Project Report
Three phase Controlled Inverter

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Declaration

We declare that the work contained in this thesis/report is my own, except where explicitly stated otherwise. In addition this work has not been submitted to obtain another degree or professional qualification.

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Contents

List of Figures

Abstract

This project covers the basic blocks of power electronics i.e rectifier and inverter. The input is three phase 400V line-line voltage which is passed through the three phase controlled rectifier. The firing angles are . The gate pulses are adjusted such that no two thyristors in a column are turned on at the same time because it will cause short circuit among the phases. The ouput voltage of rectifier is 400Vdc. It is fed into the three phase inverter. The inverter used in this case is sinousidal pulse-width-modulation inverter. The three gate pulses are generated by comparison of three sine voltages displaced by 120 degree with the saw-tooth reference waveform. The output is three phase distorted sine waveform it then passed through the LCL filter whose output is pure sine waveform. . . .

Chapter 1

Introduction

1.1 Motivation

The main objective or motivation of this report is to increase the knowledge about the concepts of Power Electronics. To practically apply all the concepts and prove them. This project is simulations based and is being done on Simulink ,Matlab. In this we have Simulated the three type of circuits which covers most of the power electronics course and have matched the simulated results with the theoretical ones. The building blocks of the project are rectifier ,inverter and LCL filter. The industrial application of this in the ups in which AC is first converted into DC which is used for charging the batteries and the output of batteries which is DC voltage is then converted into AC through inverters.

1.2 Problem Statment

The problem given in the statement is to first input the three phase AC source whose magnitude is to be 400V. The three phases are displaced by 120 degrees as in case of practical ones. Then the input is to be passed through rectifier which converts it into DC. The Rectifier we have used in this case in controlled rectifier whose firing angle can be adjusted such that we can vary the the output voltage. The gate pulses are used for controlling the firing angle .The gate pulses are such that no thristors of same leg will be on at the time instant .The output voltage is 400Vdc. This DC voltage is then fed into the inverter circuit. The inverter being used is three phase sine-pwm. The inverter converts the dc voltage into three phase AC. The three phase AC is such that it contains the steps. The three steps are then converted into the sine waveform using the LCL filter. The filter is designed such that the output voltage is pure sine waveform.

Chapter 2

Literature Review

2.1 Rectifier

Unlike diode rectifiers, PCRs or phase controlled rectifiers has an advantage of regulating the output voltage. The diode rectifiers are termed as uncontrolled rectifiers. When these diodes are switched with Thyristors, then it becomes phase control rectifier. The o/p voltage can be regulated by changing the firing angle of the Thyristors. The main application of these rectifiers is involved in speed control of DC motor.

2.1.1 Phase Controlled Rectifier

The term PCR or Phase controlled rectifier is a one type of rectifier circuit in which the diodes are switched by Thyristors or SCRs (Silicon Controlled Rectifiers). Whereas the diodes offer no control over the o/p voltage, the Thyristors can be used to differ the output voltage by adjusting the firing angle or delay. A phase control Thyristor is activated by applying a short pulse to its gate terminal and it is deactivated due to line communication or natural. In case of heavy inductive load, it is deactivated by firing another Thyristor of the rectifier during the negative half cycle of i/p voltage.

2.1.2 Three-phase bridge rectifier controlled

The controlled three-phase bridge rectifier uses thyristors in place of diodes. The output voltage is reduced by the factor cos(a).

$$V_{dc} = \frac{3\sqrt{3}V_{peak}cos\alpha}{\pi} \tag{2.1}$$

Or, expressed in terms of the line to line input voltage:

$$V_{dc} = \frac{3V_{LLpeak}cos\alpha}{\pi} \tag{2.2}$$

Where:
VLLpeak, the peak value of the line to line input voltages.

Vpeak, the peak value of the phase (line to neutral) input voltages.
a, firing angle of the thyristor (0 if diodes are used to perform rectification). The above equations are only valid when no current is drawn from the AC supply or in the theoretical case when the AC supply connections have no inductance. In practice, the supply inductance causes a reduction of DC output voltage with increasing load, typically in the range 10–20 % at full load.

The effect of supply inductance is to slow down the transfer process (called commutation) from one phase to the next. As result of this is that at each transition between a pair of devices, there is a period of overlap during which three (rather than two) devices in the bridge are conducting simultaneously. The overlap angle is usually referred to by the symbol mu (or u), and may be 20 30° at full load.
With supply inductance taken into account, the output voltage of the rectifier is reduced to.

$$V_{dc} = \frac{3V_{LLpeak}cos\alpha}{\pi} \tag{2.3}$$

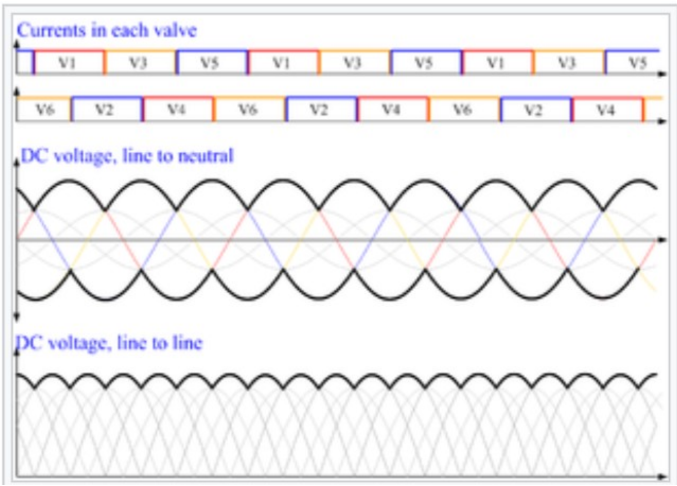


Figure 2.1: Outputs of Rectifier for firing agle zero

2.2 Inverter

A power inverter, or inverter, is an electronic device that converts direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific circuitry[1].
Inverters can be divided into two kinds:

- Voltage Source Inverters (VSI)
- Current Source Inverters (CSI)

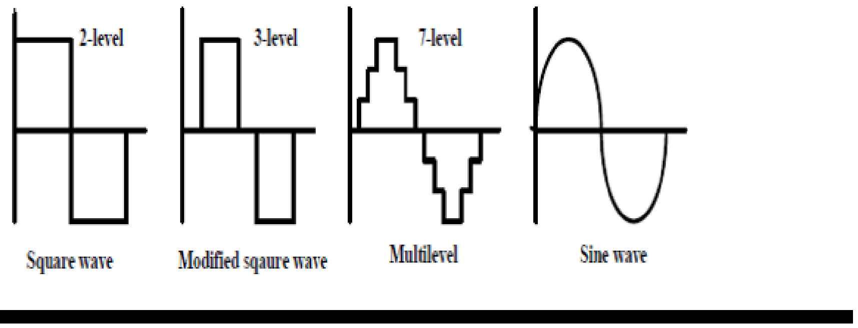


FIGURE 2.2: Outputs of Inverters at Zero firing angle

The basic component of an inverter is fast working switch like IGBT or MOSFET.However, later is more preferred because main advantage of a MOSFET is that it requires almost no input current to control the load current, when compared with IGBT.

2.2.1 MOSFET

The MOSFET [2.3] is a type of field-effect transistor (FET), most commonly fabricated by the controlled oxidation of silicon. It has an insulated gate, whose voltage determines the conductivity of the device. This ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals.
The Mosfet is further divided into n-channel Mosfet and p-channel Mosfet depending upon formation and has three modes of opertion as :

- Cutoff mode
- Ohmic mode
- Active mode

For switciing purposes Mosfet is used in active and cutoff mode.

2.3 Hierarchy of Inverter

General Hierarchy of inverter2.4 is shown below.Under the perspective of project the selective hierarchy will start from basic inverter to unequal dc sources cascaded h-bridge multilevel inverters.

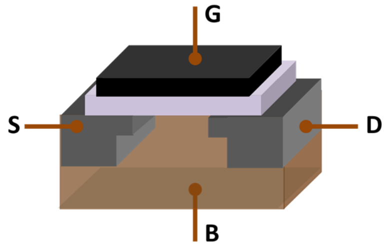


FIGURE 2.3: MOSFET showing gate (G), body (B), source (S) and drain (D) terminals. The gate is separated from the body by an insulating layer (white)

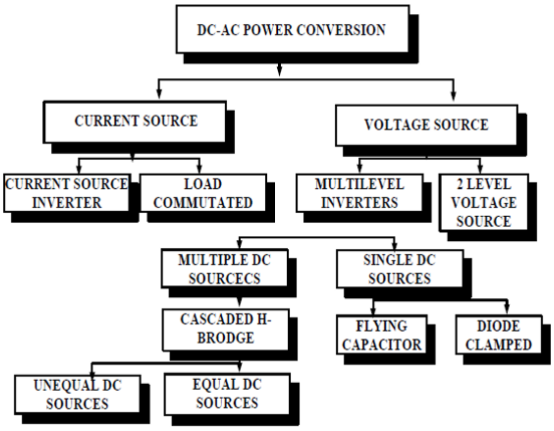


FIGURE 2.4: Hierarchy of inverter

2.4 Voltage Source Inverter

If the input dc is voltage source, the inverter is called a voltage source inverter.The VSI circuit has direct control over output (ac) voltage. Shape of voltage wave-forms output by an ideal VSI should be independent of load connected at the output.
The simplest dc voltage source for a VSI may be a battery bank, which may consist of several cells in series-parallel combination.A voltage source is called stiff, if the source voltage magnitude does not depend on load connected to it. All VSI assume stiff voltage supply at the input.Some examples where voltage source inverters are used are: UPS units, adjustable speed drives (Automatic Star Delta) for ac motors, electronic frequency changer circuits etc.
The achievable magnitude of ac voltage is limited by the magnitude of inputc dc voltage. In some cases the inverter output voltage is stepped up using a transformer to meet the load requirement. VSI is further divided into two types:

- Multilevel Inverters
- 2 Level Voltage Source

2.5 180 conduction mode

In this mode of conduction, every device is in conduction nation for one hundred eighty degree in which they are switched ON at 60 durations. The terminals A, B and C are the output terminals of the bridge that are connected to the three- delta or star connection of the load. The operation of a balanced big name linked load is defined within the diagram underneath. For the length 0 60 the factors S1, S5 and S6 are in conduction mode. The terminals A and C of the load are connected to the supply at its nice point. The terminal B is hooked up to the source at its poor point. In addition, resistances R/2 is among the neutral and the fine cease at the same time as resistance R is between the impartial and the negative terminal. The load voltages are gives as follows;

$$V_{an} = \frac{V}{3} \tag{2.4}$$

$$V_{bn} = \frac{2V}{3} \tag{2.5}$$

$$V_{cn} = \frac{V}{3} \tag{2.6}$$

The line voltages are given as follows;

$$V_{ab} = V_{an} - V_{bn} = V \tag{2.7}$$

$$V_{bc} = V_{bn} - V_{cn} = V \tag{2.8}$$

$$V_{ca} = V_{cn} - V_{an} = 0 \tag{2.9}$$

2.6 H Bridge

An H bridge 2.8 enables a reverse voltage to be applied across a load.
These circuits are often used in multiple applications to allow bidirectional movement of DC motors, DC-to-AC converters, AC/AC converters,DC-to-DC push–pull converter and many other kinds of power electronics use H bridges.
An H bridge is built with four switches 2.3. When the switches S1 and S4 are closed (and S2 and S3 are open) a positive voltage will be applied across the motor and vice versa. The point to ponder is that switches S1 and S2 should never be closed at the same time, as this would cause a short circuit on the input voltage source as seen from the figure. The same applies to the switches S3 and S4.
Thus, functioning of a single H-bridge is similar to that of conventional 2-level inverter. Each H-bridge requires an isolated dc source/capacitor to generate its corresponding output. The switches are activated in such a way that the output voltage across the load terminals is the aggregation of the voltage generated by the H-bridge.

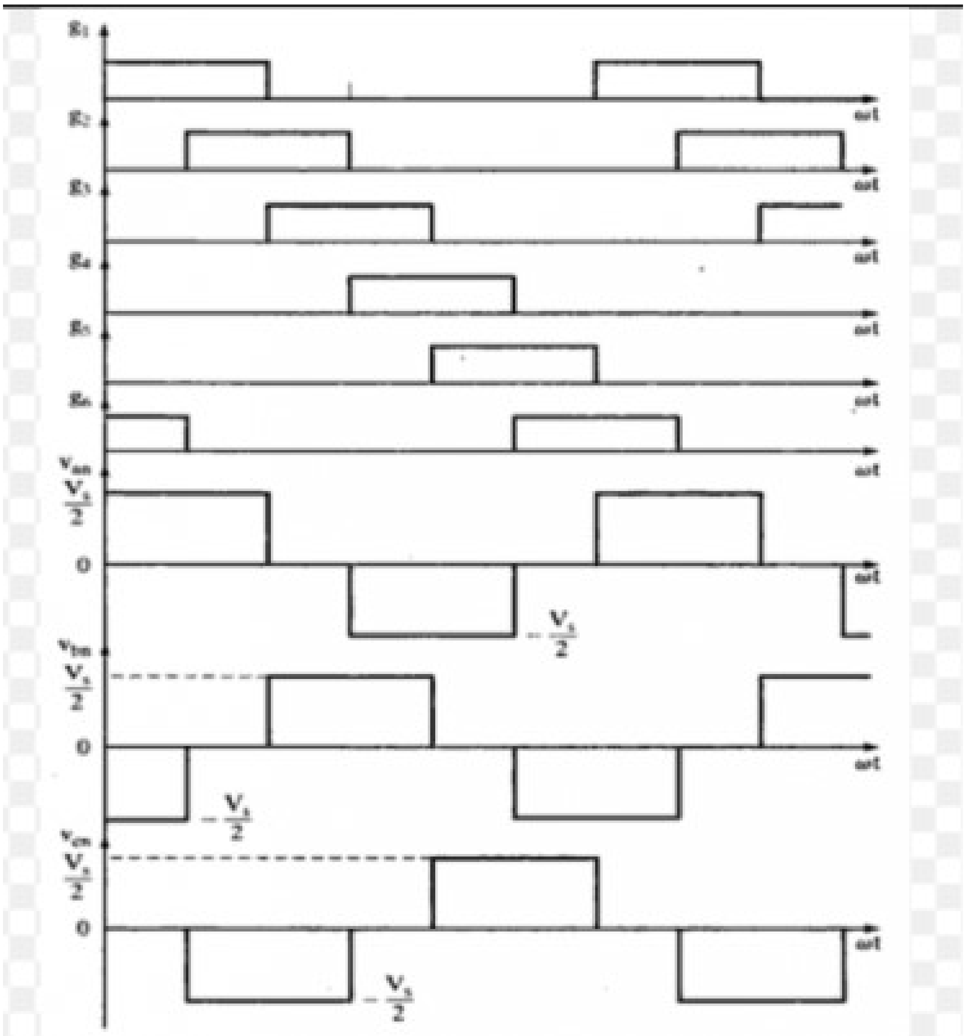


FIGURE 2.5: 180 Conduction

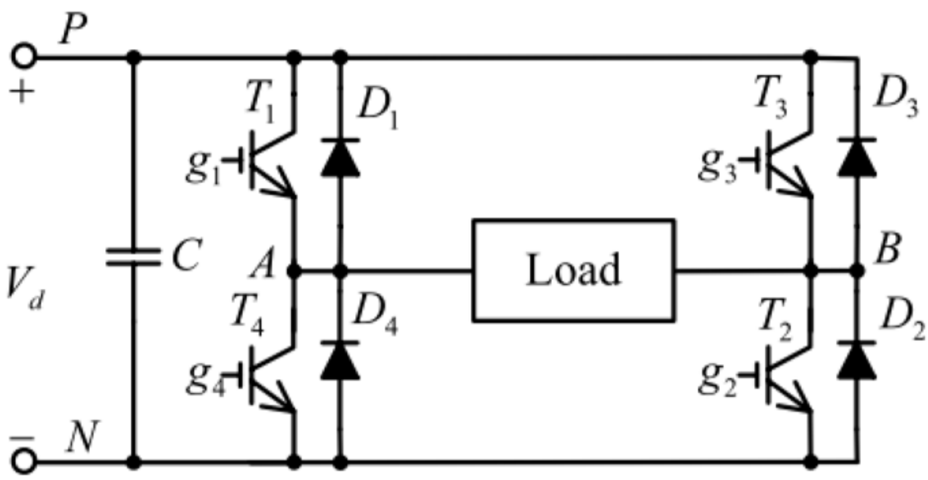


FIGURE 2.6: Unit H Bridge

2.7 Modulation Techniques for Inverter

The inverter dc voltage input V_d is usually fixed while its ac output voltage $V_(AB)$ can be adjusted by different modulation schemes. Main objectives of modulation strategy are as follows:

- Capable of operating wide range of modulation index, preferably from 0 to 1
- Less switching loss with improved overall efficiency
- Less THD in output voltage
- Obtaining high magnitude of the output fundamental frequency component
- Easy for implementation for practical applications
- Less computational burden and time

However, for the inverters used in high power applications, THD, switching losses, switching capabilities and inverter efficiency are the critical issues that must be taken into account in performance evaluation.

2.8 Classification of Modulation Techniques

Based on switching frequency for computational work modulation techniques are classified as follows:

- Sinusoidal PWM and Space Vector PWM techniques for high switching frequency.
- Selective Harmonic Elimination and Space Vector Control for fundamental switching frequency

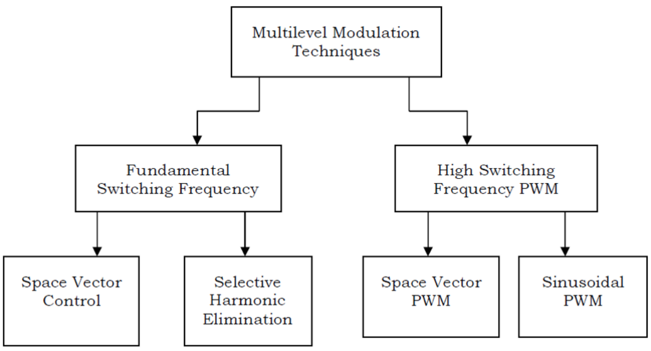


FIGURE 2.7: Classification of Modulation Techniques

2.9 Sinusoidal PWM

Carrier based sinusoidal PWM techniques which are employed in control CHBMLI can be generally classified into two categories:

- Phase-shifted carrier based pulse width modulation technique.
- Level-shifted carrier based pulse width modulation technique.

2.9.1 Level-shifted carrier based PWM (LSCPWM) technique

Level-shifted carrier based PWM (LSCPWM) technique is used to control neutral point clamped inverter and to control cascaded multilevel inverters. This technique has drawbacks such as uneven distribution of power among cells and high THD in output voltage and current wave forms. LSCPWM is further divided into three categories:

- Phase Disposition (PD-PWM): wherein all the carrier signals are in same phase.
- Phase Opposition Disposition (POD-PWM): wherein the carrier signals above the zero are out of phase with those below the zero by 180^o.
- Alternative Phase Opposition Disposition (APOD-PWM): wherein the adjacent carrier signals are out of phase by 180^o.

2.9.2 Phase shifted carrier based PWM (PSCPWM) technique

Phase shifted carrier based pulse width modulation (PSCPWM) technique is commonly used modulation technique for control of cascaded multilevel inverters because of the following reasons:

- Better harmonic profile of output voltage and current wave-forms.
- Even power distribution among levels.
- Easy to implement independently.

These advantages made PSCPWM technique popular compared to LSCPWM technique to control CHB multilevel inverters.
Generally, a multilevel inverter with m-level voltage requires $m-1$ triangular carriers. All the carriers have same frequency and same peak-to-peak amplitude with phase shift($\phi_(cr)$)between adjacent carrier waves and is given by

$$\phi_(cr) = \frac{360^o}{m-1}$$

The modulating signal is usually a three-phase sinusoidal wave with adjustable amplitude and frequency. By comparing the modulated wave $V_(mA)$ with the carrier waves gate signals are generated. The fundamental voltage component in the inverter output voltage can be controlled by modulation index M_I. Modulation index is the ratio of maximum voltage value of modulating wave V_m to carrier wave voltage $V_(cr)$. The modulation index M_I is usually adjusted by varying V_m by keeping $V_(cr)$ fixed.

$$M_I = \frac{V_m}{V_(cr)}$$

Harmonics in the case the of high switching frequency modulation techniques appears as side-bands around carrier frequency produces high THD which results in trouble some filtering.For the project case multi-carrier sinusoidal PWM technique is used.

2.10 LCL filter

The use of a LCL-filter mitigates the switching ripple injected in the grid by a three-phase active rectifier or Three-phase inverter (VSI). However stability problems could arise in the current control loop. In order to overcome them a damping resistor can be inserted, at the cost of efficiency. On the contrary the use of the active damping seems really attractive but it is often limited by the use of more sensors with respect to the standard control and by the complex tuning procedure.

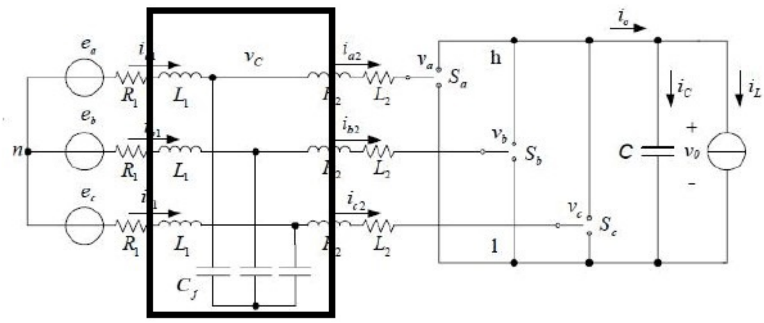
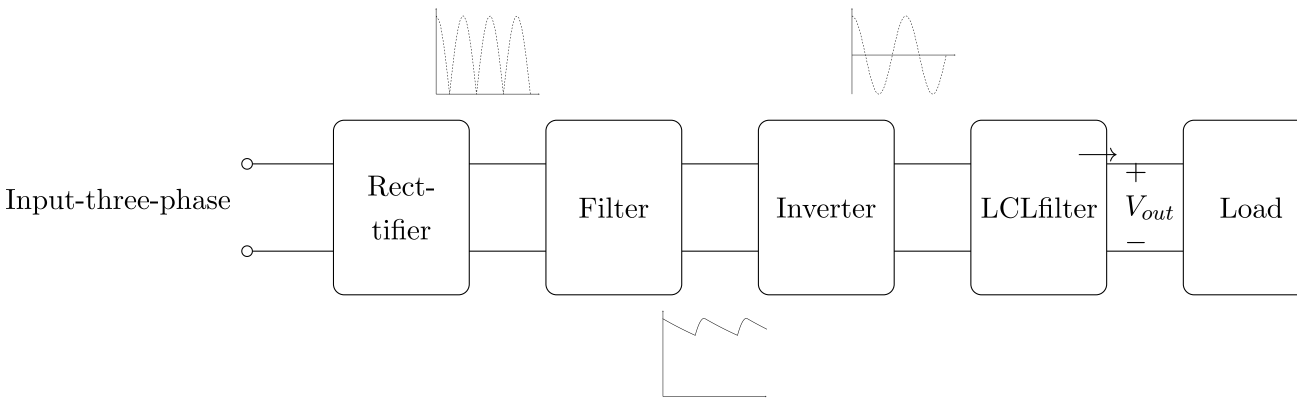


Figure 2.8: LCLfilter Circuit

Chapter 3

Software Implementation

3.1 Block Diagram



3.2 Rectifier

Below is the Matlab Simulink Diagram of Controlled Rectifier The Controlled gate pulse Simulink Diagram

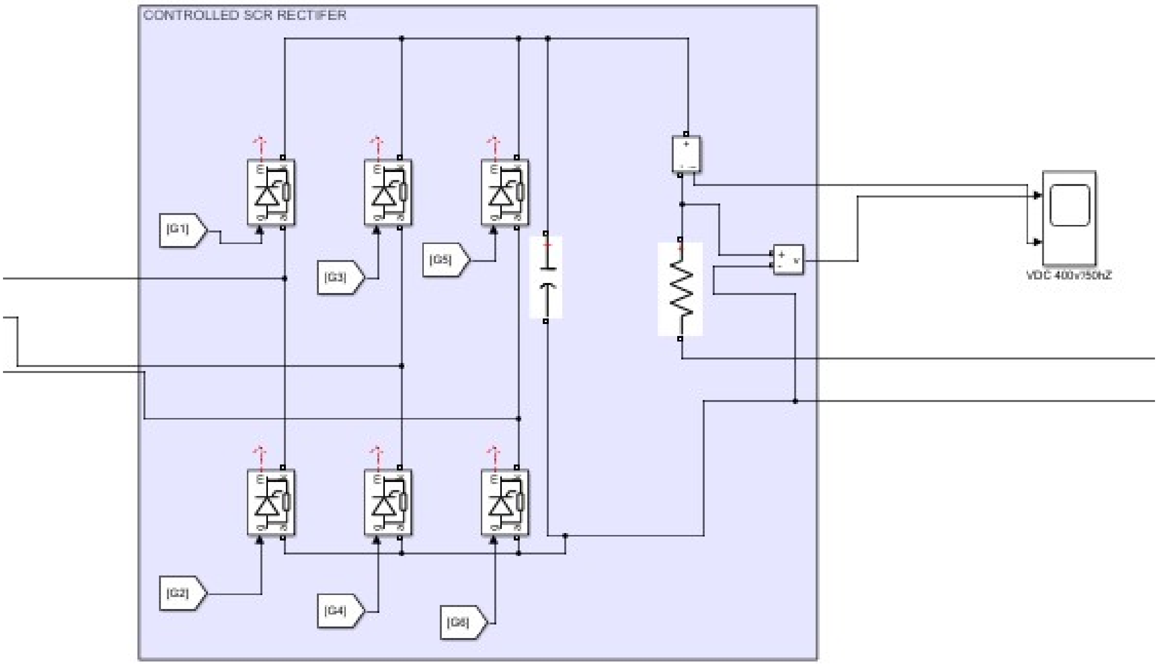


Figure 3.1: Controlled Rectifier Block

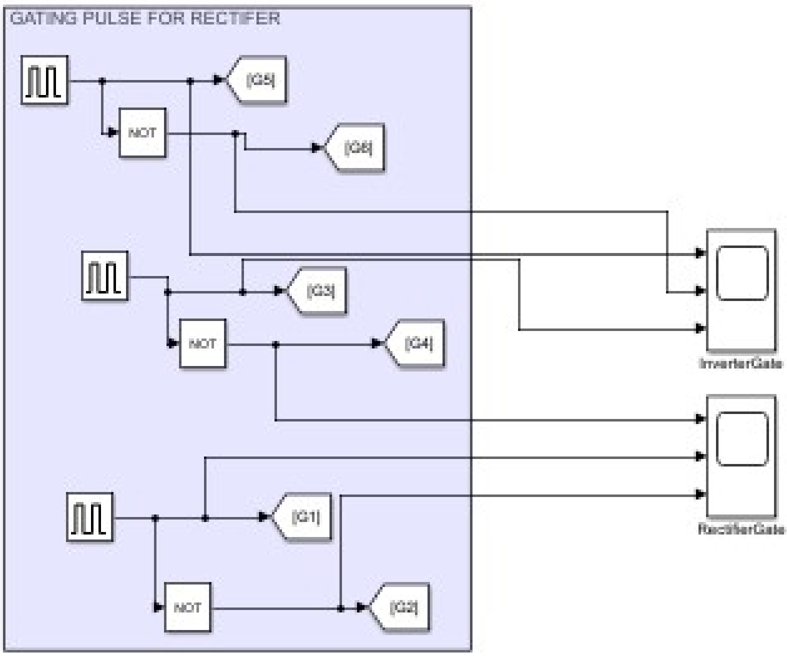


Figure 3.2: Controlled Pulse Block

3.3 Inverter

3.3.1 SPWM Inverter

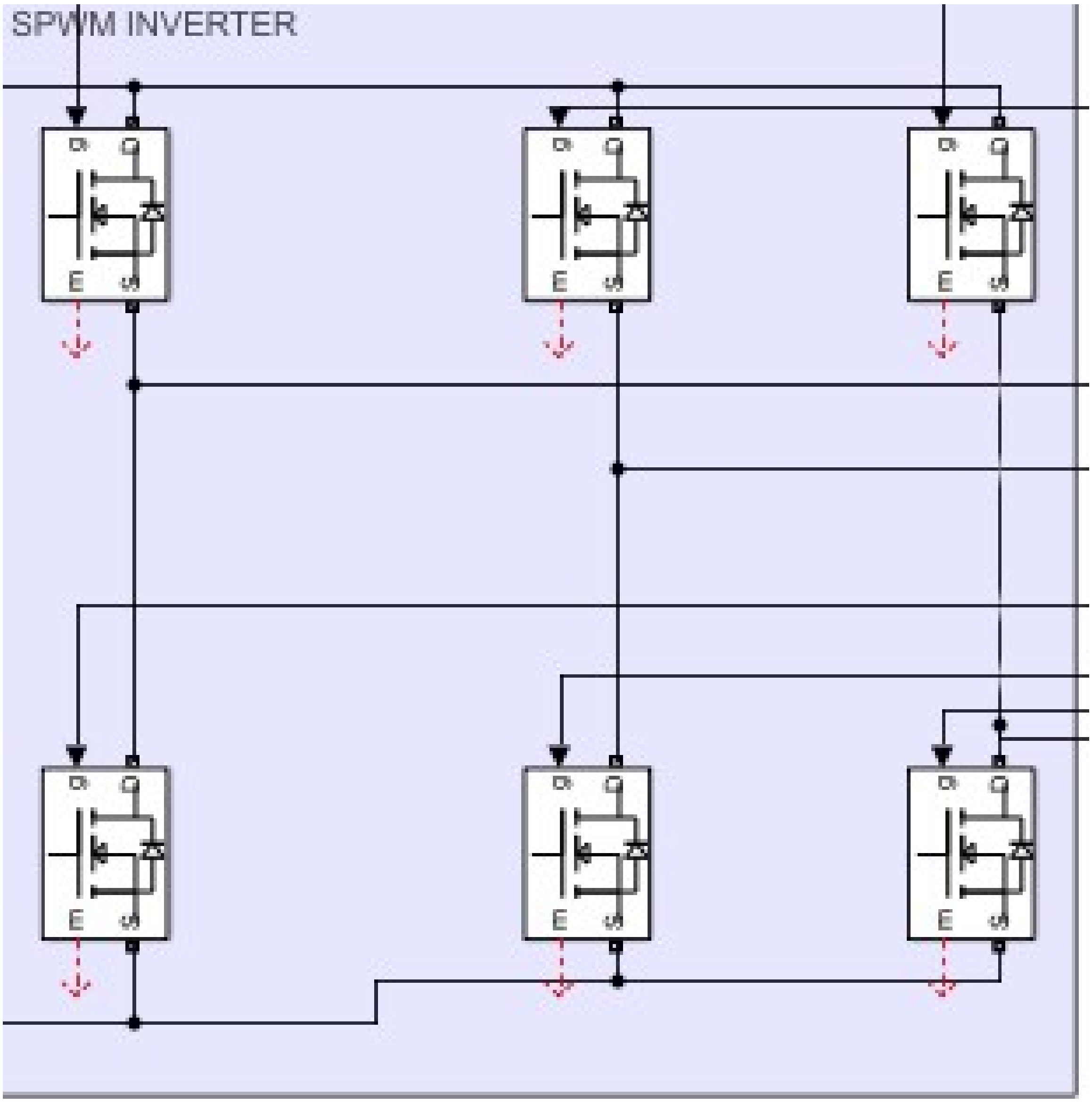


Figure 3.3: Inverter Block

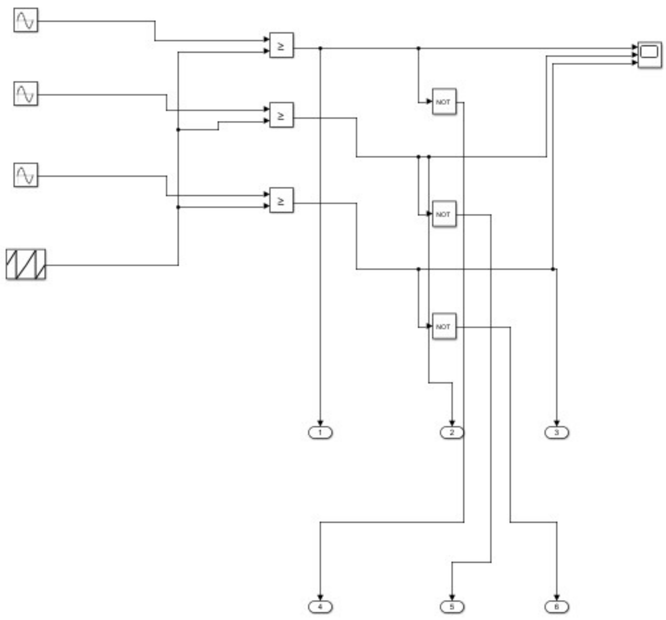


FIGURE 3.4: Controlled Pulse Block

3.3.2 180 consuction Inverter

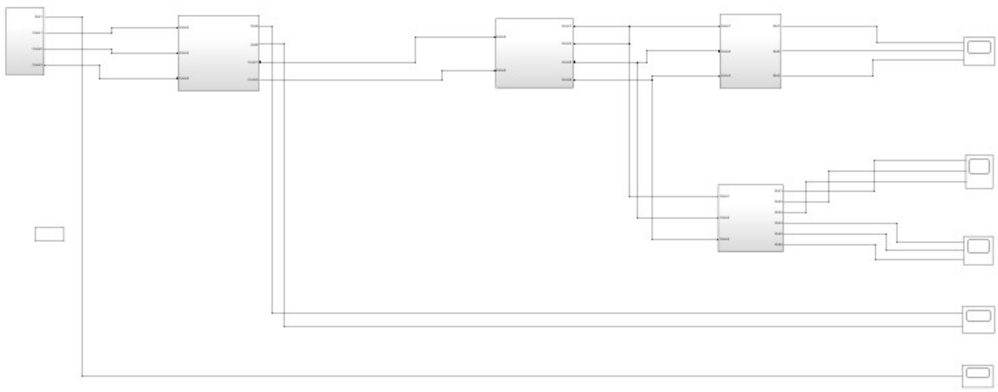


FIGURE 3.5: Simulink Diagram

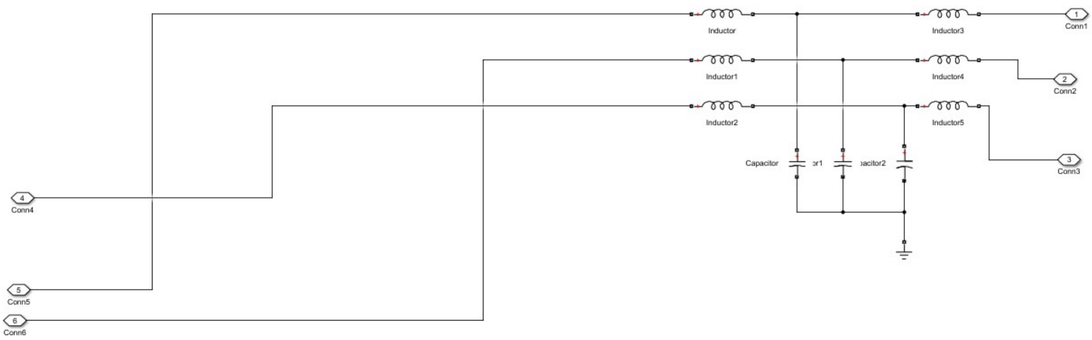


FIGURE 3.6: LCL filter

Chapter 4

Circuit Design and Analysis

4.1 Terminologies

The average value of output load voltage is V_{dc}. The average value of output load current is I_{dc}. Thus, the output dc power:

$$P_{dc} = V_{dc} I_{dc}$$

The rms value of output load voltage is V_{rms}. The rms value of output load current is I_{rms}. Thus, the output ac power[3]:

$$P_{rms} = V_{rms} I_{rms} \tag{4.1}$$

The efficiency of system is defined as

$$\eta = \frac{P_{out}}{P_{in}} \tag{4.2}$$

The effective rms(ac component) of output voltage can be calculated as:

$$V_{ac} = \sqrt[2]{V_{rms}^2 - V_{dc}^2} \tag{4.3}$$

The Form factor FF, describes the shape of output voltage as:

$$FF = \frac{V_{rms}}{V_{dc}} \tag{4.4}$$

The Ripple factor RF,measures the ripple content of output voltage as:

$$RF = \frac{V_{ac}}{V_{dc}} \tag{4.5}$$

Also,

$$RF = \sqrt[2]{FF^2 - 1} \tag{4.6}$$

Next term is TUF (Transformer Utilization Factor) is defined as:

$$TUF = \frac{P_{dc}}{V_s I_s} \tag{4.7}$$

where V_s and I_s are rms values of source voltage and current respectively.
The Displacement Factor DF is defined as;

$$DF = cos\phi \tag{4.8}$$

where ϕ is the angle between fundamental component of input current and input voltage.This ϕ is known as Displacement angle.
The Harmonic factor HF of input current is defined as:

$$HF = \sqrt{(\frac{I_s}{I_{s1}})^2 - 1} \tag{4.9}$$

where I_{s1} is the fundamental component of input current I_s. Both are expressed in RMS.
The input Power factor PF is defined as:

$$PF = \frac{I_{s1} cos\phi}{I_s} \tag{4.10}$$

Crest Factor CF which is of interest to specify the peak current ratings of devices and components is defined as:

$$CF = \frac{I_{speak}}{I_s} \tag{4.11}$$

where I_{speak} is peak input current.
Last one is THD Total Harmonic Distortion is measure harmonic distortion present in a signal and is defined as
"Ratio of sum of powers of all harmonic components to power of fundamental frequency."

$$THD = \frac{\sqrt{\sum_{i=2}^{n} V_i^2}}{V_1} \tag{4.12}$$

4.2 Design

4.2.1 Rectifier

The 3-phase half wave converter combines three single phase half wave controlled rectifiers in one single circuit feeding a common load. The thyristor S1 in series with one of the supply phase windings 'a-n' acts as one half wave controlled rectifier. The second thyristor S2 in series with the supply phase winding 'b-n' acts as the second half wave controlled rectifier. The third thyristor S3 in series with the supply phase winding acts as the third half wave controlled rectifier. Figure bellow shows three phase fully controlled rectifier.

- When thyristor S2 is triggered at

$$wt = \frac{5\pi}{6\alpha} \tag{4.13}$$

  S1 becomes reverse biased and turns-off. The load current flows through the thyristor and through the supply phase winding 'b-n'. When S2 conducts the phase voltage vbnappears across the load until the thyristor S3 is triggered.

- The 3-phase input supply is applied through the star connected supply transformer as shown in the figure. The common neutral point of the supply is connected to one end of the load while the other end of the load connected to the common cathode point.

- When the thyristor S1 is triggered at

$$wt = \frac{\pi}{6} + \alpha = 30^o + \alpha \tag{4.14}$$

  the phase voltage Van appears across the load when S1 conducts. The load current flows through the supply phase winding 'a-n' and through thyristor S1 as long as S1 conducts.

- When the thyristor S3 is triggered at

$$wt = \frac{3\pi}{2} + \alpha = 270^o + \alpha \tag{4.15}$$

  S2 is reversed biased and hence S2 turns-off. The phase voltage Van appears across the load when S3 conducts.

- When S1 is triggered again at the beginning of the next input cycle the thyristor S3 turns off as it is reverse biased naturally as soon as S1 is triggered. The figure shows the 3-phase input supply voltages, the output voltage which appears across the load, and the load current assuming a constant and ripple free load current for a highly inductive load and the current through the thyristor T1.

- For a purely resistive load where the load inductance 'L = 0' and the trigger angle

$$\alpha > \frac{\pi}{6} \tag{4.16}$$

  the load current appears as discontinuous load current and each thyristor is naturally commutated when the polarity of the corresponding phase supply voltage reverses. The frequency of output ripple frequency for a 3-phase half wave converter is fs, where fs is the input supply frequency.The 3-phase half wave converter is not normally used in practical converter systems because of the disadvantage that the supply current waveforms contain dc components.

4.2.2 Inverter

$$VL = 0.4724V_s \tag{4.17}$$

$$V_L = 0.8265V_s \tag{4.18}$$

and final noted that

$$\frac{V_L}{V_P} = \sqrt{3} \tag{4.19}$$

4.2.3 LCL filter

For

$$f_{sw} = 50Hz, f_{res} = 5Hz, S = 25KW, V_0 = 400V \tag{4.20}$$

$$ReactivePower = 5\% ratedpower \tag{4.21}$$

$$Q = 0.05\frac{25000}{3} \tag{4.22}$$

$$Q = V^2 2\pi fC \tag{4.23}$$

$$C = \frac{Q}{2\pi fv^2} \tag{4.24}$$

$$C = 8.29\mu F \tag{4.25}$$

$$L = 0.1\mu H \tag{4.26}$$

$$V_i = 360V \tag{4.27}$$

$$I = 20.8Amp \tag{4.28}$$

$$I_g = 0.0625Amp \tag{4.29}$$

Chapter 5

Simulation Results

5.1 Switching frequency

FIGURE 5.1: Output Volatge at 5KHz

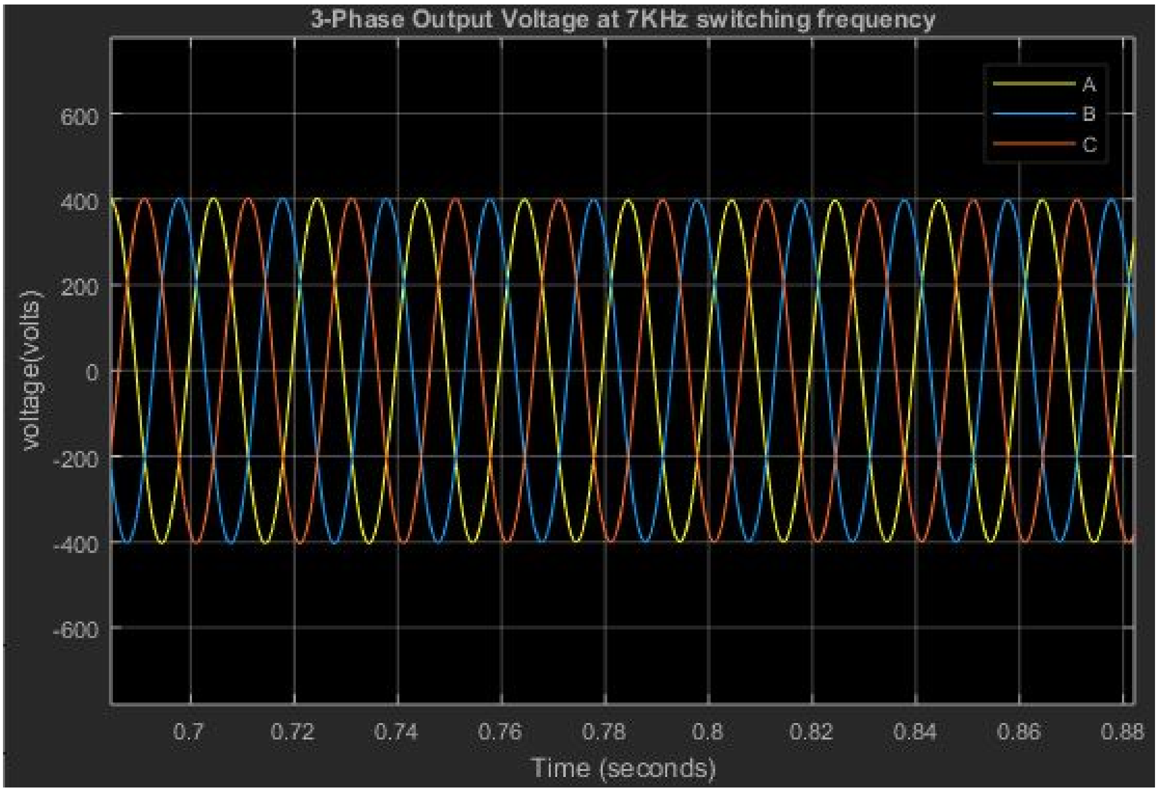


Figure 5.2: Output Volatge at 7KHz

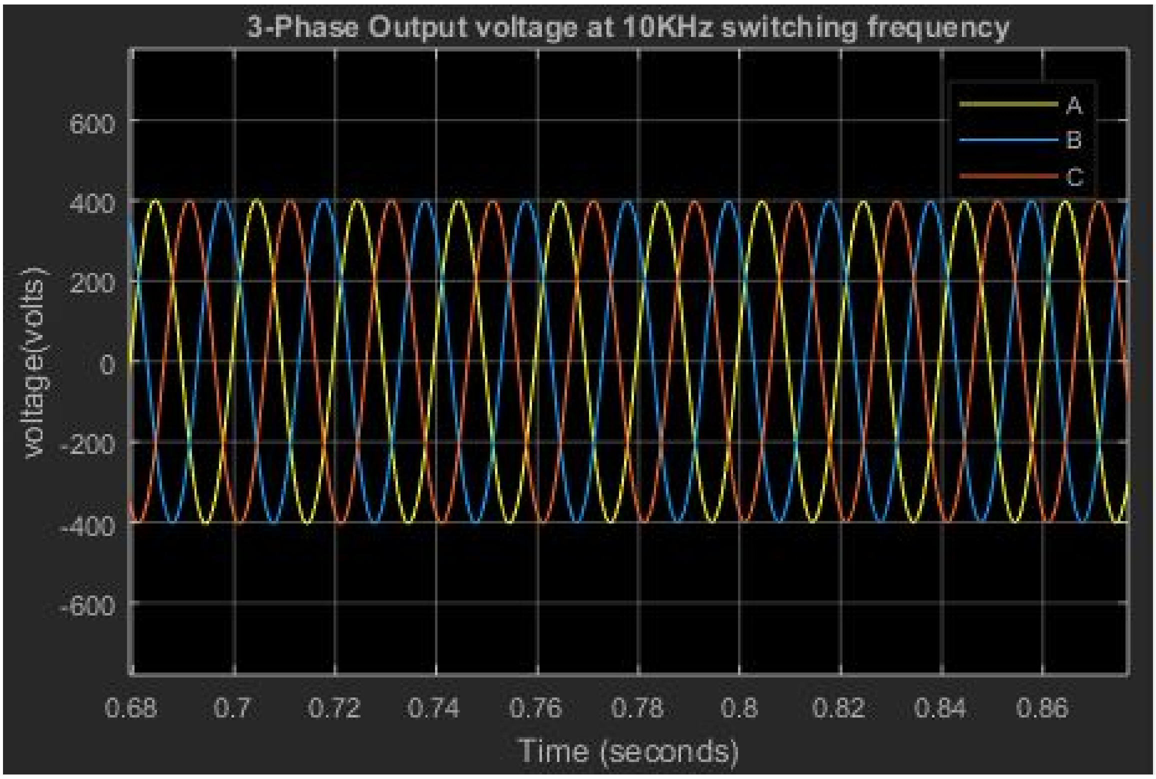


Figure 5.3: Output Volatge at 10KHz

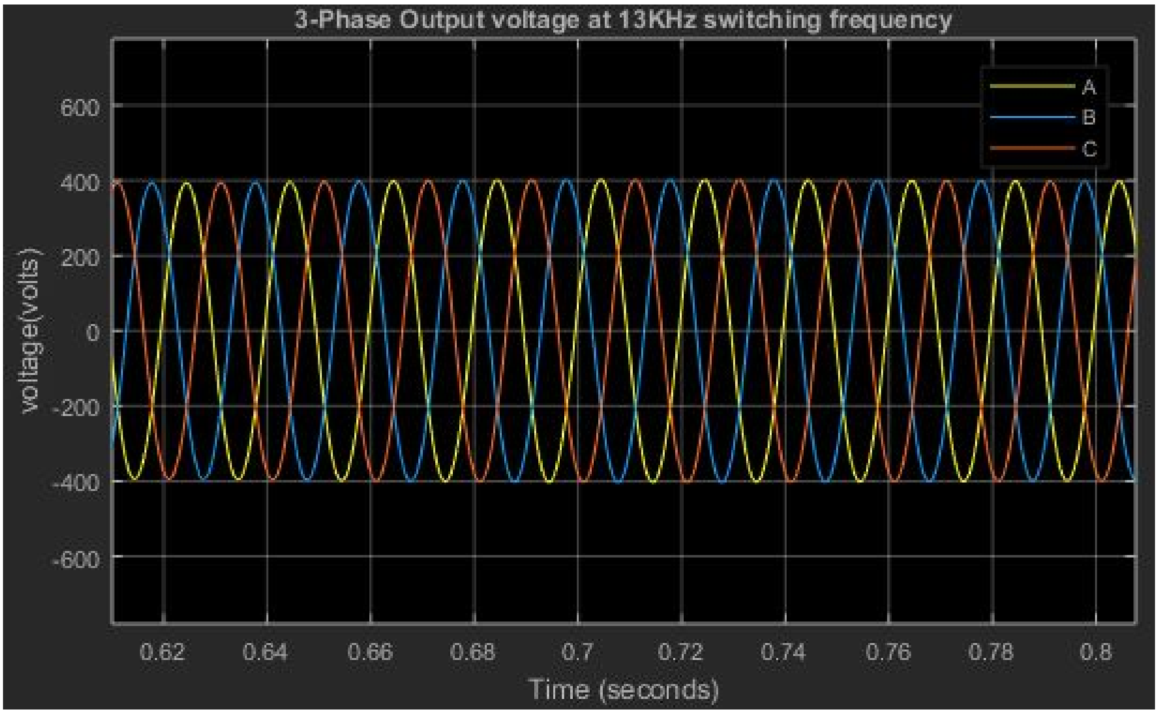


FIGURE 5.4: Output Volatge at 13KHz

FIGURE 5.5: Output Volatge at 15KHz

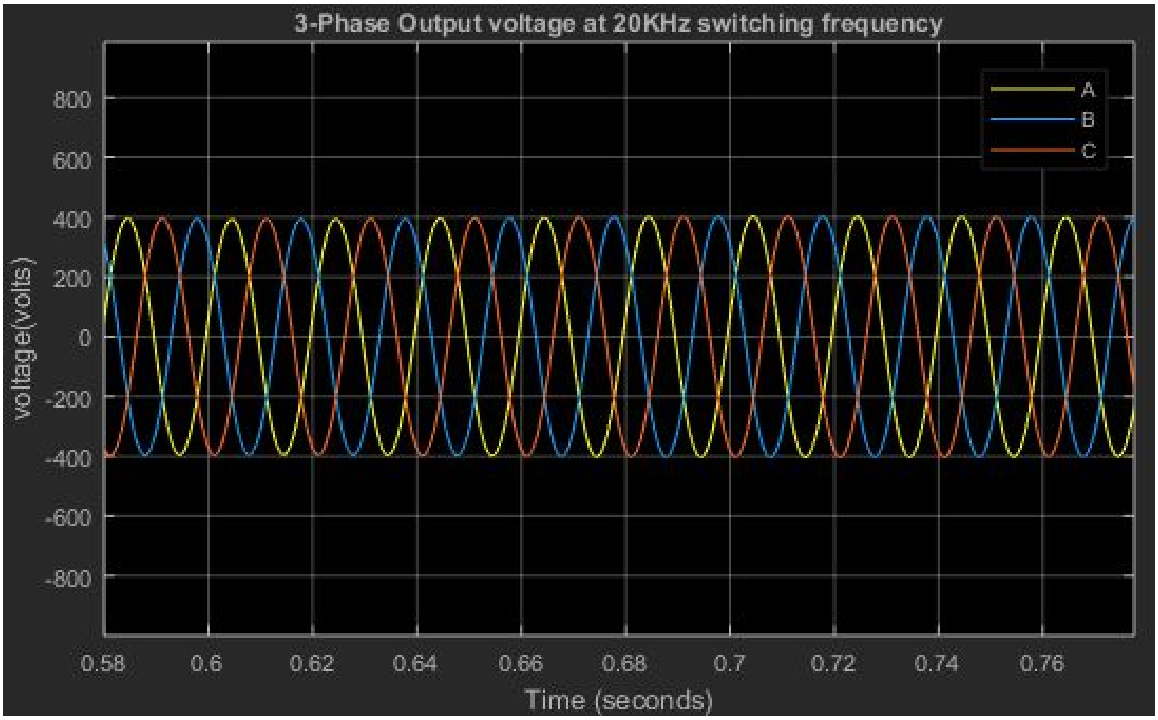


FIGURE 5.6: Output Volatge at 20KHz

5.2 Output at different rated value

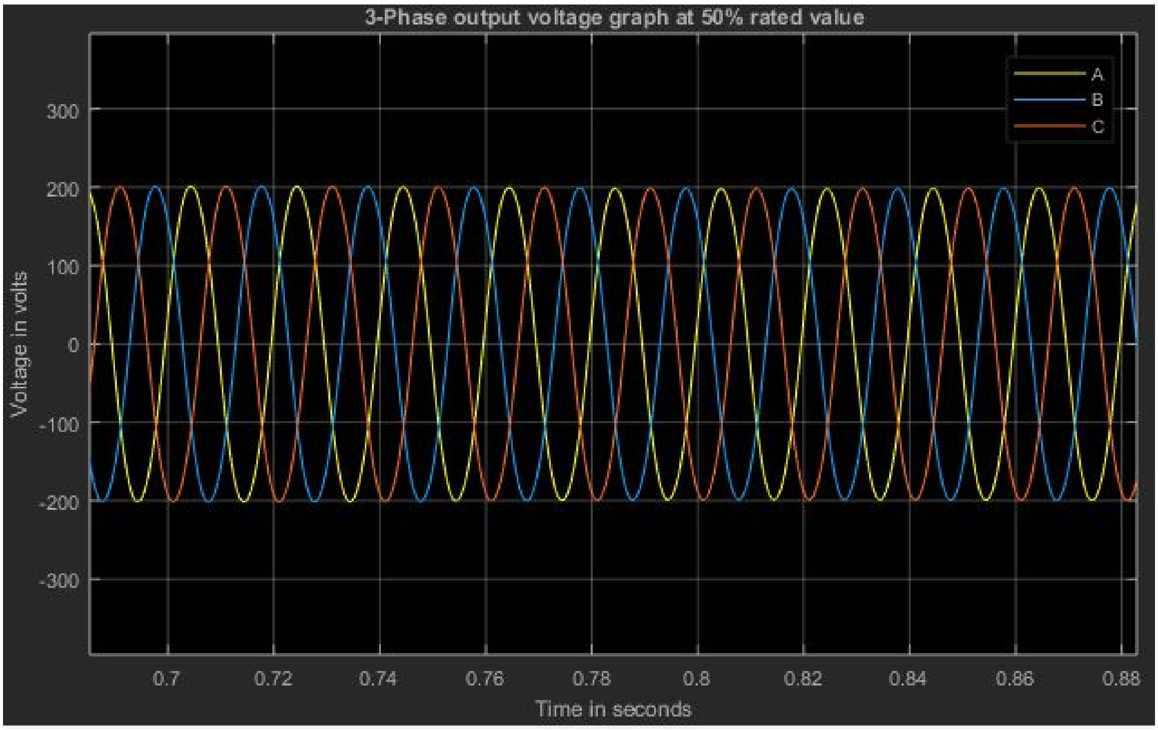


Figure 5.7: Output Volatge at 50% rated

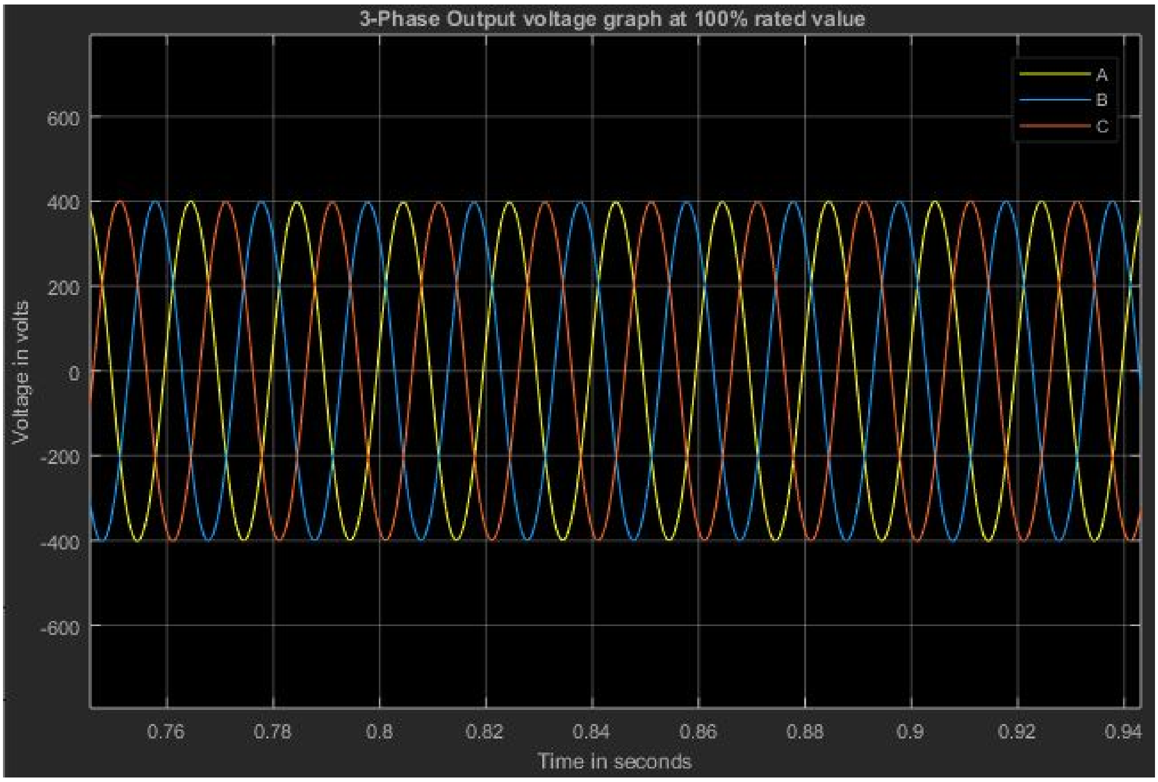


Figure 5.8: Output Volatge at 100% rated

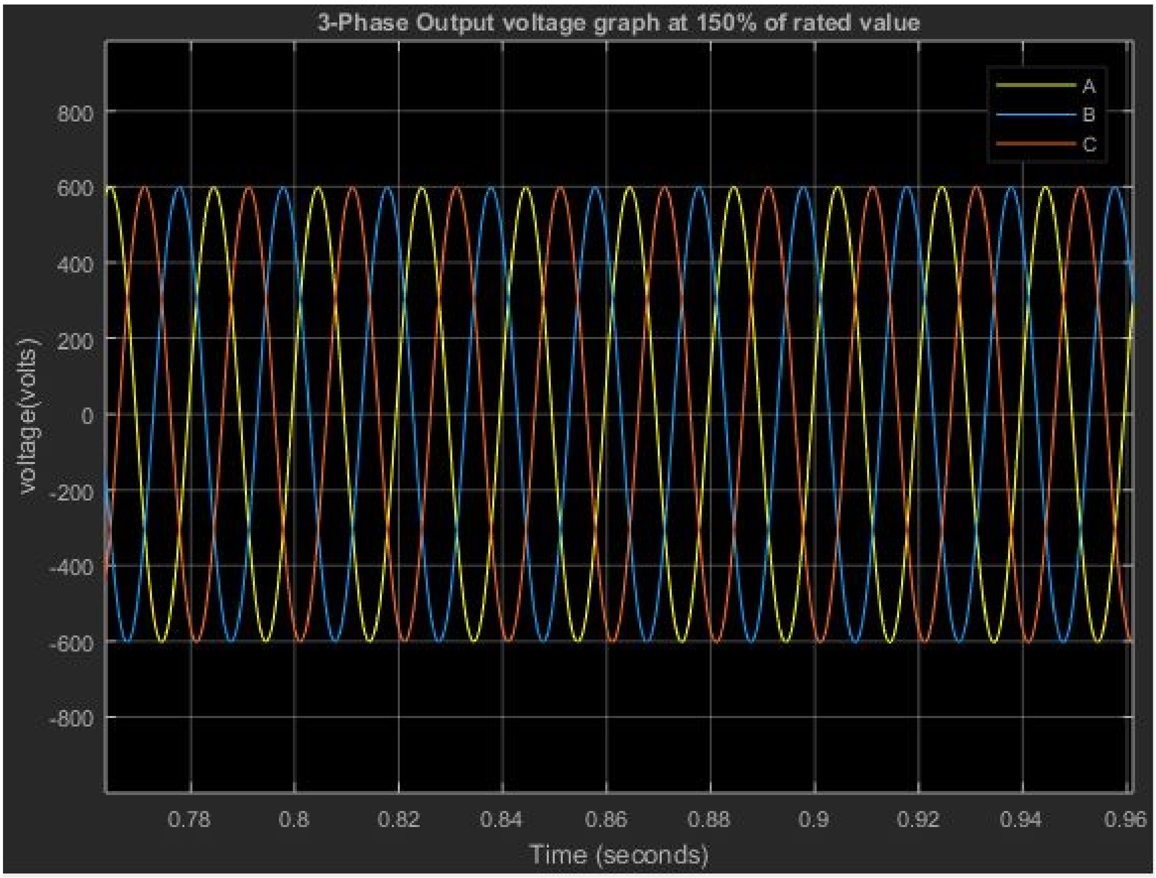


FIGURE 5.9: Output Volatge at 150% rated

5.2.1 Trend between Voltage and Index

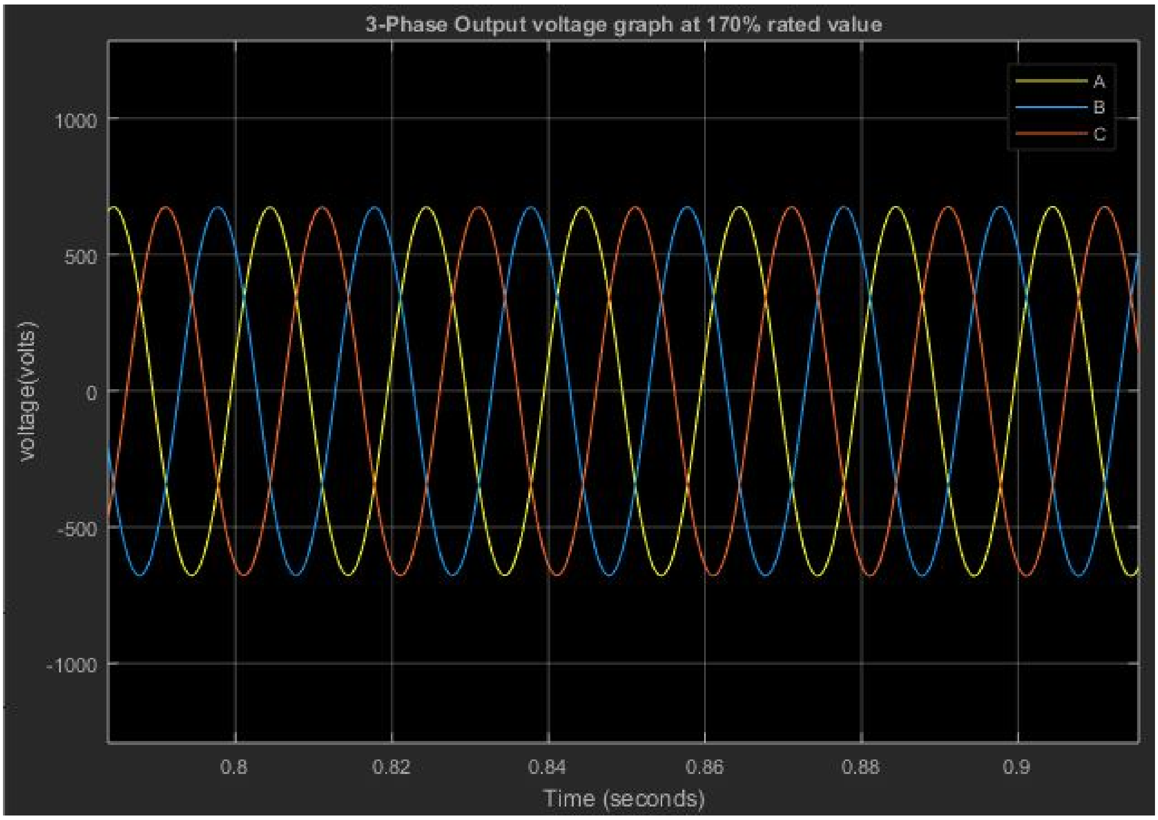


Figure 5.10: Output Volatge at 170% rated

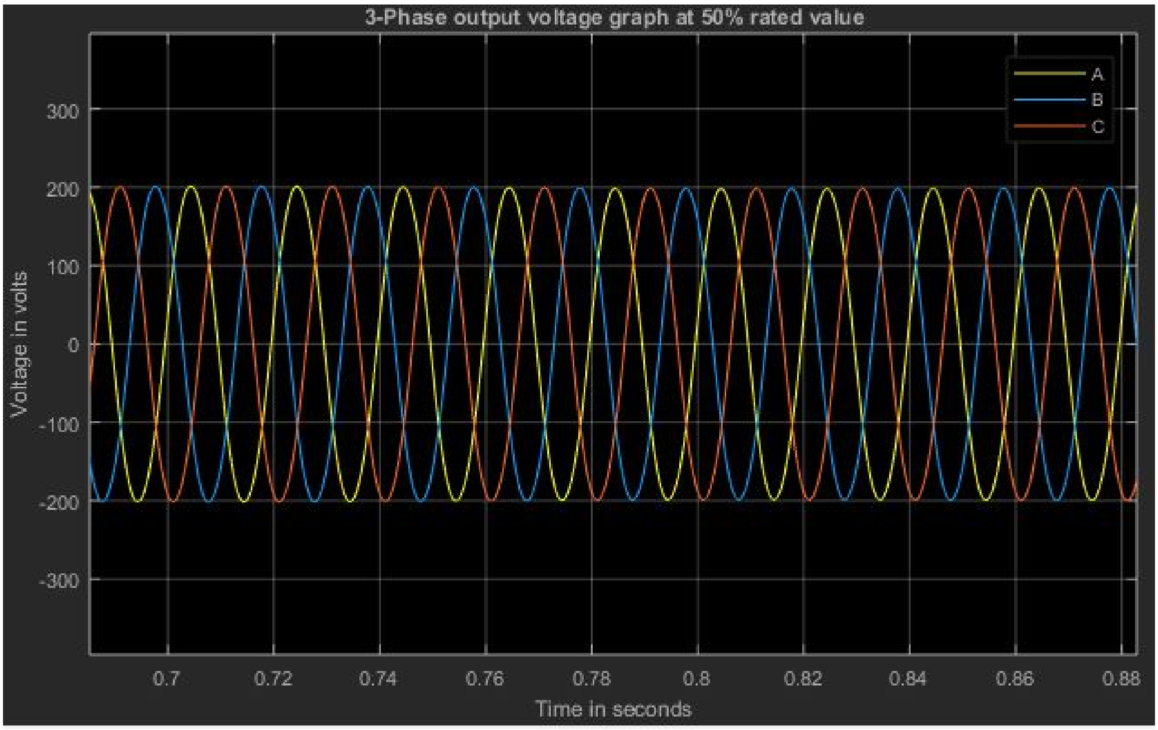


Figure 5.11: Output Volatge at 50% rated

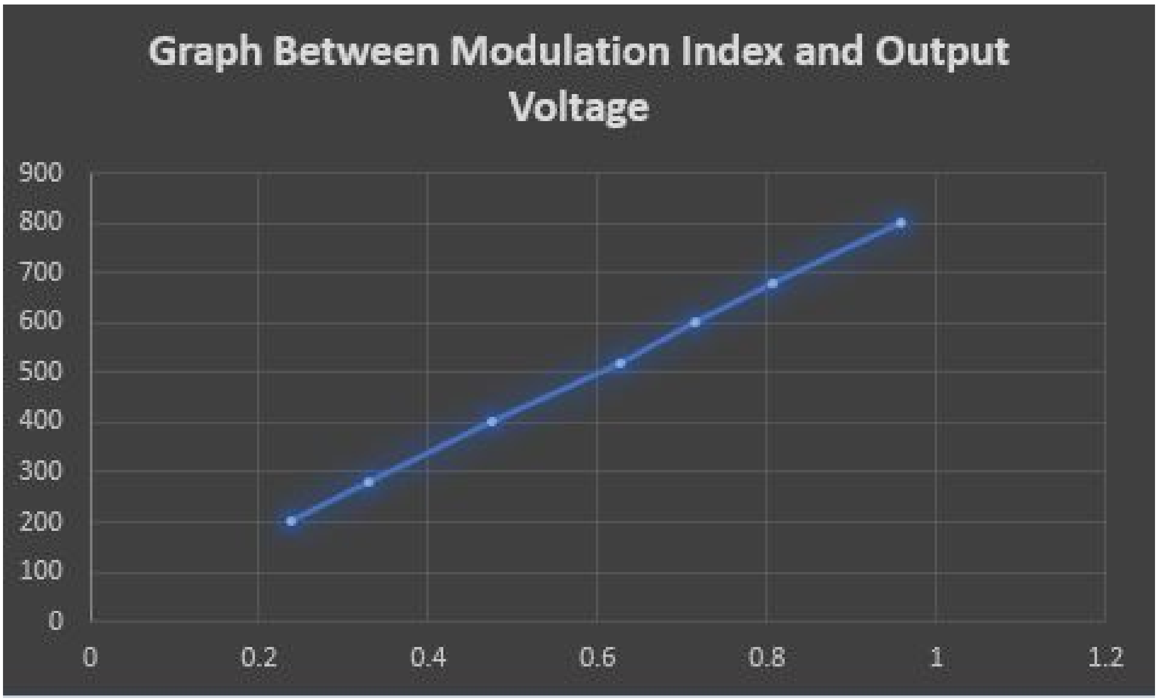


Figure 5.12: ModulationIndex and Output Volatge

5.3 Output Volatge at different frequencies

5.3.1 Volatge and frequency trend

5.4 Task3

Control the output voltage and frequency by using V/f principle. Discuss the limits of output voltage and frequency that can be achieved. Reading is attached.

5.4.1 frequency and volatge trend

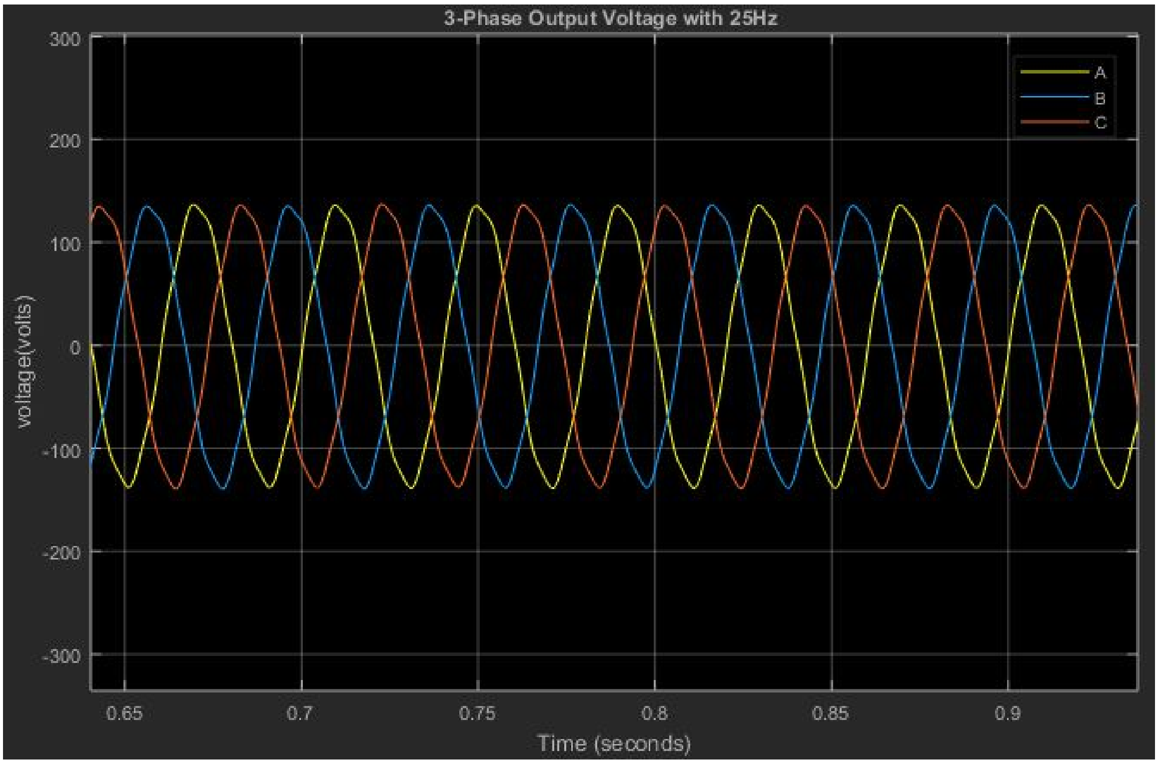


FIGURE 5.13: Output Volatge Waveform at 25Hz

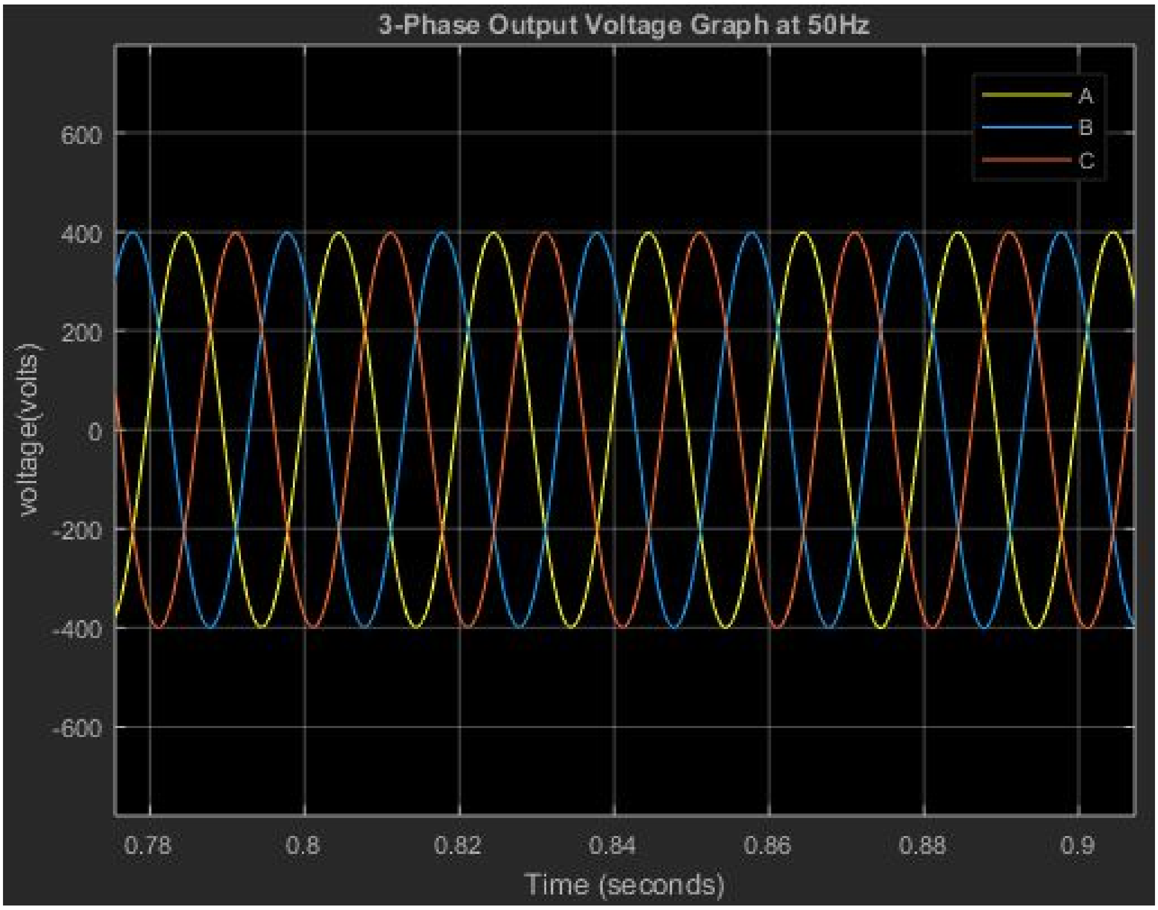


Figure 5.14: Output Volatge Waveform at 50Hz

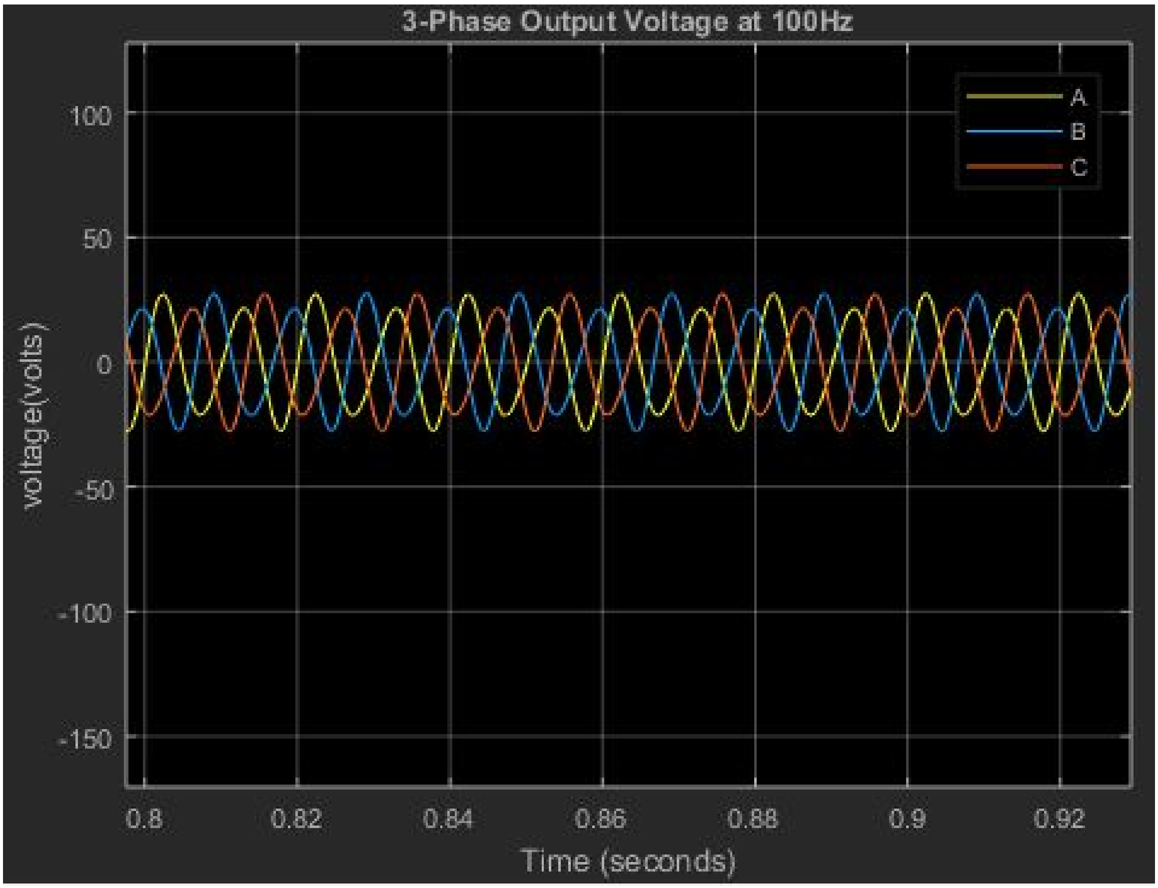


FIGURE 5.15: Output Volatge Waveform at 100Hz

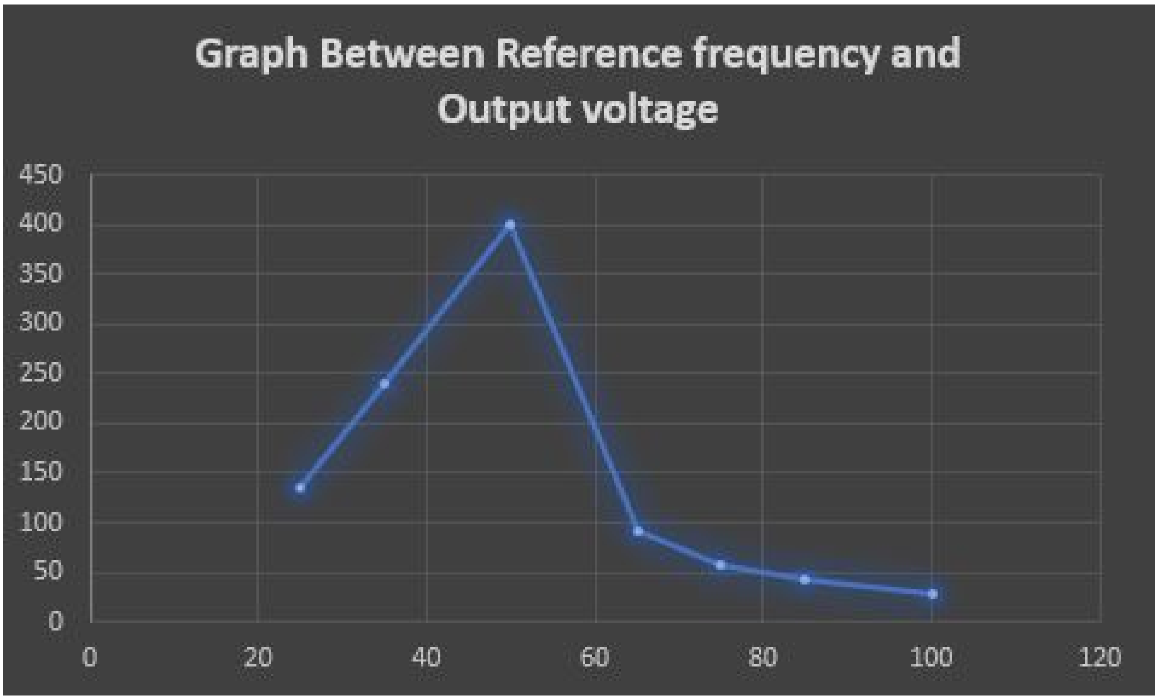


FIGURE 5.16: Graph between ref. frequency and volatge

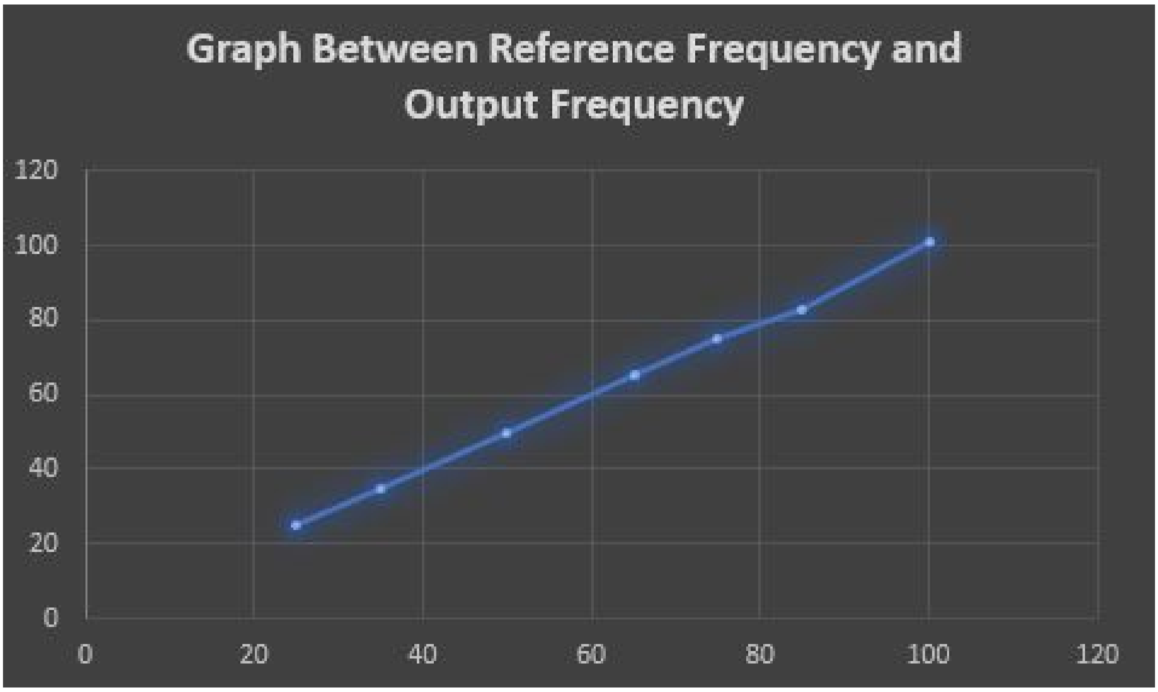


Figure 5.17: Graph between ref. frequency and output frequency

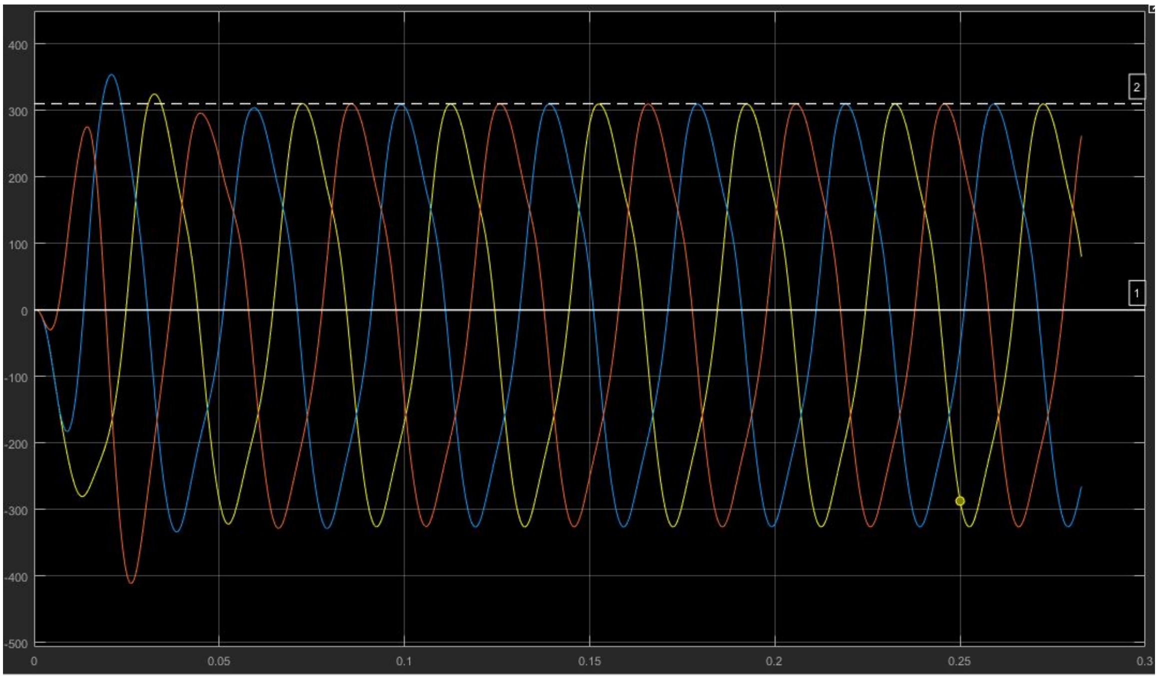


Figure 5.18: Output volatage =313 and f = 25Hz

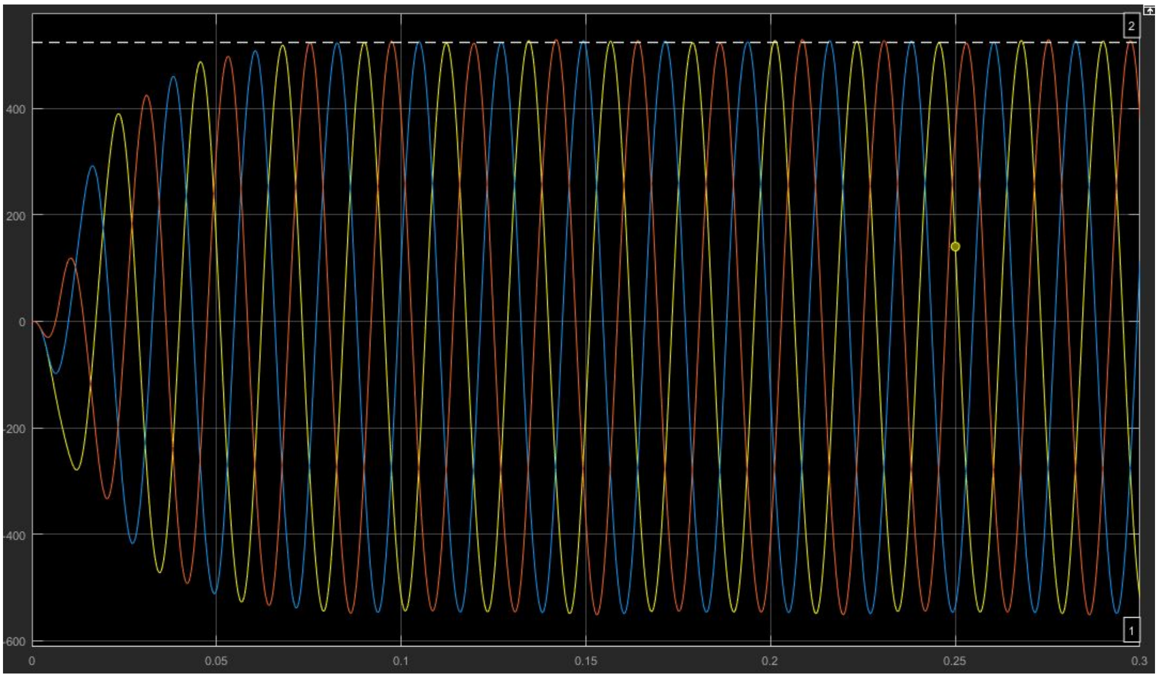


FIGURE 5.19: Output volatage =525 and f = 45Hz

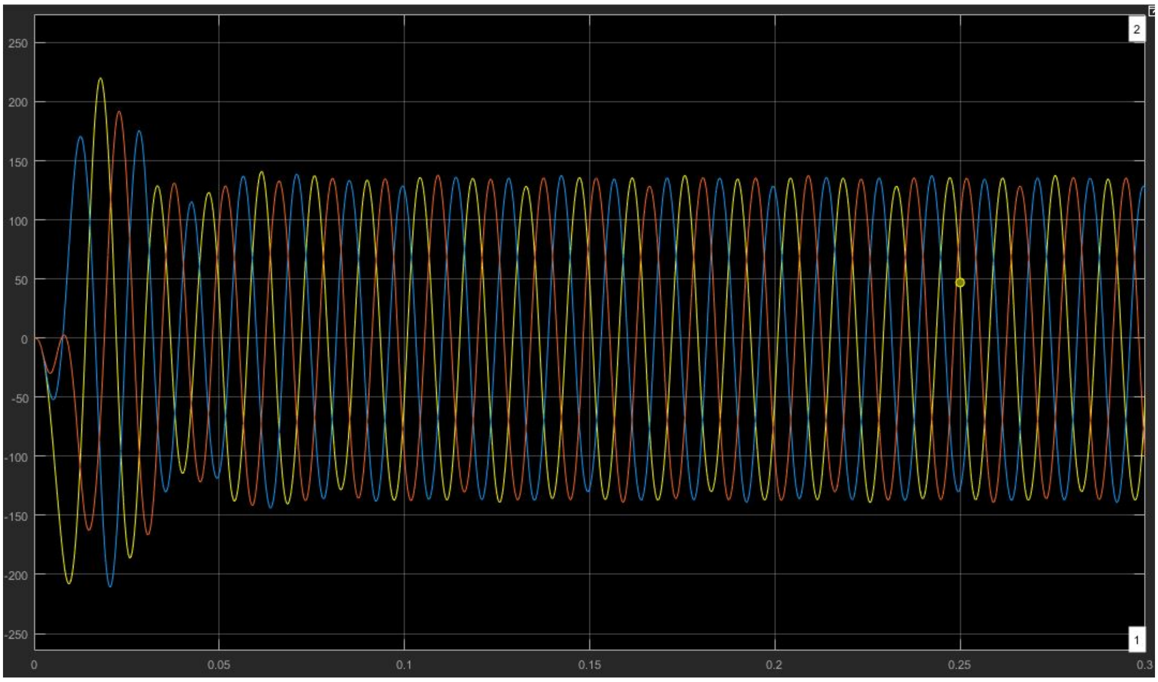


FIGURE 5.20: Output volatage =132 and f = 70Hz

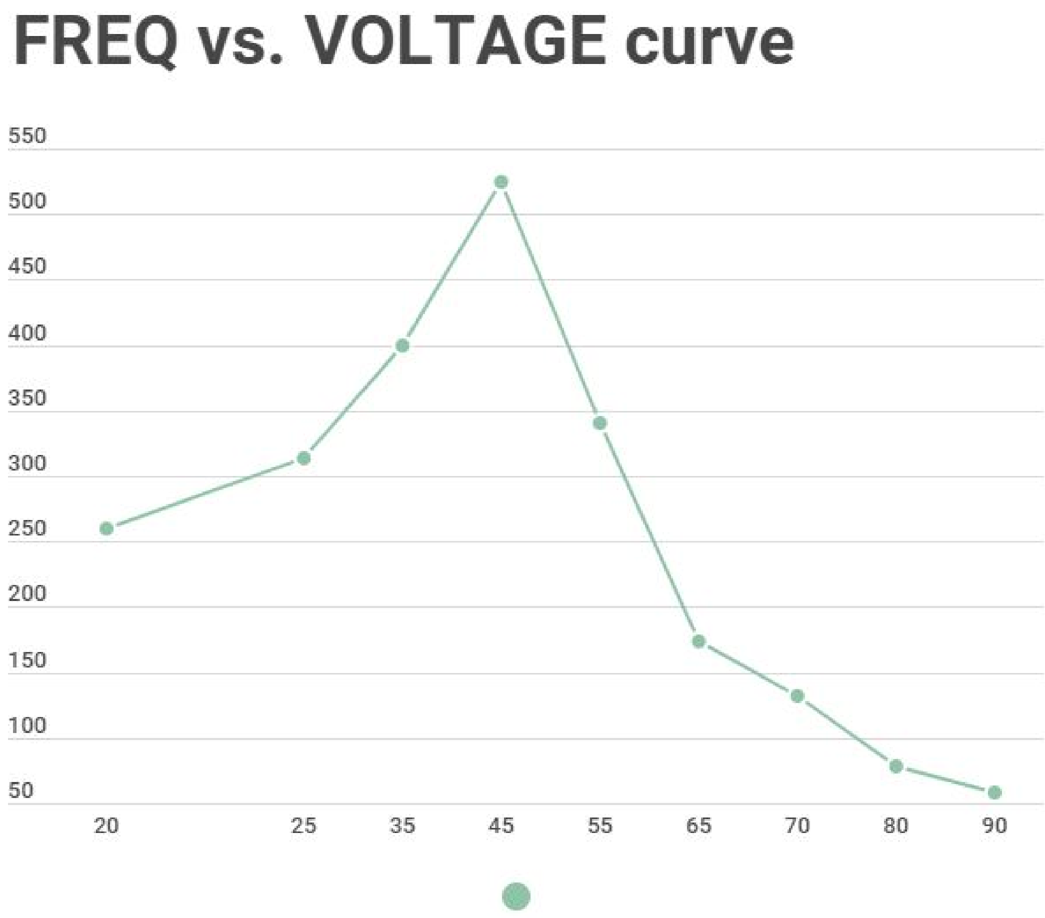


FIGURE 5.21: trend for fixedV/f ration

Chapter 6

Conclusion

In this project we have developed the three phase rectifier and three phase inverter. We could have used the batteries or simple rectifier which can output the constant dc voltage but the main purpose of three phase rectifier is to have variable dc voltage. The three phase rectifier simulated above is a controlled rectifier whose firing is such that the output voltage is 400VDC.The output can be varied by changing the gate pulses .The rectifier design should be such to remove the low order harmonics and improve the power factor. The inverter designed such that it can output the three phase output voltage of any fundamental frequency. The harmonics of non-triplets can distort the output voltage but in case of inductive load the higher order harmonics can be suppressed. The harmonics can incur the iron loses and copper loses. So the above project is useful in applications where the load require variable voltage and variable frequency(VVVF). The future work includes in increasing the efficiency of overall circuit and to cancel out the certain harmonics which can incur losses.

Chapter 7

References

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