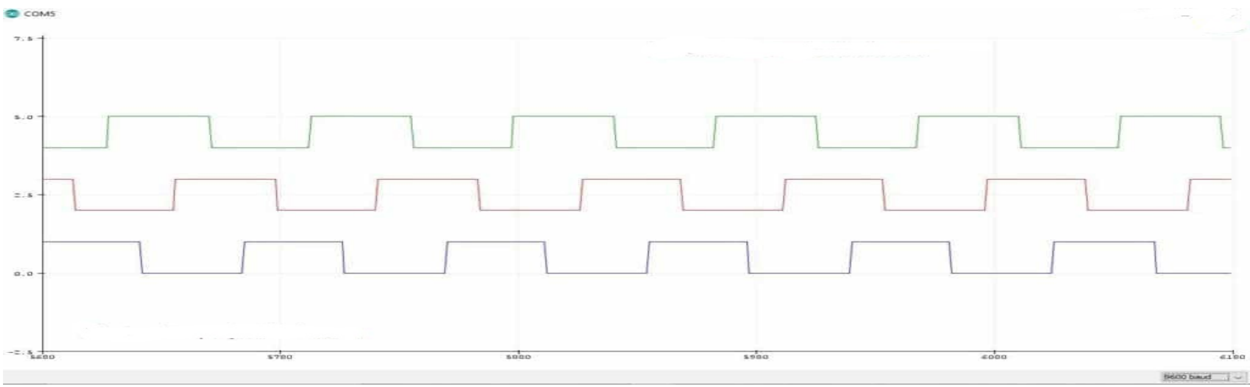
Chapter: 7

7.0 ARDUINO PROGRAM CODE

```
Const int output_1 = 9;
Const int output_2 = 10;
Const int output_3 = 11;
Const int t = 3310;
Void setup ()
{
  pin Mode (output_1, OUTPUT); // Phase 1
  pin Mode (output_2, OUTPUT); // Phase 2
  pin Mode (output_3, OUTPUT); // Phase 3
}
void loop()
{
  Delay Microseconds(t);
  Digital Write(output_1, LOW);
  Delay Microseconds(t);
  Digital Write(output_2, HIGH);
  Delay Microseconds(t);
  Digital Write(output_3, LOW);
  Delay Microseconds(t);
  Digital Write(output_1, HIGH);
  Delay Microseconds(t);
  Digital Write(output_2, LOW);
  Delay Microseconds(t);
  Digital Write(output_3, HIGH);
}
```

7.1 WAVEFORMS GENERATED BY ARDUINO

All three phase are shifted 120 degree electrically with each individual phases and yes, this is not a pure wave type.



The above wave-forms are generated by Arduino at pins 9,10 and 11. The last two waveforms are moved downwards on the oscilloscope, so that the wave form don't overlap each other and we can compare the wave-forms.

To get a clear idea we have marked the waveform so that we can see the 120 degree phase shift in the wave from.

As we can see that each waveform are 120 degree electrically shifted from each other. The generated three phase signal cannot be applied directly to the transformer to step-up; to do this the three phase signals are applied to a buffer stage which consists of BJTs and MOSFETs.

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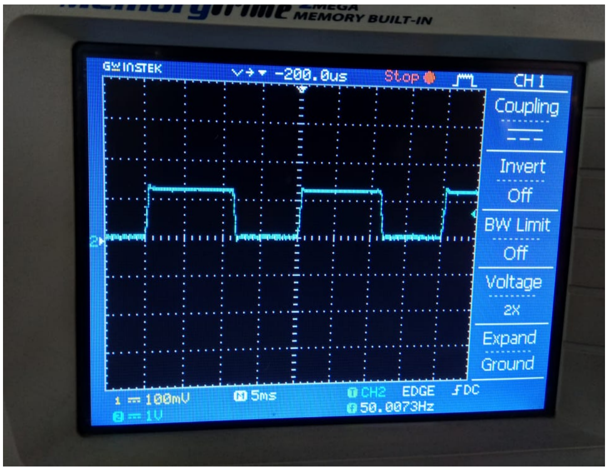
Chapter: 8

8.0 RESULT OBTAINED AND ANALYSIS

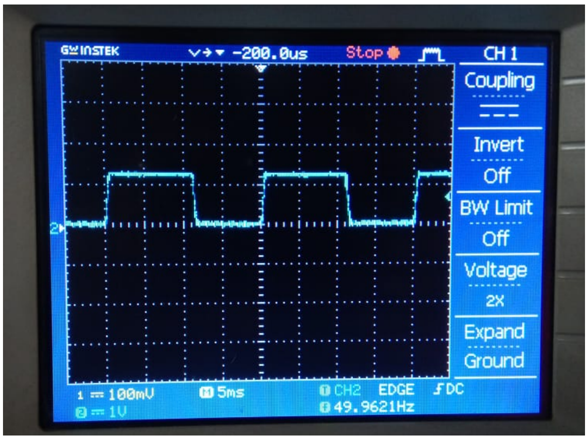
Different waveforms were obtained at different stages in the implementation of the project.

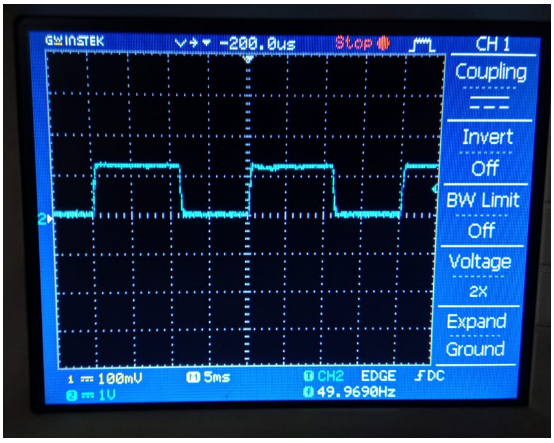
Shows a square wave obtained from all the pins of the Arduino that was to be used. The Voltage 9 V at frequency of 47 Hz. The desired output frequency was 50Hz.



The waveform is described since the delay created sets a pin then calls the delay subroutine after which it clears the pin then calls the subroutine. The duty cycle is thus 50% since the same delay subroutine is implemented upon setting a pin to either high or low. This sequence is continued indefinitely as long as power is connected to the Arduino.

The anti-Phase square waveforms generated by the Arduino pins to be connected to the three transformer primary coils. The waveforms have been coloured and one waveforms shifted downwards in position on the oscilloscope for clarity. It can be seen that both waveforms have the same frequency and duty cycle of 50%. Similar waveforms could be obtained for other Two Phases.





The output voltage obtained at the output of each transformer was 118V AC at a frequency of 47 Hz. From the design the desired output voltage was 120V AC at 50Hz. The difference between the two values of frequency can be attributed to the use of different components with unequal propagation delay.

The three phases of the inverter implemented gave same values in terms of voltage and frequency. The current that the inverter can draw from the source will depend on the load to be driven.

8.1 COMPONENTS AND COST

COMPONENTS		QUANTITY	PRICE
1.	STEP UP TRANSFORMER	3	630/-
2.	POWER MOSFET	6	264/-
3.	TRANSISTOR	6	48/-
4.	RESISTANCE 4.7K Ohm	3	4/-
5.	4PIN SOCKET	2	12/-
6.	ADAPTER	3	240/-
7.	ADAPTER SOCKET	2	12/-
8.	ARDUINO UNO	1	440/-
9.	PCB BOARDS	1	50/-
10.	FUSE WITH HOLDER	1	20/-
11.	SOLDERING IRON, SOLDERING PASTE,WIRE	1	151/-
12.	WIRES	-	25/-
13.	OTHERS	-	410/-
14.	**TOTAL**	**30**	**2306/-**

Chapter: 9

9.0 CONCLUSION AND FUTURE WORK

9.1 Conclusion

In this project an attempt has been made to come up with a three phase inverter that is suitable for low power applications.

The design was sinusoidal and actual implementation carried out from which 118 V three phases AC was generated from a 12V DC power source. The frequency of the output voltages was 47 Hz. The desired output frequency was 50 Hz the difference can be attributed to execution time and propagation delay of the various components used. An attempt was however made to take care of these factors by manipulating the value loaded to the registers that created the software loops in the Arduino. After several attempts a frequency of 47 Hz was achieved.

9.2 Recommendation for Future Work

The implementation of this project is not conclusive. A lot is still to be done to increase the output power. The following recommendation are suggested for better performance,

1. To obtain a proper sinusoidal AC power output, Advance means of harmonics should be employed. These includes: staircase modulation, stepped modulation, harmonic injection modulation and trapezoidal modulation.

2. To ensure high switching speed of order of 100 nanoseconds, a proper charging and discharging circuit should be provided to every CMOS logic inverter gate.

3. The output frequency can still be improved by loading the registers in the Arduino responsible for creating delay with different values until the desired output frequency is achieved.

APPENDIX

Three phase inverter conduction modes

180 Conduction

There are three modes of operation in a half cycle and the equivalent circuits are shown in fig C.1. the output waveforms for the line voltages are also shown in fig C.2

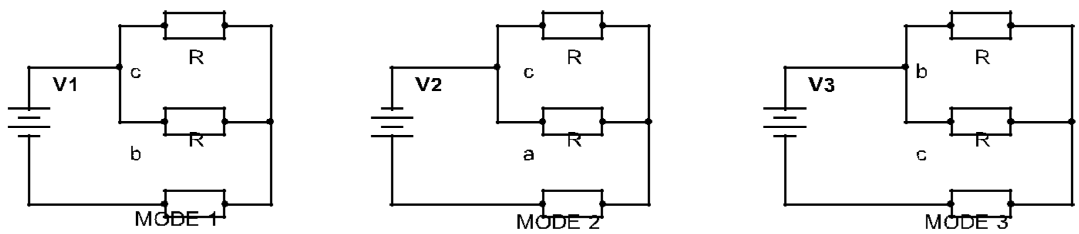


Figure C.1

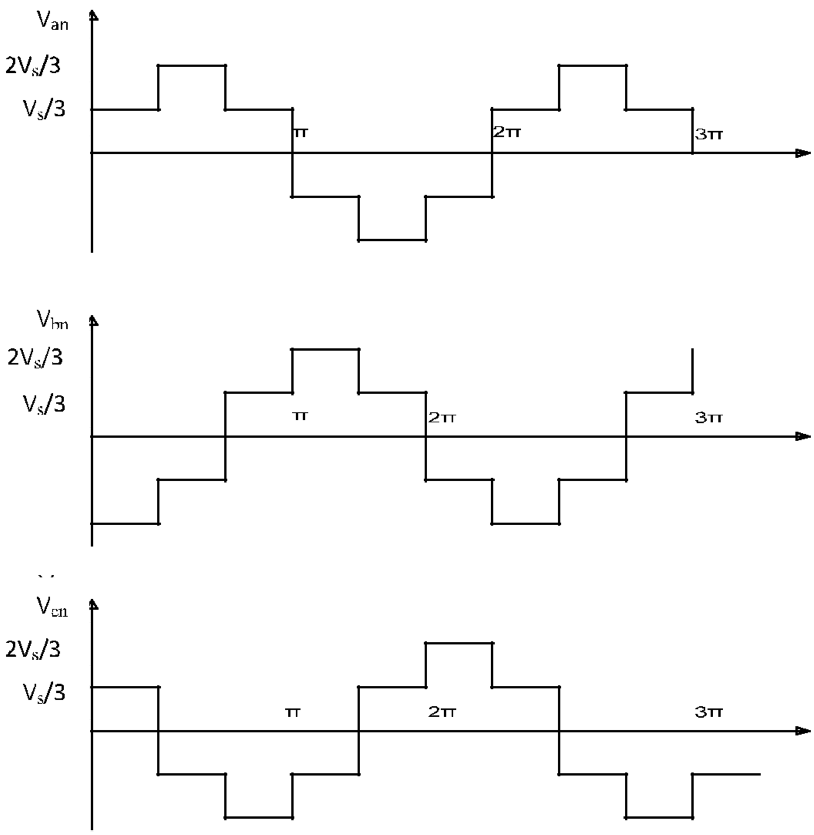


Figure C.2 Phase voltage for 180° conduction

During mode 1, for $0 \leq \omega t \leq \frac{\pi}{3}$

$$R_{cq} = R + \frac{R}{2}R = \frac{3R}{2}$$

$$i_1 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = V_{cn} = \frac{i_1 R}{2} = \frac{V_s}{3}$$

$$V_{bn} = -i_1 R = \frac{-2V_s}{3}$$

During mode 2, for $\frac{\pi}{3} \leq \omega t \leq \frac{2\pi}{3}$

$$R_{cq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_2 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = i_2 R = \frac{2V_s}{3}$$

$$V_{bn} = V_{cn} = \frac{-i_2 R}{2} = \frac{-V_s}{3}$$

During mode 3 for, $\frac{2\pi}{3} \leq \omega t \leq \pi$

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_3 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = V_{bn} = \frac{i_3 R}{2} = \frac{V_s}{3}$$

$$V_{an} = -i_3 R = \frac{-2V_s}{3}$$

The instantaneous line-to-line current voltage, V_{ab}, in Figure C.2 can be expressed in a Fourier series, recognizing that V_{ab} is shifted by 30 ° and the even harmonics are zero.

$$V_{ab} = \sum_{n=1,3,5....}^{\infty} \frac{4v_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{\pi}{6}\right) \quad \text{(a)}$$

V_{bc} and V_{ca} can be found by phase shifting V_{ab} by 120° and 240° respectively.

$$V_{bc} = \sum_{n=1,3,5....}^{\infty} \frac{4v_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{\pi}{2}\right) \quad \text{(b)}$$

$$V_{ca} = \sum_{n=1,3,5....}^{\infty} \frac{4v_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{7\pi}{6}\right) \quad \text{(c)}$$

From equations (a), (b) and (c) it can be noticed that the triple harmonics n=3, 6, 9,... would be zero in the line to line voltages.

The line to line RMS voltages can be found from,

$$V_L = \left(\frac{2}{2\pi}\int_0^{2\pi/3} V_s^2 d(\omega t)\right)^{\frac{1}{2}} \quad \text{(e)}$$

$$= \sqrt{\frac{2}{3}}\, V_s$$

$$= 0.8165\, V_s$$

From equation (a) the RMS nth component of the line voltage is

$$V_{LN} = \frac{4V_s}{\sqrt{2}\, n\pi} \cos\frac{n\pi}{6} \quad \text{(f)}$$

Which for n=1, gives the fundamental line voltage.

$$V_{L1} = \frac{4V_s}{\sqrt{2}\pi} \cos 30^{\circ}$$

The RMS value of the line-to-neutral voltages can be found from the line voltage

$$V_p = \frac{V_L}{\sqrt{3}} = \sqrt{2}\, \frac{V_s}{3} = 0.4714\, V_s$$

With resistive load, the diodes across the transistors have no function. If the load is inductive, the current in each arm of the inverter would be delayed to its voltage.

The transistors must be continuously gated since the conduction time of transistors and diodes depends on the load power factor.

For a Y connected load, the phase voltage is Van = $\frac{v_{ab}}{\sqrt{3}}$ with a delay of 30°.

The line current i_a for an RL load is given by:

$$i_a = \sum_{n=1,3,5...}^{\infty} \left[\frac{4V_s}{\sqrt{3}\, n\pi \sqrt{(R^2 + (n\omega_L)^2)}} \cos\frac{n\pi}{6}\right] \sin(n\omega t - \theta n)$$

Where $\theta_n = \tan^{-1}\frac{n\omega_L}{R}$

120° conduction mode of operation

There are three modes of operation in one-half cycle and the equivalent circuits are Y connected loads.

During mode1, for $0 \le \omega t \le \frac{\pi}{3}$, transistors 1 and 6 conduct,

$$Van = \frac{V_s}{2},\ Vbn = \frac{V_s}{2}, Vcn = 0$$

During mode 2, for $\frac{\pi}{3} \le \omega t \le \frac{2\pi}{3}$, transistors 1 and 2 conduct,

$$Van = \frac{V_s}{2},\ Vbn = 0, Vcn = \frac{-V_s}{2}$$

During mode 3 for, $\frac{2\pi}{3} \le \omega t \le \pi$, transistors 2 and 3 conduct

$$Van = 0, Vbn = \frac{V_s}{2}, Vcn = \frac{-V_s}{2}$$

The line to neutral voltages can be expressed in Fourier series as

$$V_{an} = \sum_{n=1,3,5...}^{\infty} \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t + \frac{\pi}{6}\right)$$

$$V_{bn} = \sum_{n=1,3,5...}^{\infty} \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{\pi}{2}\right)$$

$V_{cn} = \sum_{n=1,3,5\ldots}^{\infty} \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{7\pi}{6}\right)$

The line voltage between line a and b is $V_{ab} = \sqrt{3}\ V_{an}$ with a phase advance of 30 . There is a delay of 30° between turning off transistor Q1 and turning on transistor Q4. Thus there should be no short circuit of the dc supply.

At any time there, two load terminals are connected to the dc supply and the third one remains open. Since the transistor conducts for 120° the transistors are less utilized as compared to that of the 180° conduction for the same load.

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