UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

MINIMIZING TOTAL HARMONIC DISTORTION IN SINGLE PHASE INVERTERS

MASTER THESIS

Mithat Egemen ÇOBAN

Electrical and Electronics Engineering Department

Master Thesis Program

JANUARY 2018

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Supervisor: Assist. Prof. Dr. Ibrahim MAHARIQ

Mithat Egemen ÇOBAN , having student number 1403630051 and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of the jury, the presentation of the thesis prepared with the title of: Minimizing Total Harmonic Distortion in Single Phase Inverters

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Thesis Defense Date: 09.01.2018

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Mithat Egemen ÇOBAN

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First and foremost I offer my sincerest gratitude to my supervisor, Assist Dr. Ibrahim Mahariq, who has supported me throughout my thesis with his patience and knowledge. I attribute the level of my Masters Degree to his encouragement and effort and without him this thesis, too, would not have been completed or written. One simplify could not wish for a better or friendlier supervisor. My thanks and appreciation goes to my thesis committee members. I am especially grateful to Lecturer İsmail ÇALIKUŞU from Nevşehir University in Turkey for being a constant source of encouragement and helped me gain self confidence.

My final words go to my family. I want to thank my family, whose love and guidance is with me in whatever I pursue.

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January 2018 Mithat Egemen ÇOBAN

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LIST OF SYMBOLS AND ABBREVIATIONS

AC: Alternating Current

ACO: Art Colony Optimization

BJT: Bipolar Junction Transistors

DC: Direct Current

DF: Distortion Factor

FET: Field Effect Transistor

GA: Genetic Algorithms

GTO: Gate Transistor

IGBT: Insulated Gate Bipolar Transistor

Kp: Proportional Constant

Ki: Integrative Constant

LC: Inductor Capacitor

LOH: Lowest Level Harmonics

MOS: Metal Oxide Semiconductor

MOSFET: Metal Oxide Semiconductor Field Effect Transistor

PID: Proportional-Integral-Derivative Controller

PSO-PD: Particle Swarm Optimization-Proportional Derivative

PWM: Pulse Width Modulation

PV: Photovoltaics

RL: With an Inductive

SPWM: Sinusoidal Pulse Width Modulation

THD: Total Harmonic Distortion

UPS: Uninterruptible Power Supply

ABSTRACT

MINIMIZING TOTAL HARMONIC DISTORTION IN SINGLE PHASE INVERTERS

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Master, Department of Electrical and Electronics Engineering

Thesis Supervisor: Asst. Prof. Dr. Ibrahim MAHARIQ

January 2018, 101 pages

The first device that comes to mind in terms of quality and economy in energy systems is inverters. Inverters are the devices which convert the direct current to alternating current at the desired frequency and amplitude. It is desirable that do not contain u desired signals which are called harmonics. The first thing that comes to mind in the design of these inverters is that they reach the desired frequency and tension reference voltage quickly and accurately. Because the inverters actually require cost and risk to be designed, designs are made in simulation environments such as Simulink. In this thesis; H bridge single-phase inverter circuit is designed using Simulink environment. After the LC filter circuit is designed to eliminate harmonics from the system, inverter switches are driven with the PSO-PD controller so that the desired voltage can be reached in the desired frequency and voltage condition. It was obtained that the designed performance has reached the desired performance very quickly and well according to previous inverter controller algorithms.

Key words: Single Phase inverter, Total Harmonic Distortion, PI controller, PSO algorithm,

ÖZET

TEK FAZ İNVERTÖRLERDE TOTAL HARMONİK BOZULMAYI MİNİMİZE EDİLMESİ

ÇOBAN, Mithat Egemen
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Tez Danışmanı: Yrd. Doç. Dr. Ibrahim MAHARIQ
Ocak 2018, 101 sayfa

Enerji sistemlerde kalite ve tasarruf denince akla gelen ilk cihaz invertörlerdir. invertörler doğru akımı alternatif akıma istenilen frekansta ve genlikte çeviren cihazlardır. Bunun yanında harmonik adı verilen bozucu istenmeyen sinyallerdende bağımsız olması istenir. . Bu invertörlerin tasarımında ilk akla gelen şey istenilen frekansa ve gerilime referans gerilimine en hızlı ve hatasız şekilde ulaşmasıdır. invertörlerin gerçekte tasarlanması maliyeti ve riski gerektirdiğinden simulink gibi simülasyon ortamlarında tasarımlar gerçekleştirilir. Bu tezde H-Köprü tipi tek faz invertör devresi tasarlanmıştır. Devrede oluşan harmoniklerin azaltılması için filtre tasarlanırken istenilen gerilime en hızlı bir şekilde ulaşması için invertör anahtarları geliştirilen PSO-PD kontrölör ile sürülmüştür. Tasarlanan devrenin istenilen frekansa ve voltaja geçmişteki yapılan algoritmalara göre çok hızlı ve iyi bir şekilde ulaştığı gözlemlenmiştir.

Anahtar Kelimeler: Tek faz invertör, Toplam Harmonik Bozulma, PI kontrolör , PSO algoritması .

CHAPTER ONE

INTRODUCTION

1.1 THE IMPORTANCE OF POWER QUALITY

Power electronic circuits are generally having serious harmonic distortion in the power transmission line and distribution systems due to nonlinear elements of power system circuits and components. This affects the quality of the electrical energy given to the consumers. Knowing these effects of harmonics with many technical and economic effects and analysing them in the enterprises is very important both in terms of energy quality and in terms of sustainability of the operator. Harmonic current components generated by nonlinear loads cause harmonic voltages in the system. Harmonic voltages flow harmonic currents through linear and nonlinear loads connected to this system. In the presence of nonlinear loads, harmonic currents will form harmonic voltage nodes on the buses connecting the supply point and these loads. Detailed analysis of harmonic systems should be carried out in order to examine and eliminate these negative effects of harmonic components.

There are two types of approaches used to reduce harmonic problems and improve power quality in inverters and power systems. The first approach is load conditioning, making the equipment less sensitive to power decays and thus operating the system under significant voltage and current disturbances.The second approach is to set line-conditioning systems to overcome power system distortions. The second approach is very interesting due to including passive and active power filters. Passive filters are the most commonly used filters in the industry and more economical compared to other methods. Active and passive power filters are used for reducing harmonic in industrial power systems. On the other hand, active filters are very expensive compared to passive filters and are not suitable for applications in small installations because they have good system performance and reduced current harmonics but are power electronic based devices.

1.2.Literature Review

When the techniques used to reduce total harmonic distortion are examined, it is seen that the first studies are made with active and passive filters. Later, PWM and other modulation techniques have been used with the high-speed IGBTs to determine transistor condition.

In the last ten year years, it has been studied that artificial intelligence algorithms have been used in conjunction with the introduction of computer technology together with simulation techniques.

As considered previous studies, Shimuzu T(2003) and et al studies on the designing AC module inverter for solar PV panel and obtained a good performance. But this application is not fast due to chemical capacitor and they confirmed the changing chemical capacitor with film capacitor [1].

In the second circuit design is proposed by Wu W, et al. related to single-phase inverters. In this filter design, an L is added to the LC filter to bring the filter impedance close to zero, and the quality of the filter is increased to reduce the harmonics [2].

In their study in 2010, Selvajyothi and colleagues used a local observer to reduce the harmonics of the output wave and improve the signal in the output waveform. Here the local observer blog is used to predict the content of the base and harmonics [3].

Singh S compared the pi and fuzzy-based algorithms designed to reduce harmonics in 2013 and explained in his study that fuzzy applications give more optimal results than Pi-controlled applications.

1.3. Contribution of Thesis

In this thesis, inverter and its types are explained in detail in chapter 2. Inverters are commonly used in the industry to convert DC to AC current. The important role of a power inverter is to convert an alternative voltage to the desired amplitude and frequency at the output of a pure voltage at the input. Inverters are generally classified according to two separate categories; The first category is classified into two classes, single phase, and three phase, while the second category is classified into three classes, namely sinusoidal wave, modulated sinusoidal wave and square wave inverter with respect to the inverter output. After that, it has been shown how the pulse width modulation technique, which is the most important signal technique when the inverter is triggered, is applied for single and multiple levels.

In chapter 3, single phase inverter and its work mechanism are explained.PI and PD types of PID controller advantage and disadvantages are focused on in terms of single-phase inverter. And then PSO algorithms evolution, history and algorithms are discussed. Finally, Chapter 4 is related to single phase H bridge inverter design in Simulink. The first subject related to H bridge design with noise and filter applications. And the second application is PI Controlled inverter design to reduce harmonics and the final application is PSO-PD controlled design.

CHAPTER TWO

INVERTERS AND HARMONIC EFFECTS

2.1. Summary

Inverter and inverter types and application areas are discussed in Chapter 2. How inverters are triggered and the PWM technique is used in the inverter is emphasized. Finally, the causes of harmonics in inverter and the methods of reducing harmonics are briefly explained.

2.2. Inverter

A power inverter can be defined as a power electronic circuit that is used for converting Direct Current (DC) to Alternative Current(AC). The main task of this converter is to change a DC voltage or current to a symmetrical AC output voltage or current with the desired magnitude and frequency[4]. The basic block diagram of the inverter is given in Figure 2.1.

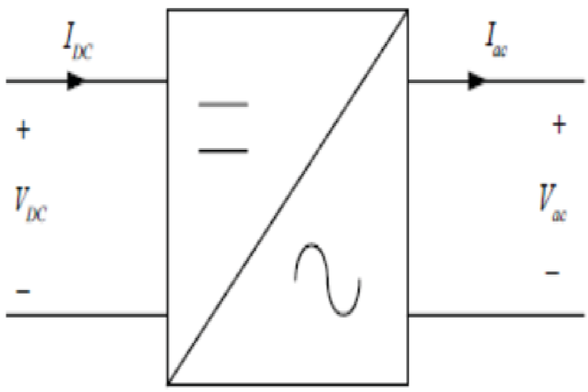


Figure 2. 1: General block diagram of inverter.

A power inverter circuit may produce sine wave, modified sine wave, pulsed modified wave, pulse width modulation applied waveform depending on the design of the system. One of the simplest forms in these waveforms is the square waveform

(THD 45%) and is often preferred in applications such as light and heating, which have low sensitivity. On the other hand, an undesired humming may occur when the inverter is connected to an audio device sensitive to square wave output operation[5]. Modified sine wave structures, which in fact are modified squares, provide rectangular pulses with some dead time between the positive and negative alternate. This is for most electronic loads, but THD is almost 24%.

Inverters can be classified into two categories according to into used phases; single-phase inverters and three-phase inverters. The output voltage of power inverters may be constant or variable frequency. An alternative voltage can be obtained by changing the dc voltage and keeping the frequency gain is constant in inverter. Ideally, it is expected that the output of a power inverter is sinusoidal, but most of the inverters are not sinusoidal because they contain harmonics depending on the frequency. With the development of the power semiconductor devices, undesirable harmonics of the output voltage can be reduced to a considerable degree with elements such as BJTs, MOSFETs or IGBTs, and the other switching techniques. In this study, IGBTs and MOSFETs are generally preferred because of their high input impedance and low conduction losses such as BJT transistors [6].

2.3. Inverter Types

It is known that an inverter converts battery DC electricity to AC electricity and generally three most common types of inverters are used for powering AC loads include; pure sine wave inverter (for general power applications) , modified sine wave inverter(for passive loads such as resistive, capacitive and inductive loads) and square wave inverter(for some resistive loads).

2.3.1. The Square Wave Inverter

A square wave inverter is one of the basic inverter types that converts a straight DC signal to a phase shifting AC signal which is typically seen low power electronics and signal processing. A desired square wave changes regularly and instantaneously between two determined levels.

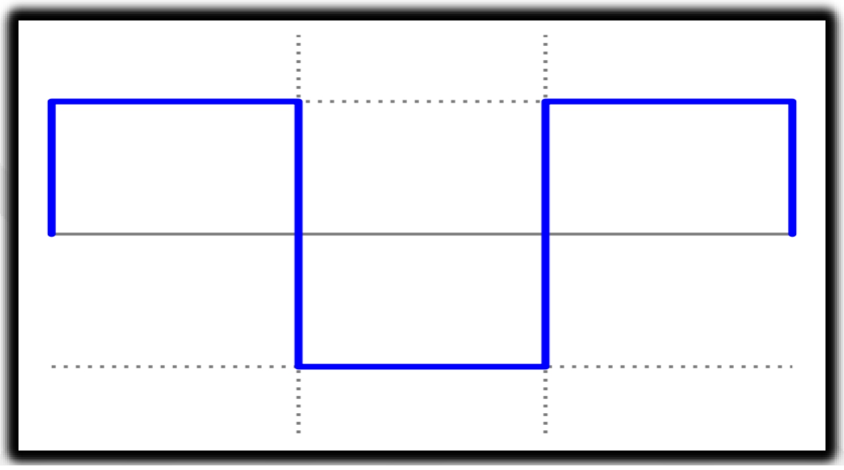


Figure 2. 2: Square Wave Inverter[2].

These inverter types cost much less than others did. The simplest construction of a square wave inverter can be achieved using an on-off switch before a typical voltage boosting circuit for a transformer. A structure of basic construction is given in following Figure.

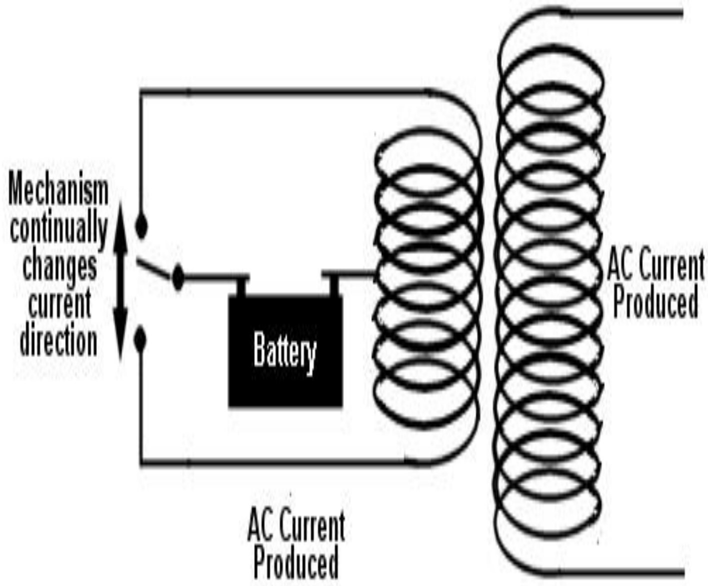


Figure 2. 3: Basic construction of square wave inverter[3].

2.3.2. Pure Sine Wave Inverter

The other type of inverter is a pure sine wave inverter which converts the dc power supply into almost pure sine wave by duplicating the supply obtained from aac source such as a plug socket.In these inverters, a very good supply is obtained with reducing harmonic reduction and enables smooth and noiseless operation of electronic systems such as computers, motors and microwave ovens another sensitive equipment**.** A battery charger is a power device which needs pure sine wave converters to better working performance[7].

Generally, two methods are used for inverting from DC power to AC power for low voltage. In the first method, various switching techniques are used for converting from DC low voltage power to a DC high voltage power source and from the DC high source to an AC sine waveform. In the second technique, a transformer is first used to increase the voltage to 220 volts after switching to low voltage dc power ac by various switching techniques.

2.3.3. Modified Sine Wave Inverter

The output signal of a modified sine wave inverter is similar to the output signal of a square wave inverter, except that a null voltage is dropped for some time before the switching operation. Although these inverters are simple and useful, they usually result in a 20% reduction in efficiency when used to feed Ac motor. They also affect the energy efficiency of the motors and transformers used for power supply. They cause the devices to lose their reliability and shorten their lifespan because they cause energy to discharged in AC voltage powered devices such as the computer they are using.

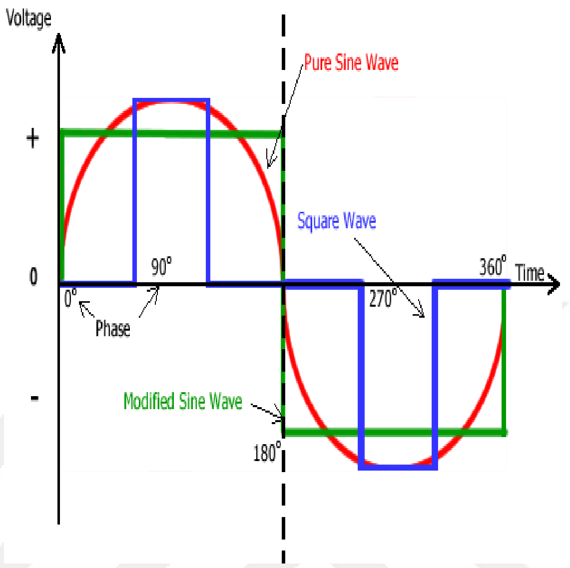


Figure 2. 4: Modified Sine Wave Inverter and other converters.

2.3. Inverter Types according to phases

Inverters are classified as half wave and Full wave inverters according to used electrical phase systems.

2.3.1. Half Wave Inverters in Single Phase

The first type of inverters that will yield an output when the inverter types are classified according to phases will be a single-phase inverter. Although both voltage and current directions can be reversed in a single-phase inverter, the voltage and current polarities may be the same or different for a given time. For this reason, it is desirable that a single-phase AC-DC converter be independent of these available polarities.

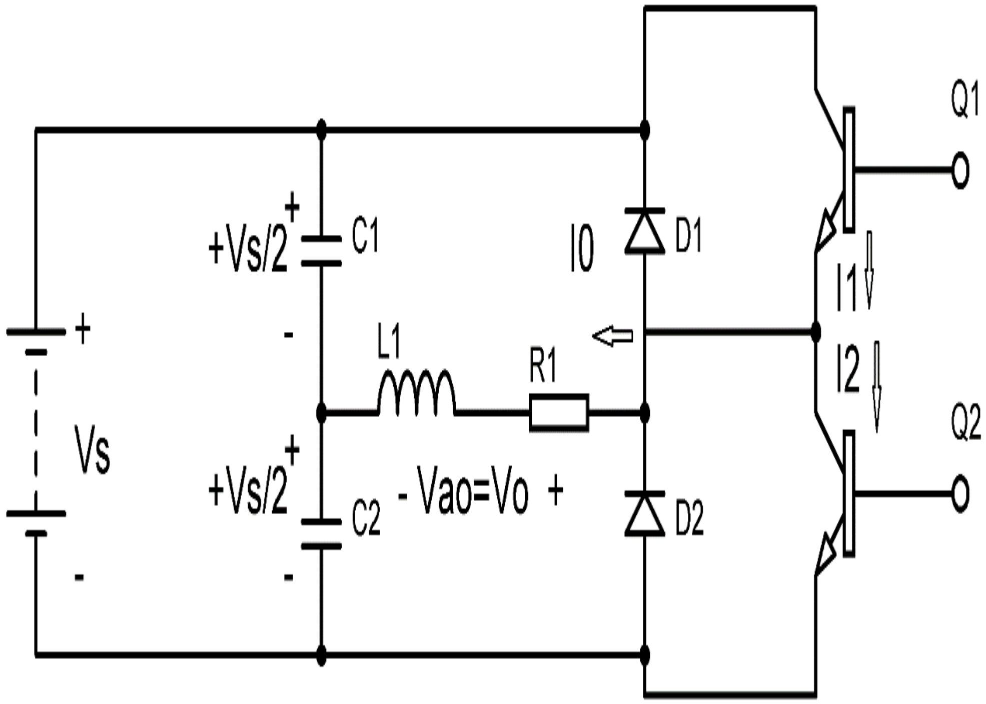


Figure 2. 5: Circuit Diagram of Single Phase Half Bridge Inverter.

A half bridge inverter consists of a DC source through which the voltage Vs / 2 is obtained across the load, as shown in Figure 2.5. When Q1 is opened and Q2 is closed, the instantaneous voltage across the load is Vs / 2 while the other side if Q2 is on and Q1 is off, the Vs / 2 voltage appears across the load. The logic circuitry is designed to prevent the DC source from being short-circuited because Q1 and Q2 are designed to not open in the same way. This allows a dead time to occur between the switches.

The instantaneous output voltage of single-phase circuit can be calculated as follows.

$$V_o = \sum_{n=1,2,3\dots}^{\infty} 2\frac{V_s}{n\pi}\sin wt \qquad (2.1)$$

And Instantaneous inverter output current,

$$V_o = \sum_{n=1,2,3\dots}^{\infty} 2\frac{V_s}{n\pi\sqrt{R^2+(nwL)^2}}\sin(nwt-\theta_n) \qquad (2.2)$$

2.3.2. Single Phase Full Wave Bridge Inverter

As can be seen in Figure 2.6, power diagram of single phase full bridge inverter uses two pairs of controlled switches ($Q_1 Q_2$ and $Q_3 Q_4$) and two pairs of diodes($D_1 D_2$ and $D_3 D_4$). The transistor devices of one pair of operating simultaneously. To improve a positive voltage $(+V_o)$ across the load, switches Q_1 and Q_2 are turned-on simultaneously whereas to have a negative voltage $(-V_o)$ across the load, we need to turn-on the switches S_3 andS_4. Here, D_1, D_2, D_3 and D_4 diodes are commonly known as feedback diodes.

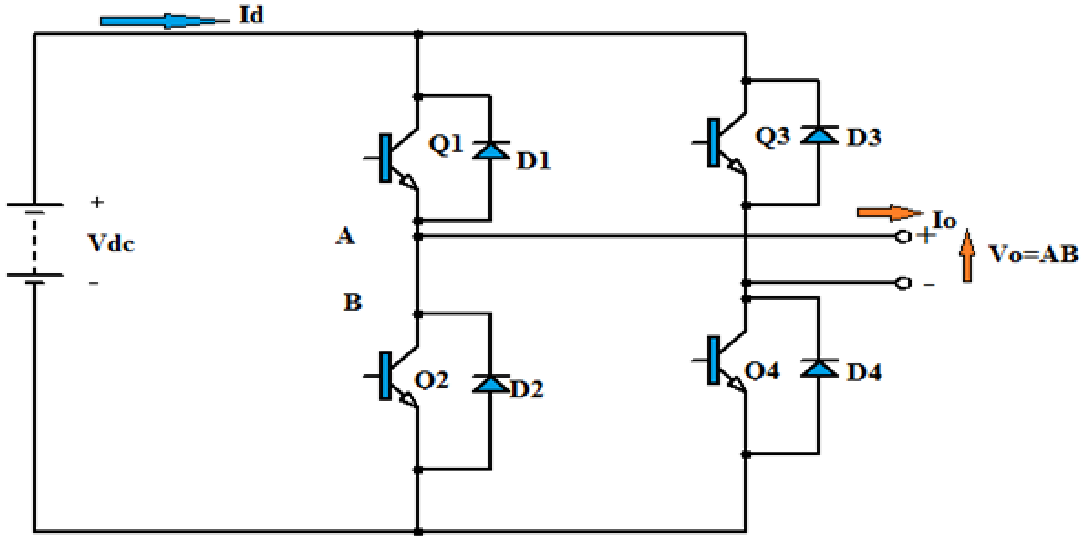


Figure 2. 6: Single-phase full wave bridge inverter.

There are two types of control mechanisms in the topology which is shown in figure 3. These are based on the principle of acting as a pair of keys (Q_1, Q_4) and (Q_2, Q_3), which means that while one pair are opened, the other pair are closed at the same moment In a square operation, switches Q_1 and Q_4 are open for half of the square waveguide, while Q_2 and Q_3 are off. The direction of the output current in a single-phase full-wave inverter is determined by the state of the semiconductor in a full-wave inverter similar to a single-phase half-wave inverter [8].

2.3.3. Three Phase Inverter

Insulated gate bipolar transistors (IGBTs) are mostly used in 3-phase inverters with various applications such as UPS (uninterruptible power supply), AC motor speed, variable frequency drives that control inverters in most applications.

IGBTs are highly preferred in three-phase systems and have high input impedance, fast response capability, good thermal stability, simple drive circuit, high voltage capability, crushing and controllability of the switching circuit and reliable short circuit. Since the IGBT is a voltage-controlled device, it provides fast switching.

A typical three-phase inverter with six isolated gate driver is shown in Figure 4. In the alternative mode, IGBT switching is applied for low and high alternation to apply dc pulses in each phase to the motor windings. Each phase is used as an IGBT switch to apply alternative alternating positive and negative high voltage DC pulses to the three-phase motor windings used as the load.

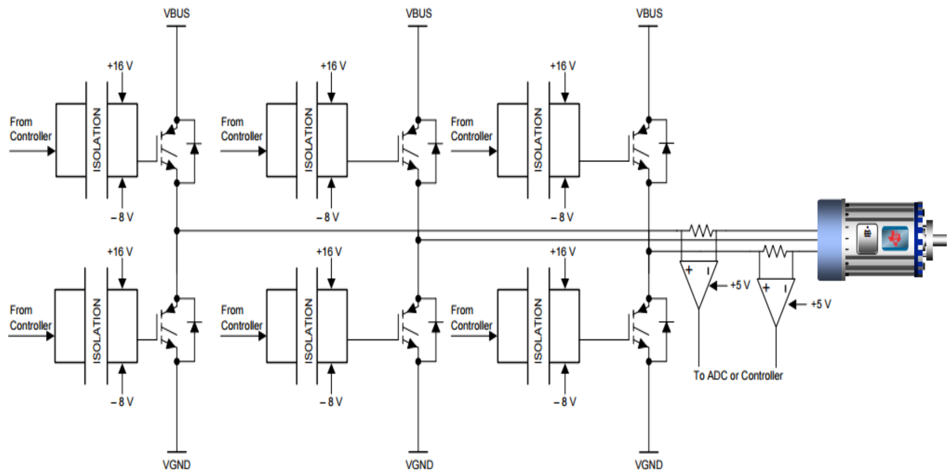


Figure 2. 7: Three Phase inverter with Isolated Gate Driver.

The motor output voltage is usually controlled using pulse width modulation (PWM). Here, the purpose of the PWM is to turn the transistor on and off several times to provide the output voltage. The output voltage value is defined as the average of the maximum voltage or maximum (peak) value of the voltage and the amount of time is defined as the time that occurs when the transistor is turned on and off [9].

2.4 PULSE WIDTH MODULATION (PWM) TECHNIQUES

PWM method is the operation of varying the width of the pulses in a pulse series indirect ration to small controlling signal: The larger the control voltage amplitude, the greater the width of the resulting pulsations. In a PWM circuit, a sinusoidal wave with the same frequency as the control voltage must be used to produce the sinusoidal wave that will be generated by the AC motors to drive the average voltage.

The basic circuits of PWM are illustrated in Figure 2.8. Figure 2.8.a shows a single-phase PWM inverter circuit which is designed with IGBT transistors. Switching transistors from IGBT1 to IGBT4 in this design are controlled by the two comparators shown in Figure 2.8.b.

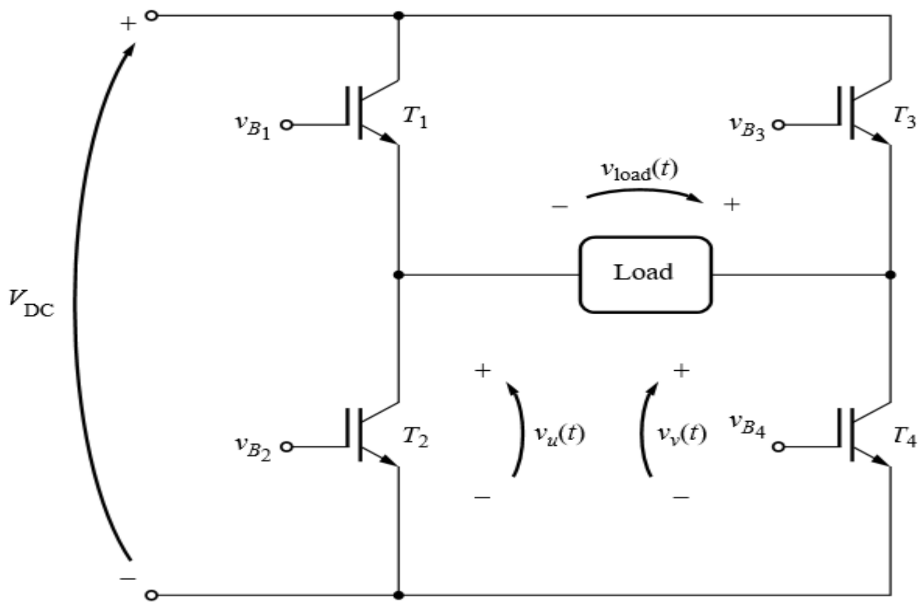


Figure 2. 8: The basic concept of PWM in Single Phase inverter.

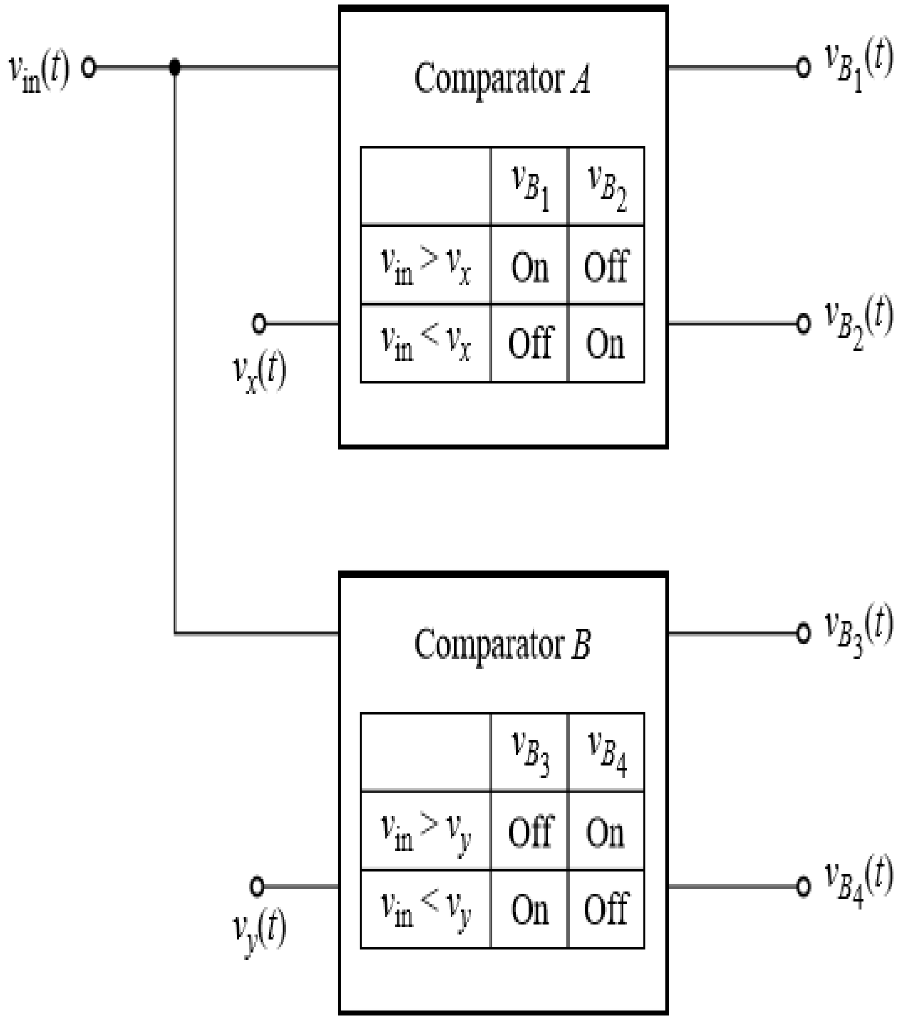


Figure 2. 9: The comparator used for controlling transistors.

A comparator is an electronic circuit or device that compares the input voltage $V_{in}(t)$ to with the reference voltage signal $V_{ref1}(t)$ and turns on or off the transistor by saturating or cutting the transistor depending on the test result. The first comparator compares $V_{in}(t)$ with the reference voltage signal $V_{ref1}(t)$ and controls the IGBT transistors T_1 and T_2 by switching on and off depending on the results of the comparison. In the same manner, the second comparator also compares $V_{in}(t)$ with the reference signal $V_{ref1}(t)$ and controls the other two transistors IGBT T_3 and T_4 depending on the comparison results. If $V_{in}(t)$ is greater than $V_{ref1}(t)$ at any time t, the first comparator turns on T_1 and turn of T_2. In the other case, it will turn off T_1 and turn on T_2. With the same operating mode and logic, for at any time t, if $V_{in}(t)$

greater than $V_{ref2}(t)$, the second comparator turn on T_3 and turn off T_4. On the other hand, it will turn off T_3 and turn on T_4. The reference signals $V_{ref1}(t)$ and $V_{ref2}(t)$ are given in Figure 2.8.c.

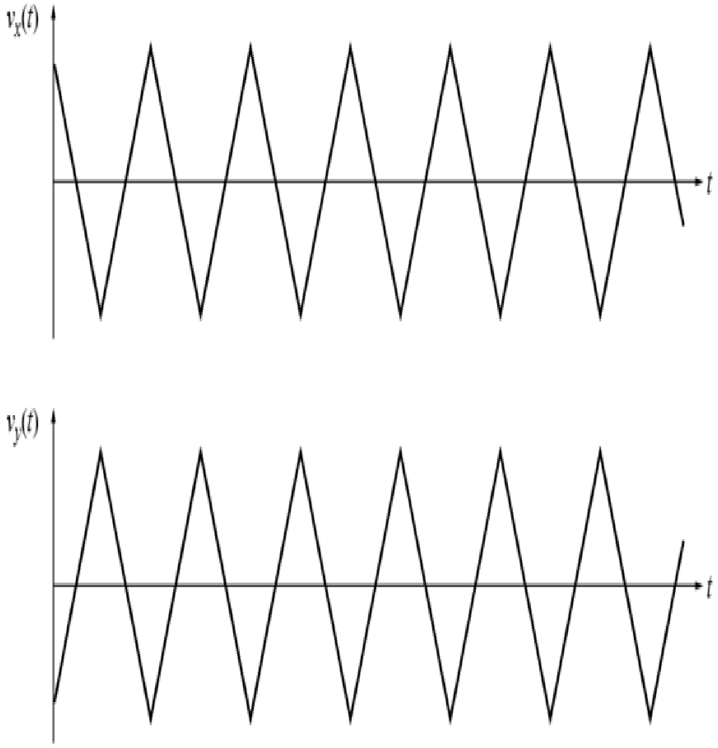


Figure 2. 10: The reference voltage for comparators.

In order to understand the operation of the PWM process and the PWM circuit, it is necessary to investigate what happens to the system when any different control voltage is applied to the system. Firstly, we assume that the control voltage is applied to zero. Then voltages $V_u(t)$ and $V_v(t)$ are same, and the load voltage out of the circuit $V_{load}(t)$ is zero(as shown in Figure 2.9)[11].

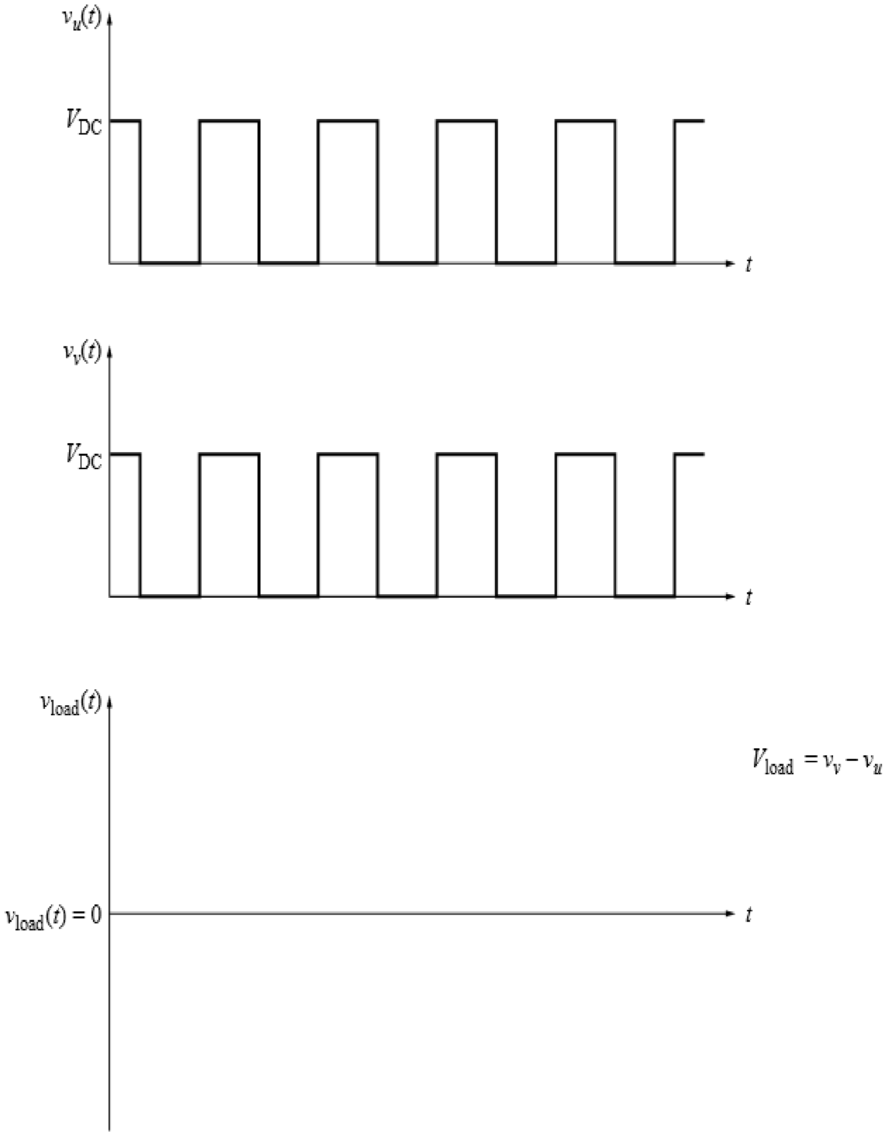


Figure 2. 11: The PWM circuit output with an input reference voltage of 0V.

A PWM converter changes the state of the output voltage many times within a single cycle of the resulting output voltage. Assuming that a PWM inverter design uses high-frequency reference voltages of up to 12 kHz, in this condition, the states of the components in this PWM inverter vary from 24,000 times to 0 and 1 logic. This quick switching means that PWM inverters will need a faster switching element than BJTs. For this reason, the PWM converter needs electronic components with high power high-frequency components such as GTO crystals, IGBTs, or power transistors for proper operation. The control voltage that feeds the comparators is usually applied digitally via a microcomputer mounted on a circuit board in the PWM motor controller. The control voltage or output pulse width can be controlled by the microcontroller in a more complex and meaningful manner. The microcontroller makes it possible to change the control voltage to achieve in any desired manner and situation with varying frequency and voltage levels.

2.5 TYPES OF PWM

PWM is separated as Synchronous and Asynchronous PWM.

2.5.1 SYNCHRONOUS PWM

This PWM signal is the signal given to the signal that the repetitive form signal is synchronized with the control signal, in other words, the repetitive form signal changes the frequency by the inverter frequency. The minimum requirement for this PWM tuning is to keep the modulation frequency of the system at an integer value [12].

2.5.2 ASYNCHRONOUS PWM

In this PWM inverter type, the control signal is a non-integer varying signal, in which the pattern signal of the repeater is held constant so that the signal is fixed. Asynchronous PWM subharmonics are important and it is expected that the amplitude of the lower harmonics is small. For this purpose, the modulation frequency is selected high. Despite this characteristic of asynchronous PWM, it can not be used to control sensitive devices which can not withstand input and output currents due to their small harmonic values.

- PWM switching modes are divided into Mono-polar and Bi-polar PWM switching.

2.5.2.1. PWM (BI-POLAR SWITCHING)

Such PWMs are used in systems where the output polarity can be reversed, such as in a full bridge rectifier circuit. The full wave Working principle is the same as full wave. But there are two key pairs that are ON and OFF at the same time. As the output voltage varies between +Vd and –Vd, the switching scheme is referred to as bi-polar.

2.5.2.2 PWM (UNI-POLAR SWITCHING)

Uni-polar or monopolar switching is utilized in power systems which have unipolar output voltage such as single switch inverters where the switches in inverters legs are controlled individually. There are two control signals shifted 180 degrees apart, compared with the repetitive pattern signal to generate the pulses for the inverter legs. For the same switching frequency, a Uni-polar PWM generates a better output voltage waveform than a BI-polar since it uses effective switching provided by doubling the output voltage reducing the ripple.

2.6 SINUSOIDAL PULSE WIDTH MODULATION TECHNIQUE

The sinusoidal pulse width modulation (SPWM) technique is used to generate a sinusoidal waveform by filtering the pulse waveform with a variable or non-constant output width. A better filtered sinusoidal output can be made using the waveform of the high switching frequency or by changing the frequency and amplitude of the reference signal In the SPWM technique, the distortion factor (DF) and the lowest level harmonics (LOH) are significantly reduced and hold the pulses at different widths instead of holding the pulses at equal widths, as in the case of multiple pulse width modulation. Figure 2.12 depicts that each phase is connected to the middle of each inverter foot and that the inverter consists of six switches up to six stages S1 to S6 [13].

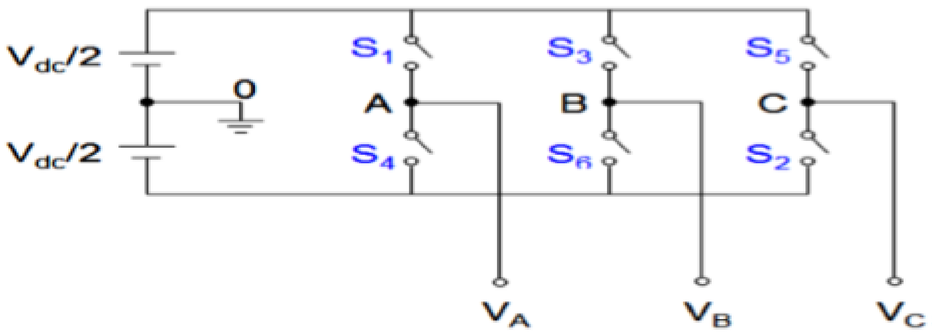


Figure 2. 12: Circuit model of Three-phase inverter with switch symbol.

Figure 2.13 represents the circuit that performs the control signal generator for the SPWM. The most common usage of PWM technology in inverters is to use the triangle wave carrier signal and sinusoidal wave as reference signal and compare these two waveforms with the help of comparator to produce the pulse signal.

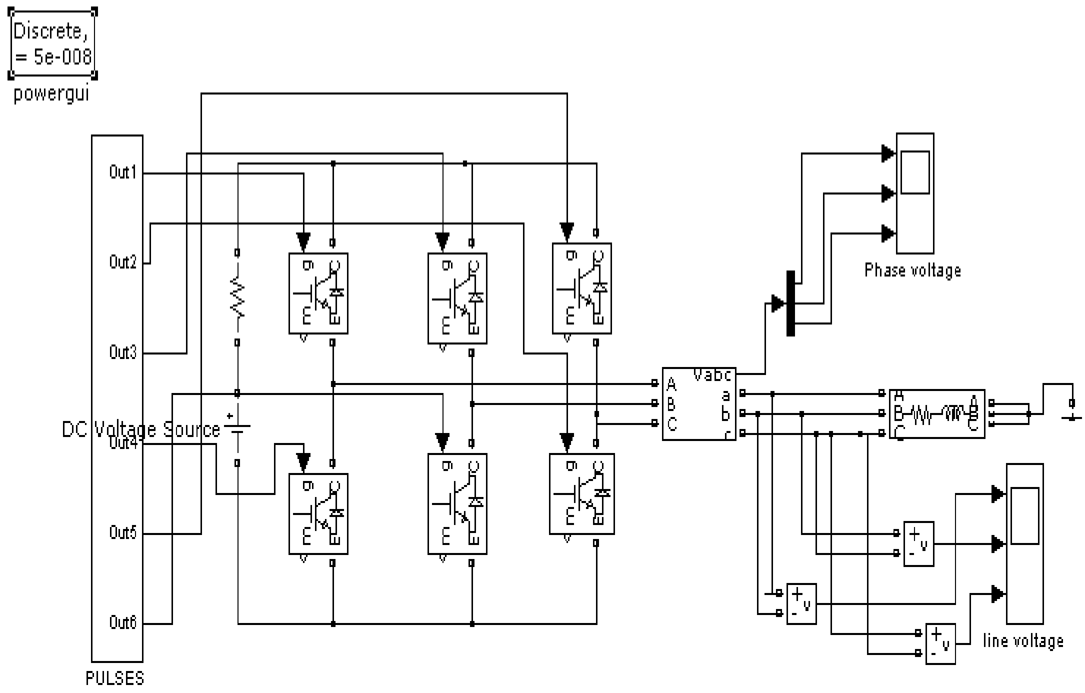


Figure 2. 13: The block diagram of control signal generation for SPWM method.

Using the sinusoidal pulse width modulation technique, the sample output voltages per phase and output voltages per neutral are shown in Figure 2.12.

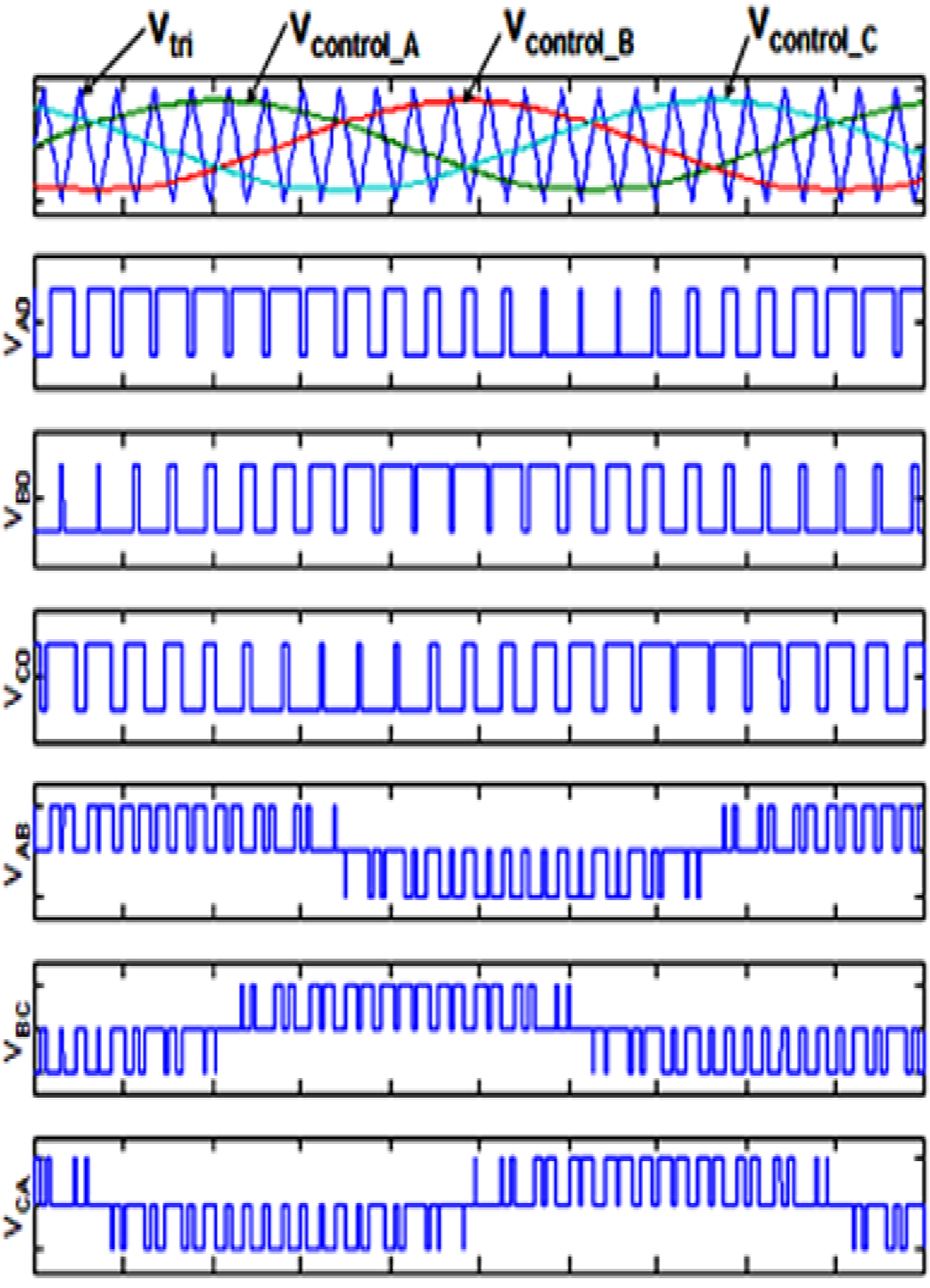


Figure 2. 14: The output voltage for SPWM technique.

The modulation ratio can be expressed as the ratio of the magnitude of the output voltage produced for SPWM to the fundamental peak value of the maximum square wave.

$$m_a = \frac{V_{PWM}}{V_{max-sixstep}} = \frac{V_{dc}/_2}{V_{dc}/_\pi} \qquad (2.3)$$

Where the maximum output voltage is generated using the SPWM and $V_{max} - six - step$, the fundamental peak value of the square wave is obtained. The frequency modulation ratio can be expressed as the ratio of the carrier waveguide frequency to the modulating (reference) signal frequency.

$$m_f = \frac{f_c}{f_o} \qquad (2.4)$$

Where f_c is the frequency signal of the carrier and f_o is the frequency of the reference signal, m_f is the modulation frequency to be used to come from above the harmonic.

2.7 Delta Modulation Technique in Inverters

In delta modulation technique, a sinusoidal signal is used as reference signal. A band is expressed by a suitable upper and lower limit throughout the duration of the sinusoidal signal's curvature. Here, this band is called "window" and a triangle-like carrier signal oscillates in the window. The two switching states of the generated gate signal are characterized by the rise and fall of the carrier wave. Another name for this technique is hysteresis modulation. The output voltage can be changed by changing the frequency of the reference sinusoidal signal. The output voltage can be changed by changing the frequency of the reference sine signal, similar to the SPWM technique. In addition to this, a triangular signal performs forced oscillation in a definite window and used comparators are required to compare the reference and carrier waves to generated modulation pulse[14].

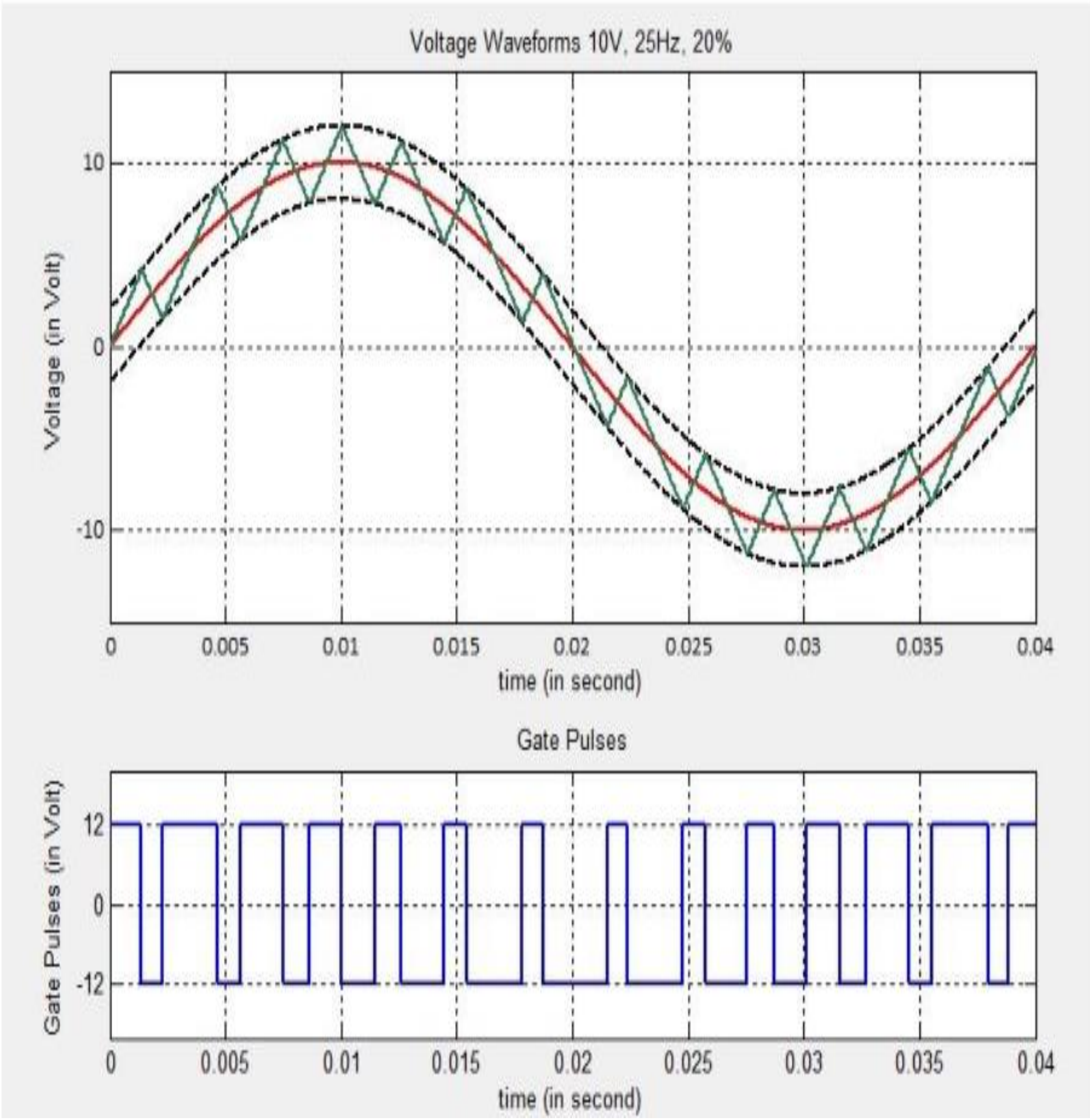


Figure 2. 15: Delta modulation waveforms.

2.7. Total Harmonic Distortion Effect in Electrical Power Systems

The quality of power of distribution systems is the most important parameter playing a role in power regulation and consumption.Power supplies or generators draw a distorted waveform containing harmonics and behave like nonlinear loads and these harmonics can cause problems ranging from noise disturbances in communication, distortion of conductors and transformers to isolation of transformers and transformers. For this reason, this harmonic is important to measure total effect. Total Harmonic Distortion is known as the sum of all the harmonics in a system with a more accurate expression of how much of the waveform power of the distortion caused by the harmonics is measured.

2.7.1 Definition of Total Harmonic Distortion

The concept of total harmonic distortion is defined as harmonics and distortion since it is difficult and complicated to understand and is generally a complicated concept. Loads in the power system are usually examined in two parts, linear or non-linear loads. This shows that the quality of the power system is directly related to the quality of the load. Here, each load is due to the current drawing of the path. Linear loads actually draw a sinusoidal current and usually maintain this waveform. Since most households work in this way, they are in the class of linear loads. However, in some cases, nonlinear loads may also draw a non-sinusoidal current. This is the deviation of the current wave from a pure or natural sinus wave because of the deviation of the waveguide from the sinus wave.

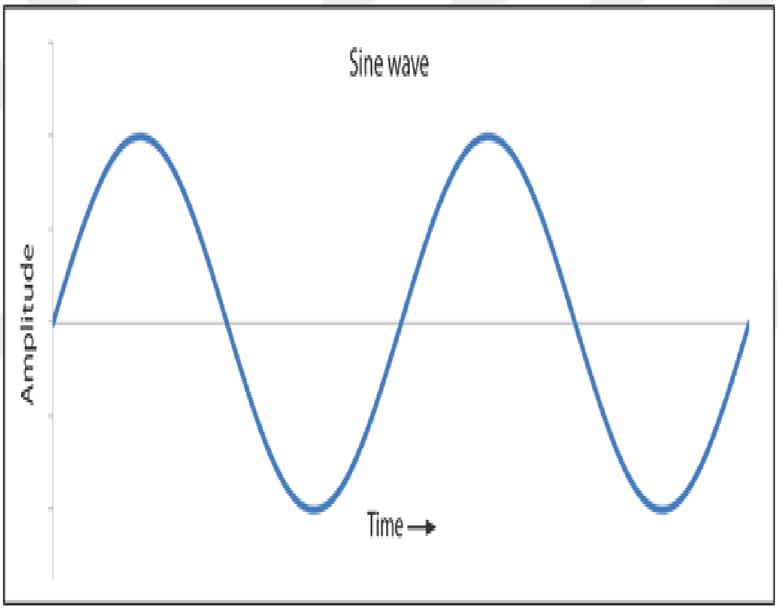


Figure 2. 16: Ideal pure sine wave.

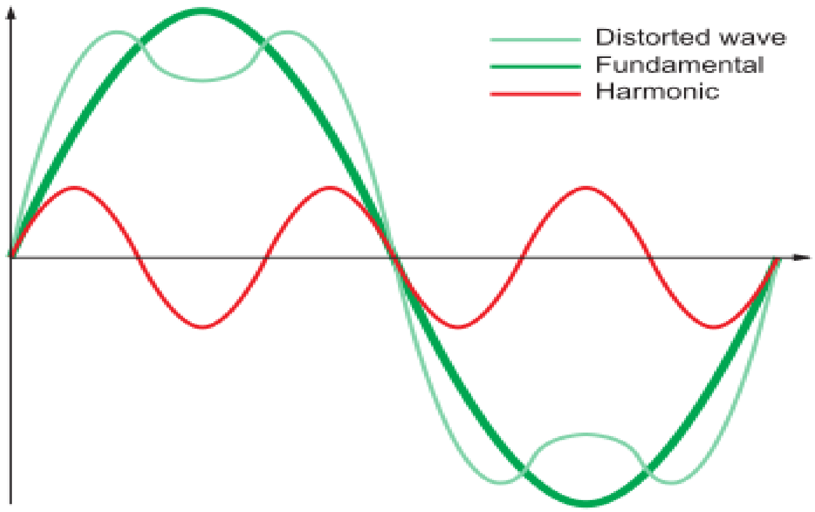


Figure 2. 17: Distorted or noise included waveform.

When Figure 2.14 is examined, it is seen that the distortions in the wave shape greatly change the shape of the sinus. In other words, regardless of the level of complexity of the fundamental wave, this distortion is actually the composition of multiple waveforms called harmonics. Harmonics have frequencies that are exact multiples of the fundamental frequency of the waveform in the frequency domain. For example, considering a signal with a fundamental waveform of 50Hz, there will be 2nd, 3rd, 4th and 5th harmonic components at 100Hz, 150Hz, 200Hz, and 250Hz, respectively.

If the definition of harmonic distortion is to be repeated after these definitions, then the sum of all these harmonic components is the deviation from the pure sinusoidal values of a resultant harmonic. The ideal sine wave has zero harmonic components, so it does not contain the upper harmonics. For this reason, there is nothing to disrupt this perfect wave[15].

Total harmonic distortion (THD) is expressed as the sum of all harmonic components of the voltage or current waveform, as compared to the fundamental component of the voltage or current wave, ie, zero harmonics:

$$THD = \frac{\sqrt{(V_2^2+V_3^2+\cdots+V_n^2)}}{V_1} \times 100\% \qquad (2.5)$$

The above formula shows the calculation of THD for any given voltage signal. The result of which is actually a percentage of the harmonic components compared to the fundamental component of a signal. The higher the percentage, the more signal distortion in the used network signal.

2.7.2. Effects of Harmonics on the Power System

Harmonics in a single-phase inverter system that affects both the inverting connected components and the power system. The harmonics produced by the harmonics cause a wide variety of problems in the form of nonsinusoidal waves that are created in voltage and current.

The adverse effects observed in the energy systems of harmonics are:

- Overheating of transformers
- Increase of voltage drop
- Increasing energy consumption
- Heating problem in devices
- Waveform distortion of generator and network voltage
- Excessive reactive loading in compensation systems
- Rotating machines also produce momentum oscillations and overheating
- Perforation of dielectric materials
- Noise in audio and video systems
- Change in power factor
- Resonance events coming from the mains, overvoltage and current effect caused by resonance
- Incorrect measurements of induction counters
- Incorrect operation of protection elements

2.7.3 Resonance Events Caused by Harmonics

One of the biggest harmful effects of harmonics is the resonance effect. The frequency at which the inductive reactance is equal to the capacitive reactance is called the "resonance frequency". As known, as the frequency increases in the power systems, the inductive reactance increases while the capacitive reactance decreases. That is, the frequency of the power system is inversely proportional to the capacitive reactance, which is proportional to the inductive reactance.

If the resonance of the system occurs at a value close to one of the harmonic frequencies, it will reveal harmonic currents and voltages at the extreme level. One of the most important factors affecting the harmonic levels is the resonance in series or parallel resonance.

2.7.3.1 Series Resonance State

The series resonance state is the result of the fact that the inductive and capacitive reactance in an electric circuit are equal to each other. Since the impedance is low in the case of series resonance, high-value resonance currents will flow through the circuit even when a low voltage is applied to the circuit.

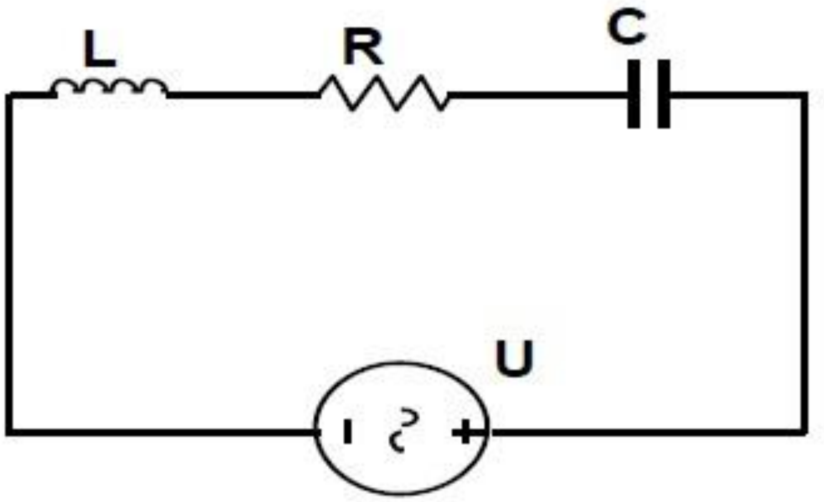


Figure 2. 18: Circuit of Series Resonance State.

2.7.3.2 Parallel Resonance State

This resonance phenomenon can occur because the number of floors in the power system is not corrected or because of the capacitors used in the filters. In this case, the inductive and capacitive reactance is the same as the series resonance. However, the effect of this equation is different according to the series resonance. If the inductive and capacitive reactance is parallel to each other, the value of admittance is lower. In other words, even a small resonance current, which is switched off, causes very great voltages.

To sum up, the impedance in the parallel resonance circuits takes the maximum value, so that even if a small current flows through the circuit, high amplitude and dangerous resonance voltages are present in the terminal voltages of the elements.

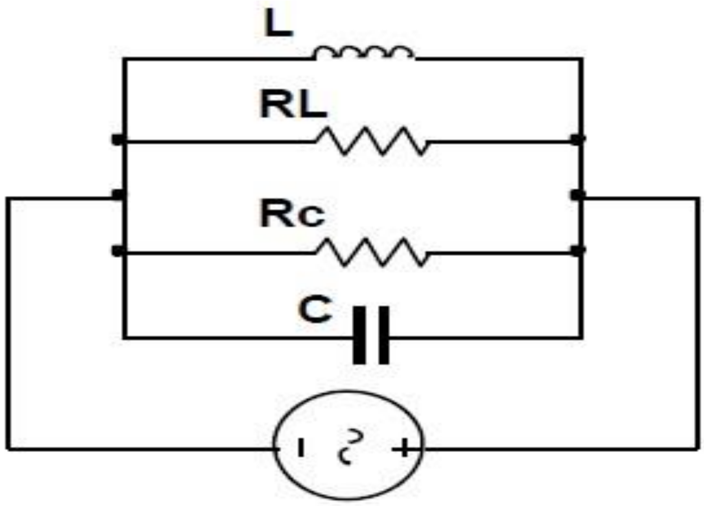


Figure 2. 19: Parallel resonance circuit in power systems.

2.7.3.4 Resonance Effects

Harmonics are the resultant resonance, which is usually greater at times when the system is less charged.

Usually in resonance,

- Voltages of L and C elements increase overcurrent flows.
- Insulation on the circuit elements, permanent damage to the dielectric materials of the capacitors may occur due to overheating.
- As a result of increasing the harmonic stresses, the total harmonic distortion (THD) value increases and the voltage applied to the consumer is distorted in waveform, the energy quality is affected negatively.

2.7.3.4.5. The Effects of Harmonics on Capacitors

Capacitors or condensers are one of the most affected by harmonics, although they do not produce harmonics. The harmonic effect is usually observed in parallel-connected capacitor groups. Overvoltages and currents that occur because of the resonance phenomenon of the harmonics on the capacitors shorten the life of the capacitors.

2.5.5. Effects of Harmonics on Transformers

As mentioned above, transformers are nonlinear elements. Nonlinear elements are harmonic sources, as we know it. Transformers are harmful sources of harmonics even though they are harmonic sources. Occurred current harmonics increase the copper losses in the transformers and voltage harmonics cause iron losses. Therefore, the harmonic effects on the transformers reduce the efficiency of the transformer.

2.5.6. The Effects of Harmonics on Transmission Lines

This impedance value is based on the lines used to calculate a certain impedance value while laying energy transmission lines. Harmonics in the system cause this impedance value to increase. Therefore, this increase in impedance will cause both line losses and also increase dielectric stress on the line. Therefore, this increase in impedance will cause both line losses and increase dielectric stress on the line.

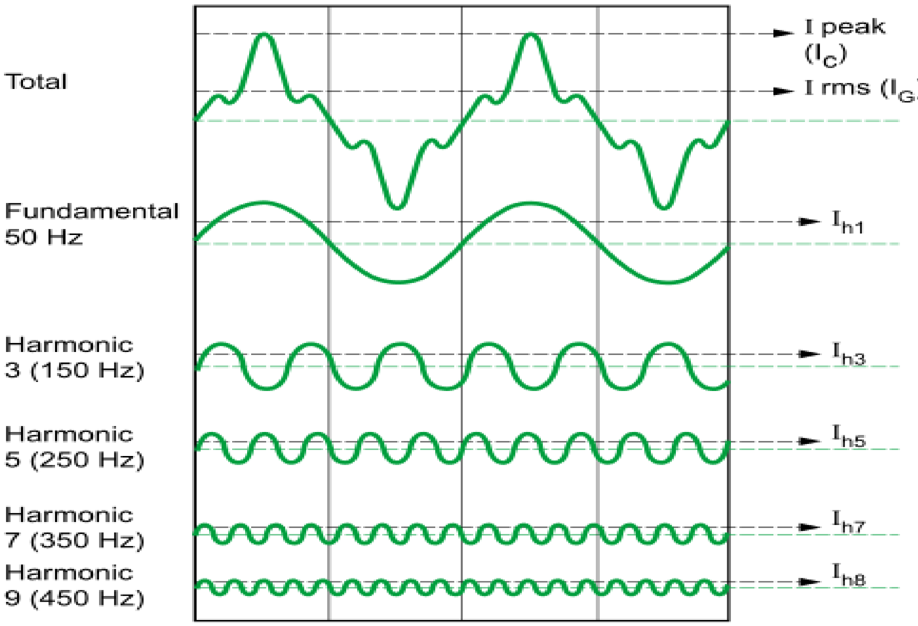


Figure 2. 20: 50Hz city network and harmonics effect on the signal[3].

2.5.7. Effects of Harmonics on Protective Systems

The protection elements are manufactured based on a certain current and voltage values. The most troubling situation that harmonics create on protective elements is in distance protection relays. Since the distance protection relays are intended to operate according to the impedance value of the line, the frequency value is an important quantity for proper operation of the relay. Since the harmonic effect of harmonics directly affects the line impedance, the protective systems prevent proper operation.

2.5.8. Effects of harmonics on rotating machines (motor-generator)

It is also possible to understand if the rotary machines are under the harmonic influence without measuring. In a rotating machine that is under harmonic effect, the machine is vibrating and noisy due to occurring harmonic moments. At the same time, in machines exposed to current harmonics, increased iron losses in machines subjected to increased copper losses and voltage harmonics decrease in the yield of the finishing machines.

2.6. Classic Harmonic Reduction Methods

There are two commonly used methods to achieve harmonics. One of them is in the design phase and the other is made in the circuit with the following members. In order to eliminate the harmonics, these elements are called "Harmonic Filter" which enables to eliminate the harmonic components that are formed by the nonlinear elements present in the circuit.

To reduce the effects of the harmonic order of the current or the back of the harmonic filters. There are two types of filters, active and passive harmonic filters.

2.6.1. Passive Filters

Although the investment cost of active filters is higher than that of passive filters, it is inevitable to use them in some systems. Passive filters are based on a specific power distribution, meaning that the passive filters become useless if the power of the system increases. It is also very difficult to incorporate passive filters into the system. Compared to these negative aspects of passive filters, active filters are biologically capable of removing the harmonic problem due to the ability to adjust for multiple harmonic frequencies. However, the most important feature of active filters is that they continue harmonic compensation despite the changes made in the existing distribution system.

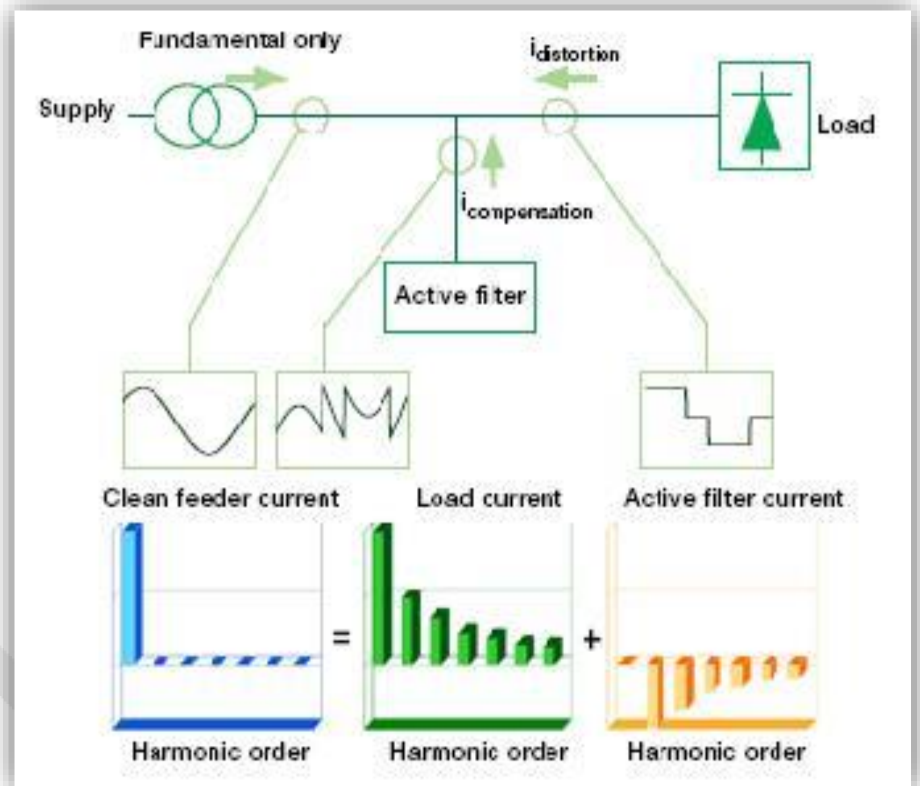


Figure 2.21: Eliminating of Harmony in the System with Active Filter.

The working principle of active power filters is to send a current with the same amplitude but opposite phase to the harmonics produced by the nonlinear elements. These types of filters are made using power electronic elements. When we look at the structure of the active filters, the harmonic detection block consists of three parts, the current control circuit, and the converter.

2.6.2. Active Filters

Active power filters are often used to compensate for current and voltage harmonics of inverters. Active power filters reduce current harmonics generated by nonlinear loads and are able to draw or generate reactive power. The working principle of the active power filter is based on the addition of a current in the system of the same amplitude but opposite phase to the harmonics of the load [16].

Passive filters can be connected in series and parallel depending on the situation.

2.6.2.1 Series Filter

Series filters are connected in series to the harmonic source as the name implies. Often the use of single-phase systems where the 3rd harmonic is active is common. The operating logic of the series filters is connected in series between the harmonic source and the mains to block the harmonic flow by exhibiting a high impedance to the harmonic flow. The important point here is the series filters; It only shows a high impedance value for the set frequency value. It will not serve as a filter for frequency values outside it.

The only disadvantage of the series filters is that they must be isolated according to the full load current and line voltage because they are in series.

2.6.2.2 Parallel Filters

Shunt filters are connected in parallel to the harmonic source as the name implies. The operating logic of the shunt filters is based on the transfer of the harmonic current to the ground through this impedance by obtaining a low impedance at the frequency of the harmonics desired to be destroyed.

In shunt filters, as in the case of series filters, it only affects the harmonic of the specified frequency value.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Summary

In this section, the simulative design of single-phase inverters are explained using Matlab Simulink environment and the PID-PSO algorithms are briefly introduced. Firstly, IGBT elements used to create single phase H bridge inverter and working operation of single phase is explained. Secondly, PI and PD controller are used to drive transistor gate and finally the working steps of particle swarm optimization algorithm are explained.

3.2. Insulated Gate Bipolar Transistor (IGBT)

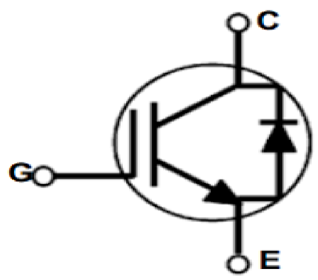


Figure 3. 1: The electronic symbol of IGBT

Insulated Gate Bipolar Transistors with high-speed features (IGBTs) are fundamentally a 3-legged semiconductor device. The other type of transistor has 4 layers (P-N-P-N) and is controlled by a metal oxide semiconductor (MOS) called isolated transistor. This electronic equipment is used in power electronic circuits such as inverters for gating purpose. Therefore, IGBT is one of the first elements that come to mind in terms of electronic. This element is an electronic switching element which performs the switching operation fast and efficiently because of the most preferred and usage reasons. The IGBT is used for the purpose of opening and closing switching such as amplifier circuits and inverter circuits. In addition to this feature, inverters have the ability to synthesize complex waveforms with PWM (Pulse Width Modulation) technique and low pass filters.

The IGBT is an element that can be used in the gate driving characteristics of the MOSFET and in the high current-to-low voltage saturation capacity of the BJT type (bipolar) transistor. The IGBT also uses the FET transistor type isolation gate to control the input values, while the BJT transistor uses the transitional feature of the power transistor.

3.3 Single phase inverter Circuit in Matlab Simulink

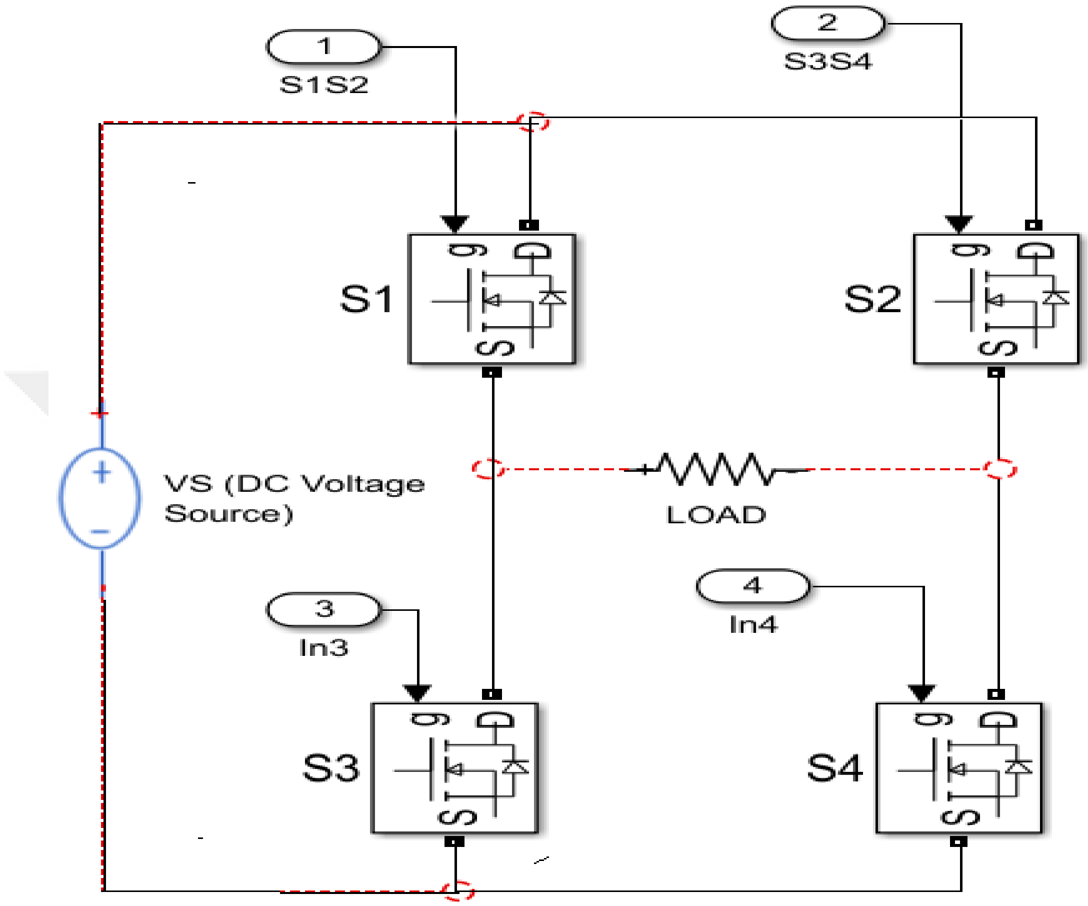


Figure 3. 2: Single phase inverter in Simulink.

Figure 3.2 shows a single-phase full-bridge inverter simulated in Matlab Simulink environment. In this circuit, the load voltage is Vs when S1 and S2 are in transmission, and the load voltage is -Vs when S3 and S4 are in transmission. The frequency of the output voltage can be controlled by changing the period T, which is the period. The 4 IGBTs connected to the RL load in the circuit are used for high speed switching The basic operating principle of the inverters is to briefly convert the DC power to AC power at the desired output voltage and frequency. The inverters are mainly categorized into two types; voltage source inverters and current source inverters. Voltage source inverters have been used in the above simulation circuit. The voltage source inverter type is a frequency converter used where the dc source has small or insignificant impedance. In other words, voltage source inverters have a solid DC voltage source at their input terminals.

3.4. CONTROLLER ALGORITHMS

3.4.1 PI controller Algorithm

The P-I controller is typically the controller type used to remove the steady-state error due to the proportional-P controller. On the other hand, there is a disruptive effect of the system in terms of response speed and overall stability of the system. This controller is commonly used in systems such as inverters where the speed of the system does not exist or the system requires fast switching. Since the P-I controller's ability to predict future faults in the system is insufficient, it can not reduce the lift time and oscillations. In systems using PI, the reference voltage generally does not increase except for a small amount and does not cause any change in overshoot. The PI controller is obtained by setting the parameters P and I to the D parameter in the PID controller given below.

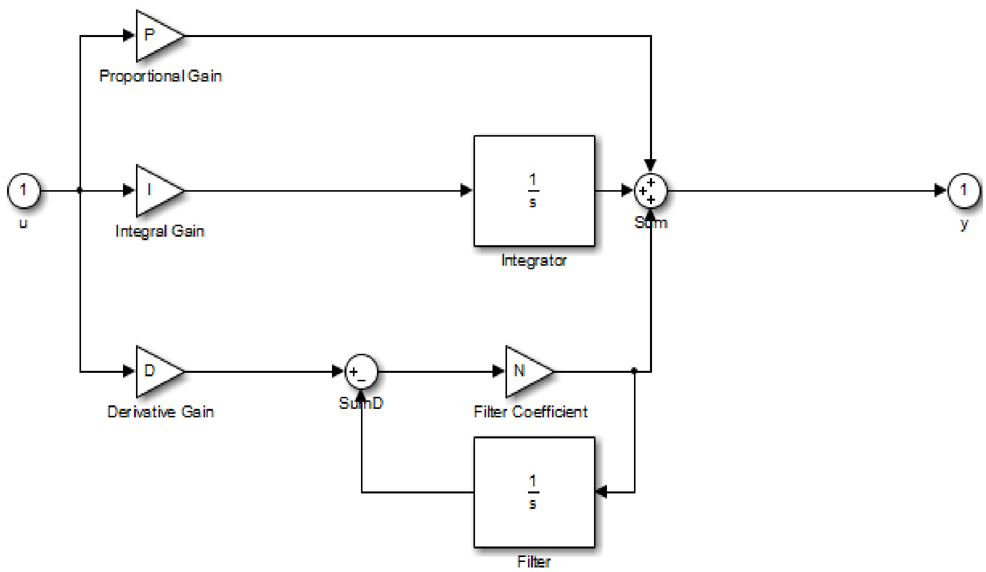


Figure 3. 3: Open circuit of PID Controller in MATLAB Simulink.

The overall control function of the PID Controller can be mathematically expressed as:

$$u(t) = K_p e(t) + Ki \int_0^t e(t')dt' + K_d \frac{de(t)}{dt} \qquad (3.1)$$

Where $K_p, K_i$and k_d , all non-negative, denotes the coeefficients for the proportional,integral and derivative terms, respectively(sometimes denoted P,I and D).

3.4.2 PD Controller Algorithm

The goal of using the PD controller is to improve the system's stability by improving its control performance as it has the ability to predict the future failure of the system response. To avoid the effects of the sudden change in the value of the error signal, the derivative is obtained from the output response of the system variable instead of the error signal. For this reason, the D mode should be designed to be proportional to the variation of the output variable to avoid sudden changes in control output due to sudden changes in the error signal. D control in PD control directly increases the process noise, so it is not preferable to use the D-only control mechanism alone.

3.4.3. Particle Swarm Optimization

Particle Swarm Optimization (PSO) inspired by moving fish and insects developed by Kenedy and Eberhart (1995) optimization method (8). It is basically an algorithm based on herd intelligence. It has been seen that animals that move in flocks, such as food and safety, often move randomly to make their movements easier to achieve. It is based on sharing social information between PSOs.Generation where the search is in genetic algorithms is done. Each individual is called a particle, and a population of particles is called a swarm. Each particle adjusts its position to the best position on the track, taking advantage of its previous experience. PSO is based mainly on the approximation of the position of the individuals in the herd to the individual with the best position of the crawl. This approach speed is a random situation, and often the individuals in the herd are in better position than the previous position in their new movements, and this process continues until the target is reached (8). PSO has been used successfully in many optimization problems such as order quantity determination, scheduling problems, power and voltage control, determining motor parameters, supply selection and sorting problems.

The PSO algorithm schematic is shown in Figure 3.4.

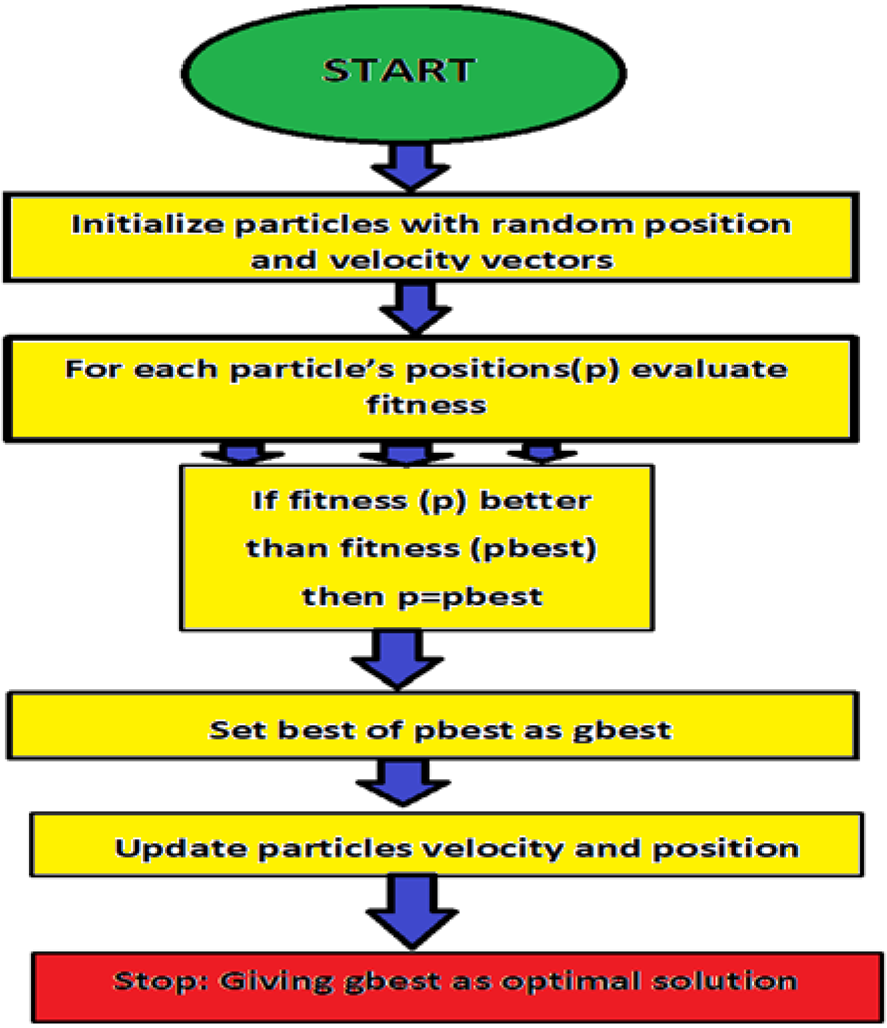


Figure 3. 4: The PSO algorithm.

Compared to GA, the advantages of PSO are that it is easy to implement PSO and does not require many parameters such as GA to adjust. PSO algorithms have yielded effective results in many areas and applications such as function optimization, artificial neural network training, fuzzy system control and GA applied fields.

3.4.3.1 The history and Background of PSO Algorithm

The term "artificial life" is used to define research on man-made systems that have some of the essential characteristics of life: Artificial life seems to focus heavily on two topics: first, methods of analyzing biological systems in which healing is used; and second, methods of computing biological methods.

This project focuses on the second topic, and many computer techniques inspired by biological systems are based on this assumption. For example, the artificial neural network is a simplified version of the human brain and nervous system; The genetic algorithm is inspired by the hereditary properties of human evolution. This project describes the PSO algorithm which deals with the social system, another type of biological system, more specifically, the collective behavior of simple individuals interacting with their environments and with each other. Because of this feature, this algorithm is known as swarm intelligence. All the simulations in this algorithm used local processes such as those modeled by cellular automata and hosted unforeseen group dynamics of social behavior.The most well-known examples of the PSO algorithm are the floys and boids simulations. Both simulations are normally used in computer animation or computer-aided design, but on the contrary, they are used to interpret the movement of organisms within a bird's swarm or fish school.

Two popular methods known to be effective in the swarm intelligence method in computational computing areas are the Ant Colony (ACO) and particle swarm optimization (PSO). ACO is inspired by the behavior of ants and has been applied successfully several times in discrete optimization problems. The concept of particle mass has been used to graphically simulate the choreography of a bird's block or fish school bird, although it appears as a simulation of a simplified social system. Nevertheless, it has been observed that the particle stack model has a curative effect.

3.6.3 Algorithm

The algorithm basically consists of the following steps;

i. Randomly generated initial positions and velocities are used to generate the starting trajectory.
ii. The fitness values of all the particles in the flock are calculated.
iii. For each particle, the local best is found in the current generation. The number of the best in the herd is as many as the number of particles.
iv. The global best is selected from the local generations of the current generation.
v. Position and speeds are renewed as follows.

$$V_{id} = W * V_{id} + c_1 * rand_1 * (P_{id} - X_{id}) + c_2 * rand2 * (P_{gd} - X_{id}) \quad (3.2)$$

$$X_{id} = X_{id} + V_{id} \qquad (3.3)$$

Where X_{id} gives the position and V_{id} speed values, $rand_1$ and $rand2$ are randomly generated numbers. W is the inertia weight value, c_1 andc_2 are the scaling factors.

vi. Steps 2, 3, 4, 5 are repeated until the stopping criterion is established.

According to the C1 particle's own experience, C2 directs the movement according to the experience of other particles in the flock. Selecting low values allows the particles to travel farther away from this region before they are drawn toward the target region. However, the time to reach the target may be longer. On the other hand, selecting high values can lead to unexpected movements and skipping the target zone while accelerating to reach the target. It is generally stated that obtaining C1 = C2 = 2 gives good results.

The PSO algorithm is given below as Pseudocode in Figure 3.5.

```
for i = 1 →PopSize do
    Construct particle with randomly initialised machine number and order.
end for
repeat
    pbest← 2^31
    for i = 1 →PopSize do
            fitness←calcfitness(pop[i])
            if fitness <pbest then
                    pbest← fitness
            end if
            if fitness< fitness(gbest) then
                    gbest← pop[i]
            end if
    end for
    for i = 1 →PopSize do
            v[i + 1] ←wv[i] + r1c1(pbest - pos[i]) + r2c2(gbest - pos[i])
            pos[i + 1] ←pos[i] + v[i] (ensuring to clamp the position within range)
    end for
    iterations← iterations + 1
until iterations ≥ numIterations
```

Figure 3. 5: Pseudo Code of PSO

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Summary

In this section, the design of the single-phase H Bridge inverter was first realized. In this designed system, an LC filter is used to frequency dependent harmonics. Secondly, the gate terminals of the transistors are controlled with PI and PSO-PD to reduce total harmonic distortion using PI and PSO-PD controller. Finally, the results are displayed and discussed.

4.2. Results and Discussions

The inverters are transducers convert direct current to alternating current. The importance of inverter is used for converting a symmetrical alternative voltage to the desired amplitude and frequency at the output of a true voltage at the input. In this work, an inverter with a frequency of 50 Hz is provided with a reference voltage of 200 and 240 V so that the system can reach this voltage.

The most commonly used types of inverters are single-phase inverters such as home appliances. In this study, a single-phase inverter was designed with MATLAB Simulink to provide pure signal electricity for a 220-volt city network. The inverter output is obtained by comparing sinus signal with triangle signal in the comparator circuit.

The Matlab Simulink model of the designed single-phase inverter is shown in Figure 4.1 and its output graphic is given Figure 4.2. As can be seen, four MOSFETs are used in single-phase inverter design to form of H bridge type. The output of single phase inverter was obtained as nearly 350V AC voltage which included noise because supply voltage of H Bridge inverter is adjusted as 350V. The MOSFET gate terminals named as In1 In2 In3 In4 because they are used as inputs. Output voltage obtained from between S1-S3 and S2-S4 because the two MOSFETs are works symmetrically the other two transistors.

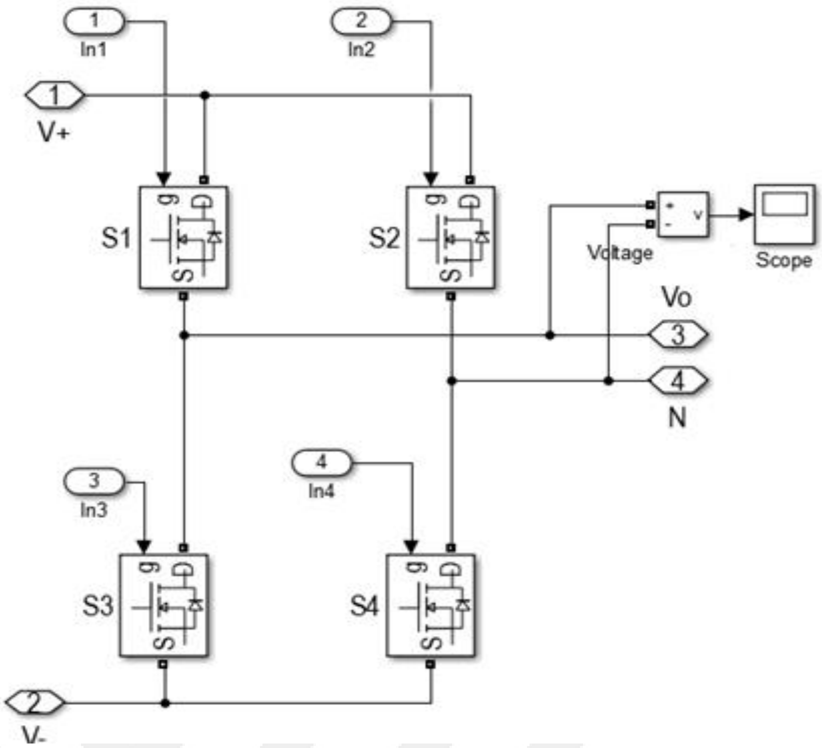


Figure 4. 1: Simulink model of H-Bridge Single Phase inverter.

Figure 4.1 shows a single phase H-Bridge inverter consisting of 4 IGBTs. The gate of each IGBT is used as a switching input.

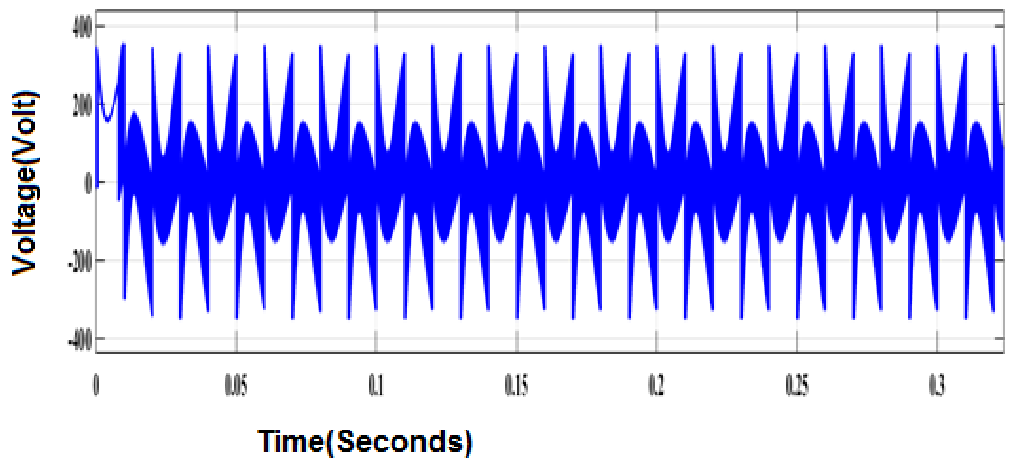


Figure 4. 2: The output of Single Phase H-Bridge with noise.

When looking at the output of a single-phase inverter, the maximum voltage of the reference voltage at the output of the system, 380 V, is obtained. The frequency was found to be 50Hz. After the creating block diagram of H bridge inverter, it was transformed into a sub-system in MATLAB to simplifying circuit schematic (Figure 4.2). After the subsystem has been set up, the H bridge inverter is supplied with V1 having a supply voltage of 380 V as shown in Figure 4.3. The output signal of H bridge inverter is shown Figure 4.3 and its output is same the previous schema. However, this circuit was given to understand the frequency of city network clearly.

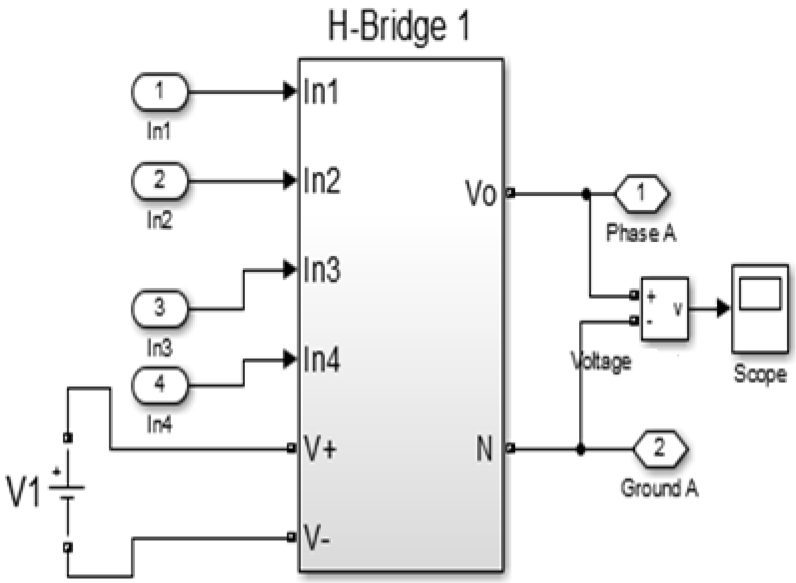


Figure 4. 3: Subsystem of H-Bridge Single Phase Inverter.

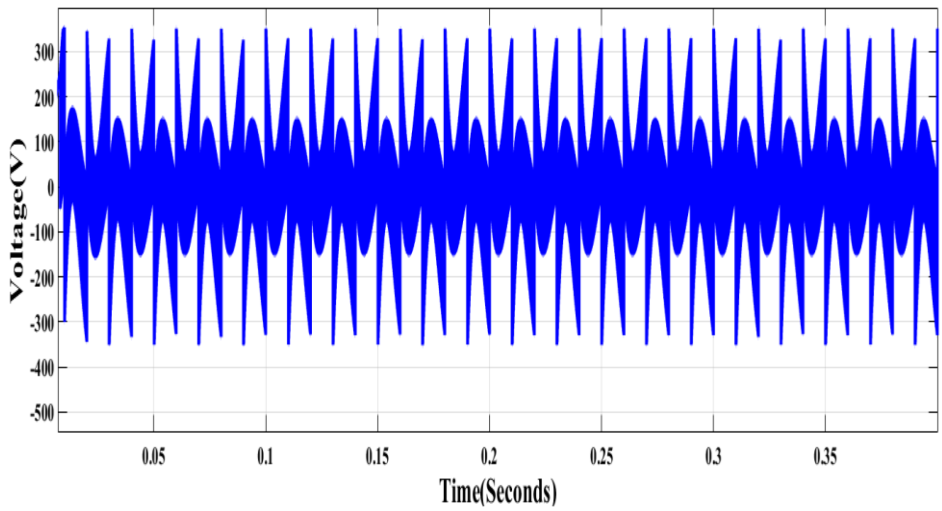


Figure 4. 4: The output of Subsystem of H-Bridge Single Phase System.

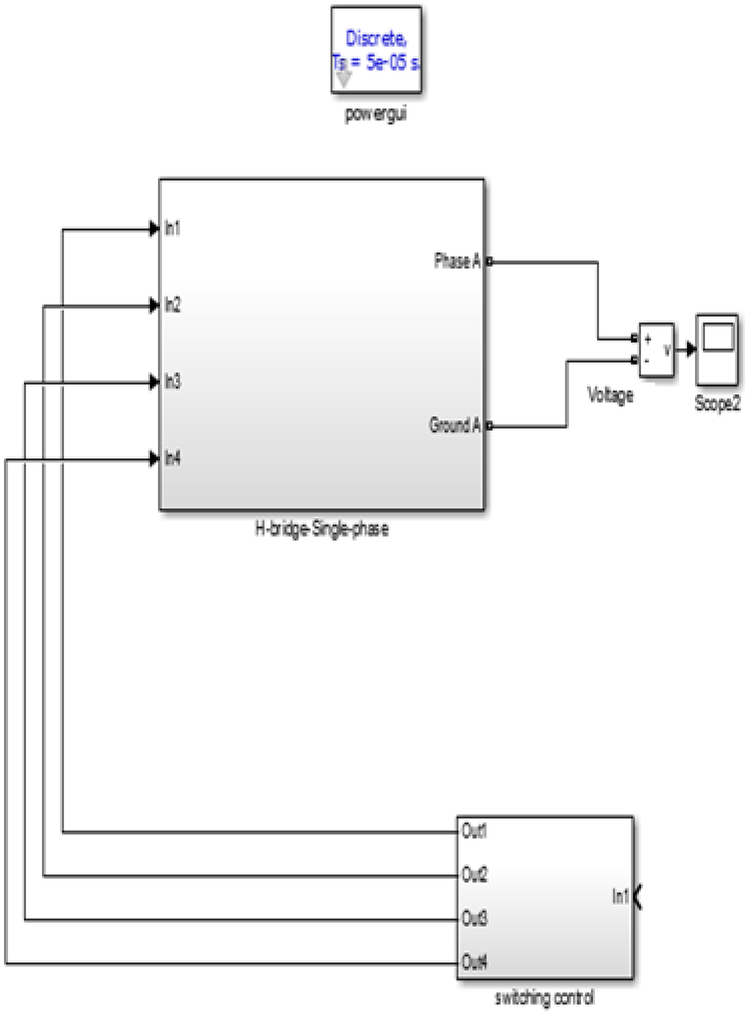


Figure 4. 5: Simulink Model of H-Bridge circuit with Switching Control Circuit

As can be seen from the above picture, the outputs are connected to the comparator circuit subsystem, which is provided to provide switching control for IGBT. Created switching control sub-system is shown in Figure 4.6. In fact, the switching control circuit is a circuit that compares the triad with a sinusoid and generates a DC signal according to the signal in this comparator. Two sinusoidal and two triangular signal comparators with 1V and 50 Hz frequency for 4 MOSFET inputs is implemented in this design. Two logical operator outputs, one for each gate, are used for the other two MOSFET gate switches in the absence.

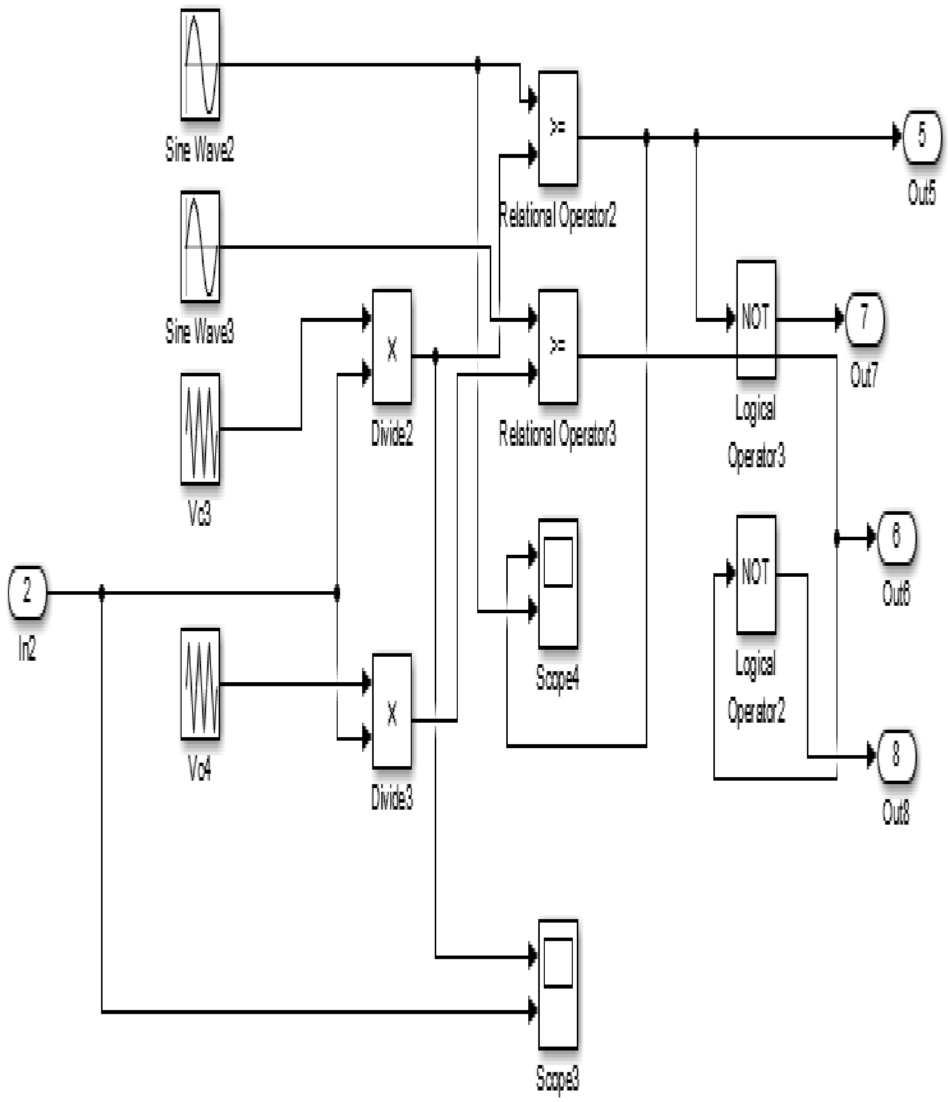
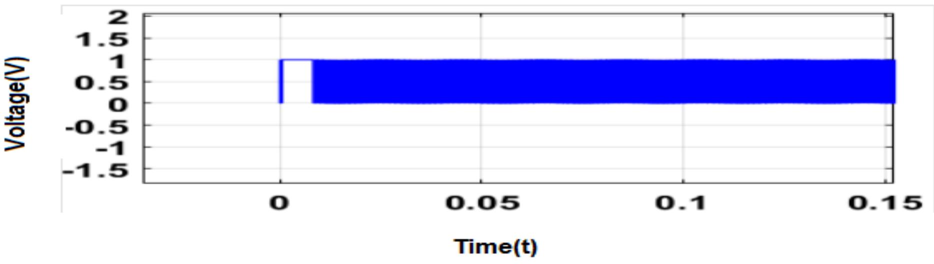
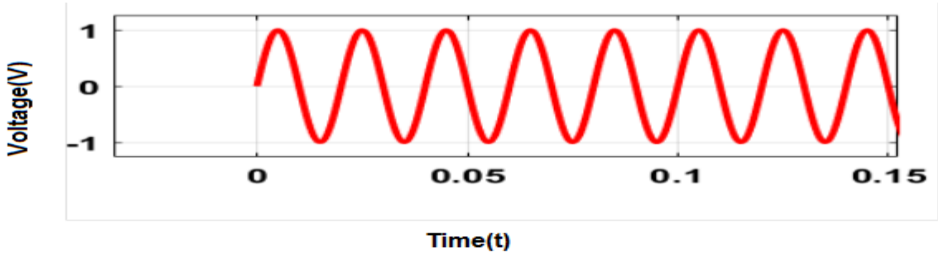


Figure 4. 6: Open schematic of Switching Control Subsystem.

In the comparator circuit above, triangular and sinusoidal signals are compared and a square signal is obtained. DC signal generated against sinusoid Figure 4.7 shows DC signal against triangle as shown in Figure 4.8. Figure 4.7 shows the DC signal obtained from the upper part, while the lower part shows the sinusoidal part used.

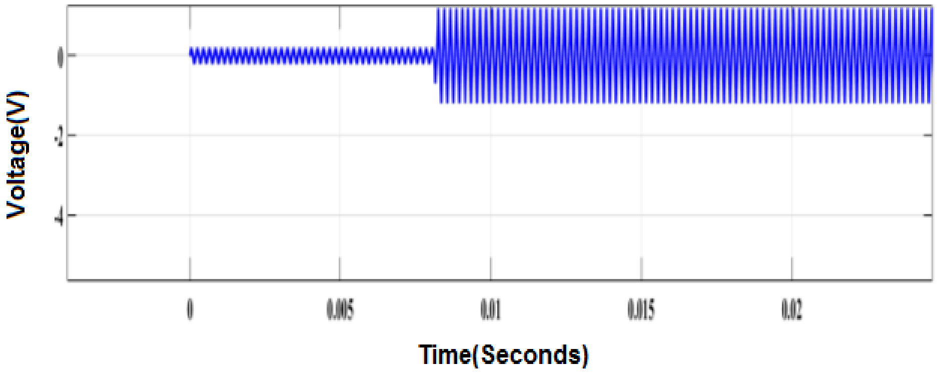


(a) Square Signal

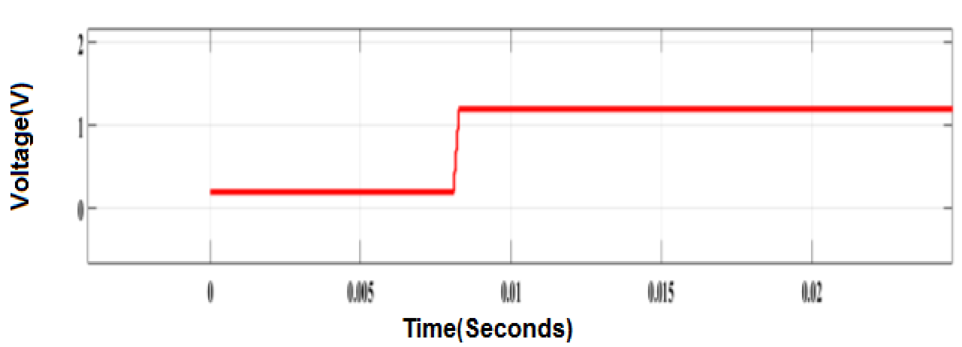


(b) Pure Sinus Signal

Figure 4. 7: Obtained DC signal by comparing sinusoidal(b) and triangular(a) signal.



(a) Triangular Signal



(b) Square Signal

Figure 4. 8: DC signal obtained from the comparator using triangular signal.

When the above signals are examined, it is observed that obtaining the dc signal is easier and more reliable than the other dc conversion methods by comparing the triangle and the sinus signals.

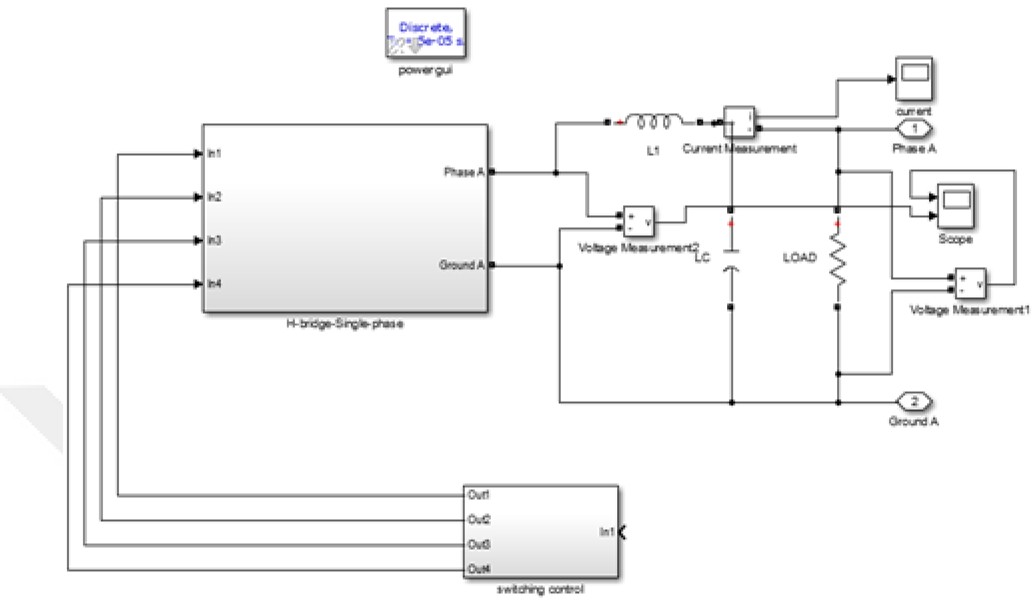


Figure 4. 9: Adding LC filter to output system of Single Phase H Bridge Inverter.

The output of the H bridge single-phase inverter is "chopped AC voltage with zero DC component". This signal contains high-frequency harmonics which is higher than 50 Hz. For this reason, an LC low-pass filter is used at the inverter output to reduce the high-frequency harmonics because "high purity" sine wave output is required in some applications such as UPS. In Figure 4.7, LC filter was added into H bridge output for reducing harmonics. A resistor of 5 Ohm is connected as a load so that the output can be measured and the voltage can be taken.

In LC filter, L and C are selected as 0.6mH and 15mF respectively. The cutoff frequency (Fc) is calculated using below equation.

$$F_c = \frac{1}{2\pi\sqrt{LC}} = 53{,}052\ Hz \qquad (4.1)$$

Where the signals above the frequency of 53,052 Hz are eliminated using LC filter and the output of LC filter was obtained as in Figure 4.10 for current. After LC filtration, it appears that the signal is cleared from the high-frequency signals and a more pure signal is obtained.

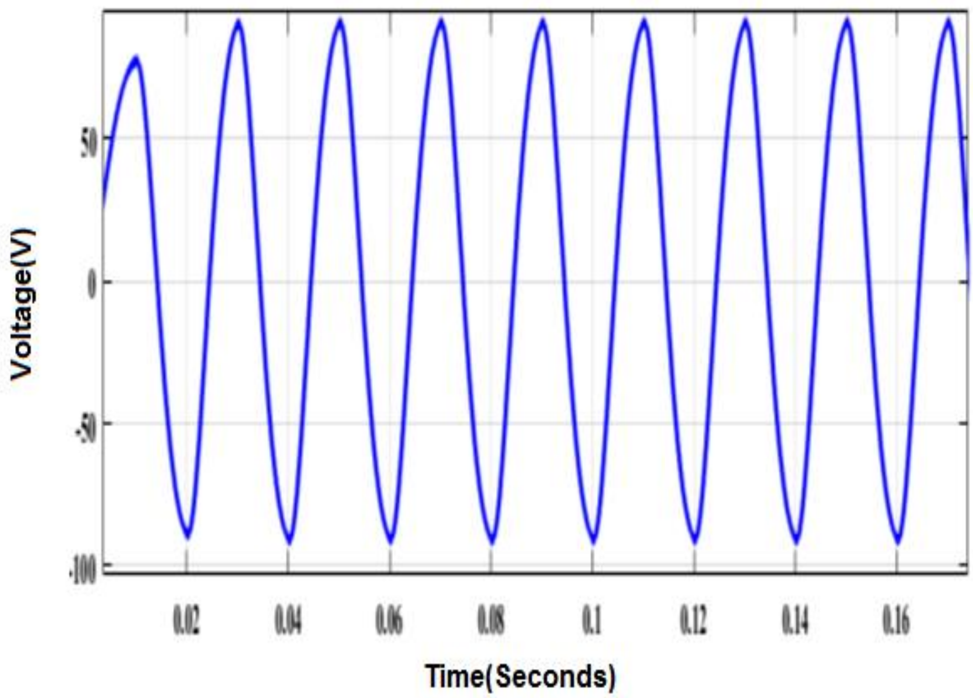


Figure 4. 10: The current output of single phase H bridge inverter after added LC filter.

In Figure 4.11, the upper section shows the filtered inverter voltage output, while the lower section shows the inverter voltage output without inverter filter. As can be understood from the figure, the high-frequency noise is seen before the filtration is not visible in the upper part of the filter.

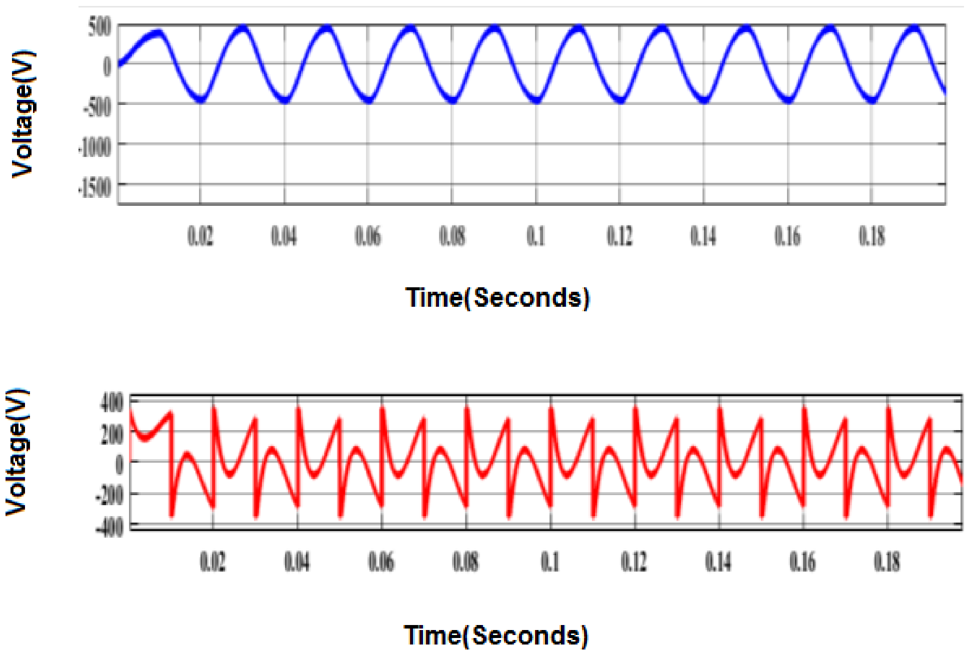


Figure 4. 11: The inverter output with and without LC filter.

A reference voltage of 200V was set to generate the signal at the desired voltage level after the signal having the desired frequency of 50 Hz was generated and a control mechanism including the P controller was added to the system so that the signal can be delivered most quickly and efficiently. Harmonic reduction in the system is achieved by providing the optimum alpha coefficient or gating signal. The switch angles in the single-phase H-bridge inverter are controlled to provide the optimum alpha coefficient When the Ki coefficient of the PI controller is set to 0 in the PI controller-based system, the results are shown in Figure 4.12-4.17 are obtained. Thus, the system is run with proportional controller base. Here, Kp values are set to 0.05, 0.1, 0.2, 0.3 0.7 respectively in order to understand the effect of Kp.

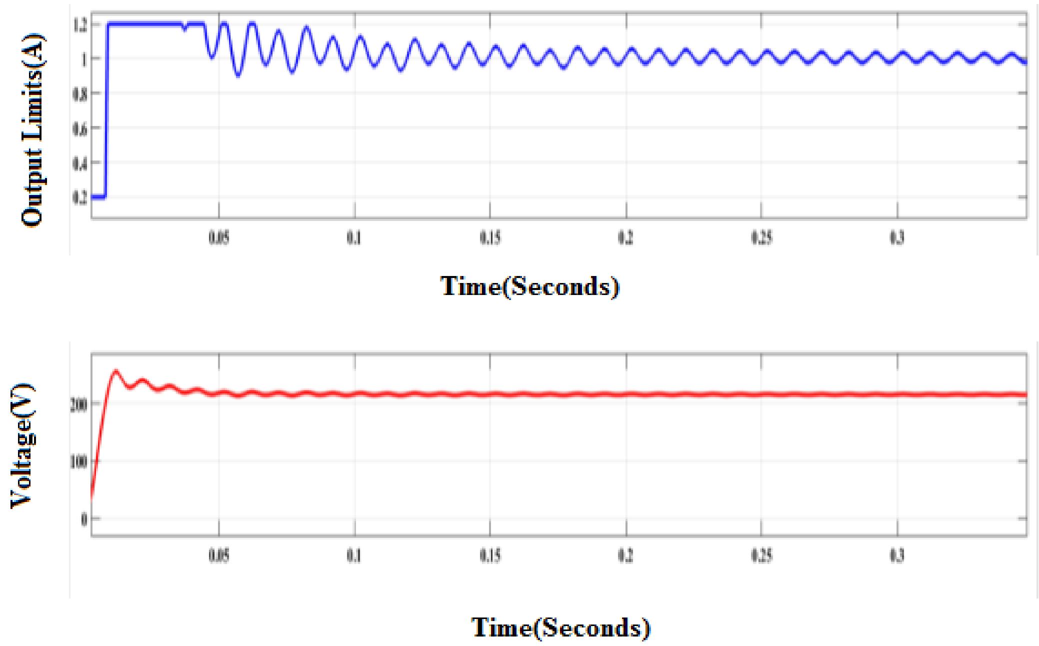


Figure 4. 12: Proportional controller based Single phase inverter for Kp=0.05

Setting the Proportional value to 0.05 results in Oscillation. Overshut Existing THD is 5.40%. This is not a desired result.

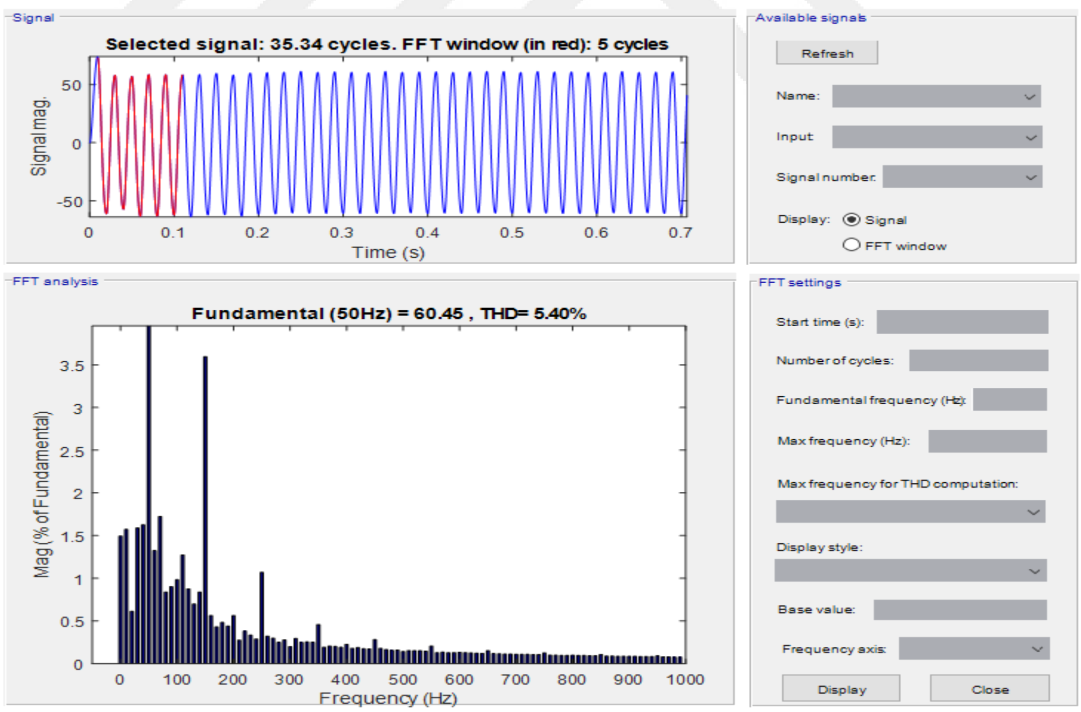


Figure 4. 13: FFT analysis and THD analysis Proportional controlled based Single Phase Inverter for Kp=0.05. FFT analysis and THD analysis Proportional controlled based Single Phase Inverter for Kp=0.05.

When the Kp value is set to 0.05, the system does not reach the desired current for a long time. However, the voltage is 205V instead of the desired voltage. The value of the harmonic is 5.4%, which is not lower than the 5V specified for the inverter.

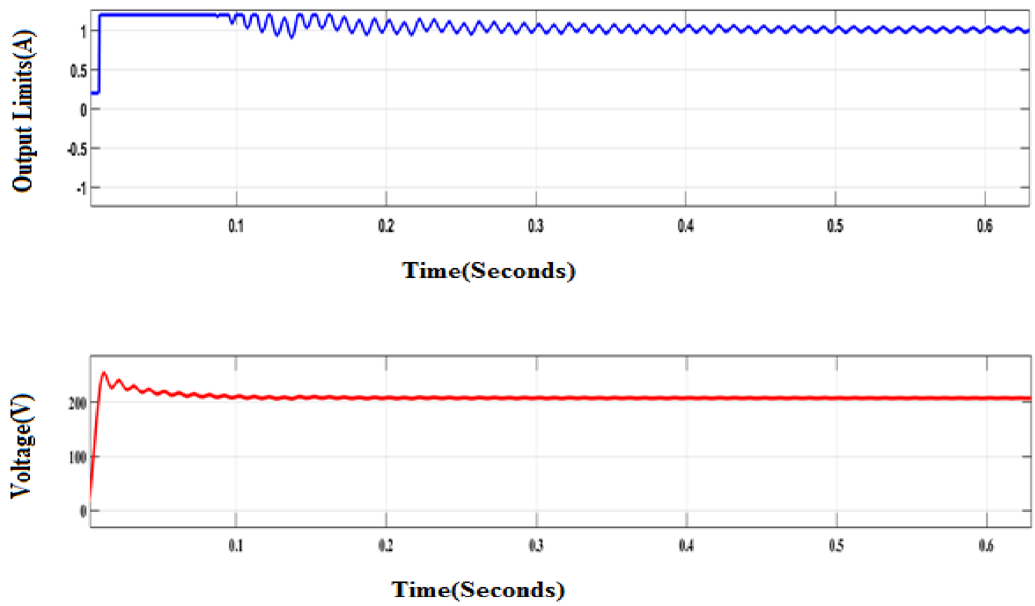


Figure 4. 14: Proportional controller based Single Phase Inverter for Kp=0.1.

In Figure 4.14, when the Kp value is increased, it is seen that the result is quite far from the desired value even though the oscillation is decreased.

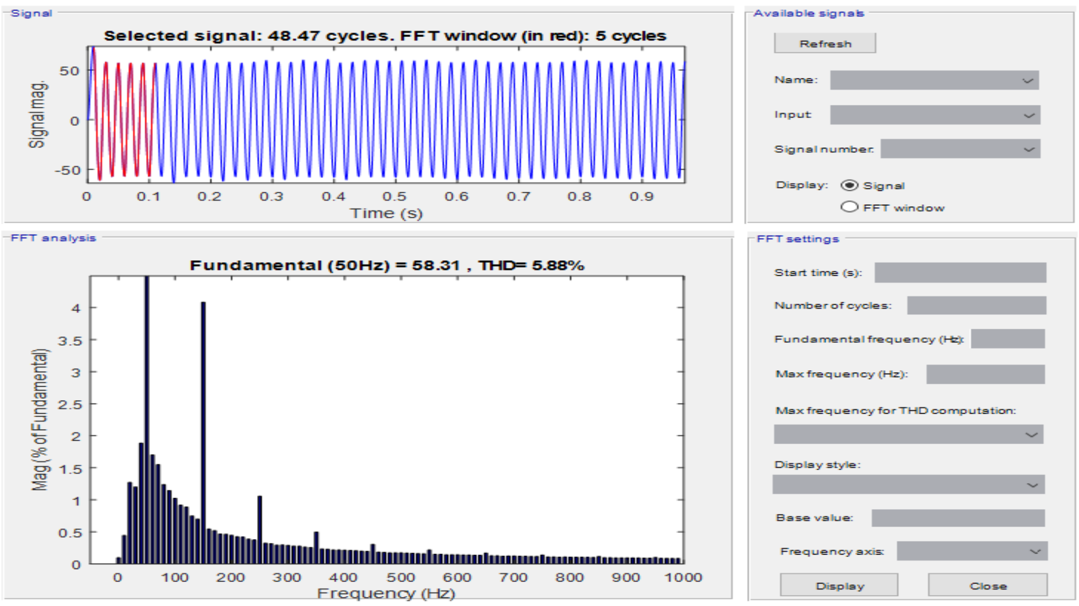


Figure 4. 15: FFT analysis and THD analysis Proportional controlled based Single Phase Inverter for Kp=0.1.

When the Kp value is set to 0.1, the desired reference current and voltage can not be reached, and the THD value has risen and it is observed that the harmonic distortion increases by 5.88% (Figure 4.15).

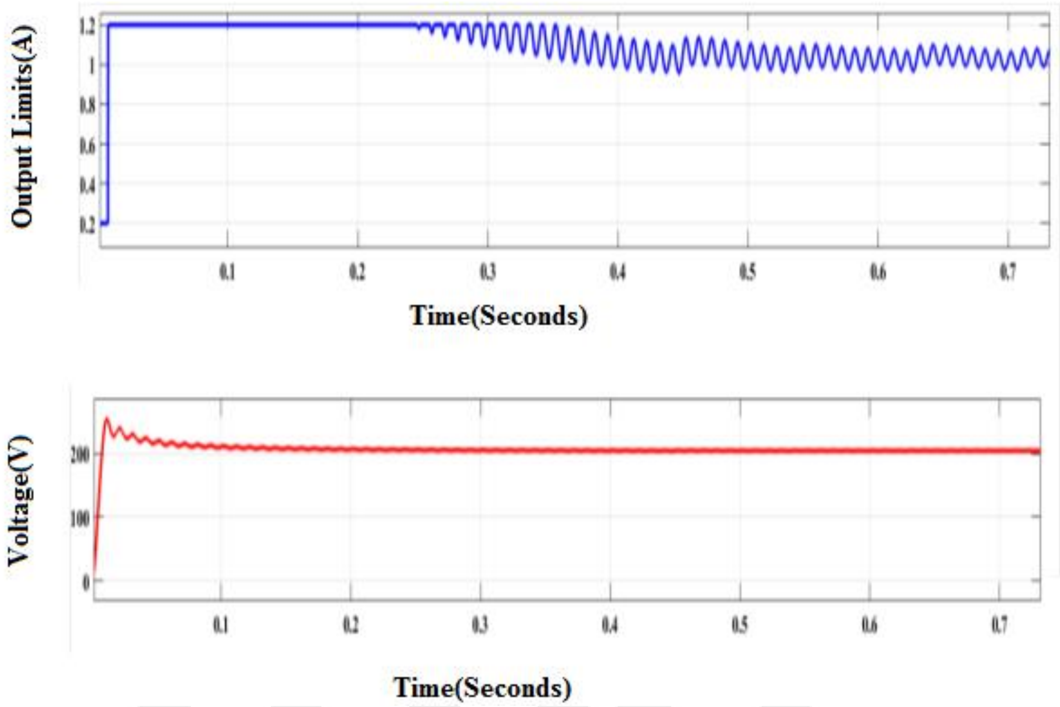


Figure 4. 16: Proportional controller based Single phase inverter for Kp=0.2.

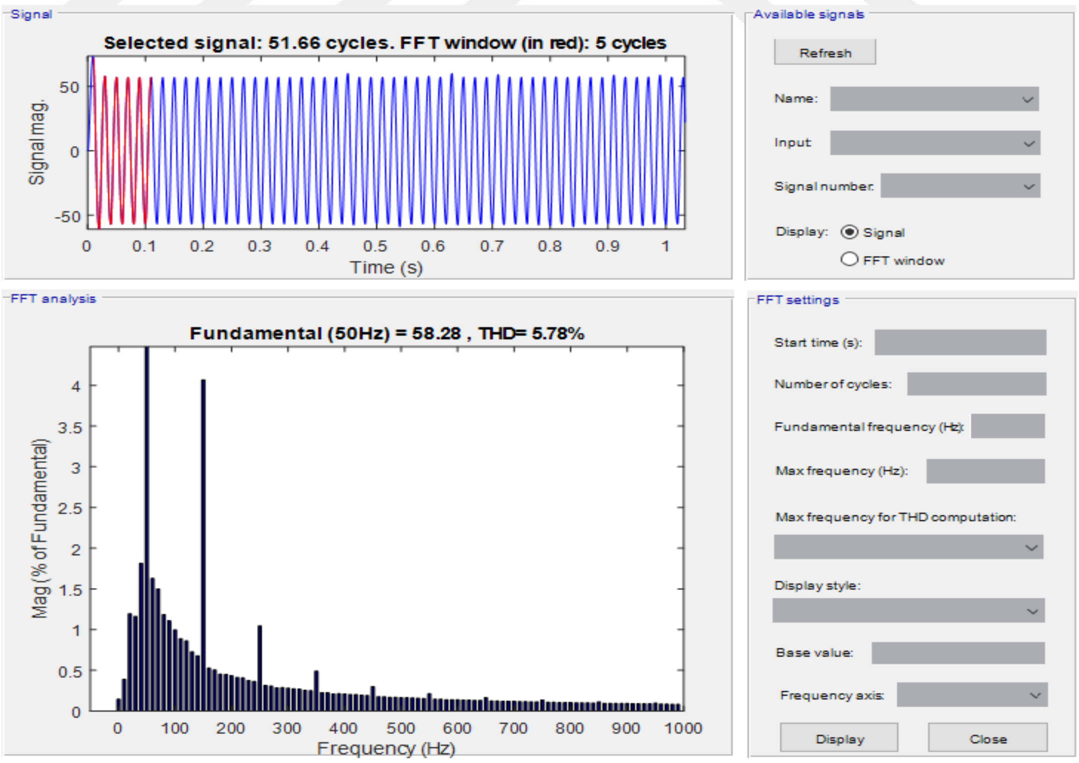


Figure 4. 17: FFT analysis and THD analysis of Proportional controlled based Single-Phase Inverter for Kp=0.2

When the Kp value was increased, the oscillation still continued and the overshoot value was observed to increase, but the THD did not go below 5%. Here, the Proportional controller examines the effects of this controller on the inverter because of our application.With the Kp value of 0.2, when the THD value is achieved as 5.78%, the desired reference strain and flow can not be achieved.

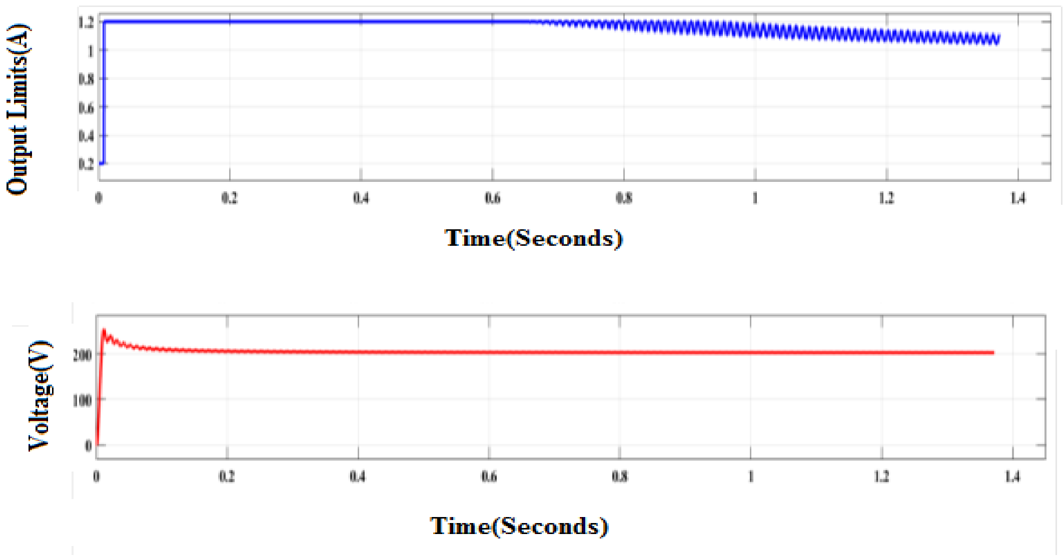


Figure 4. 18: Proportional controller based Single phase inverter for Kp=0.3

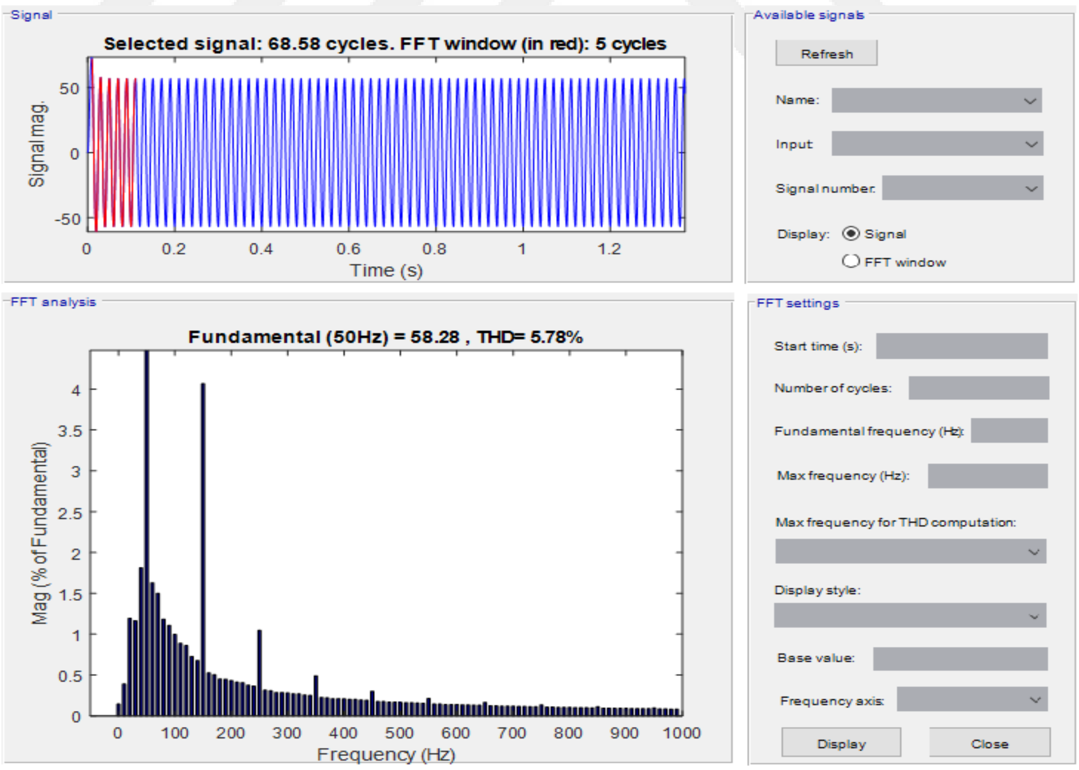


Figure 4. 19: FFT analysis and THD analysis of Proportional controlled based Single Phase Inverter for Kp=0.3

When Kp is given a value of 0.3, we see a decrease in oscillation, but overshut voltage surpasses the value of THD(Figure 4.18 and Figure 4.19). The THD ratio of the system does not change when the desired tension and flow reach times are reduced when the Kp value is set to 0.3. The highest THD ratio in the system was in the 58.28Hz.

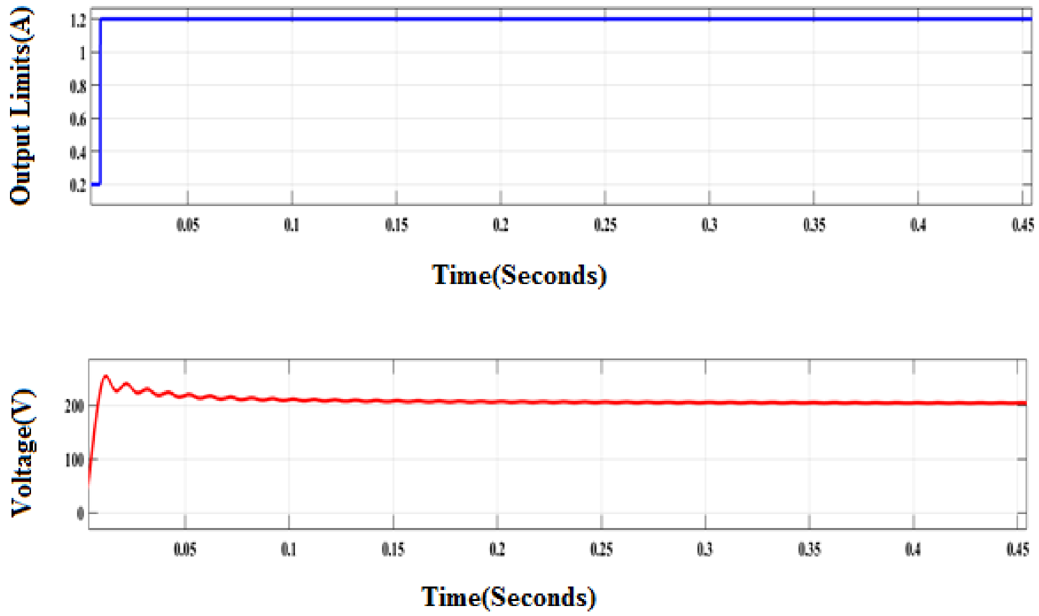


Figure 4. 20: Proportional controller based Single phase inverter for Kp=0.7.

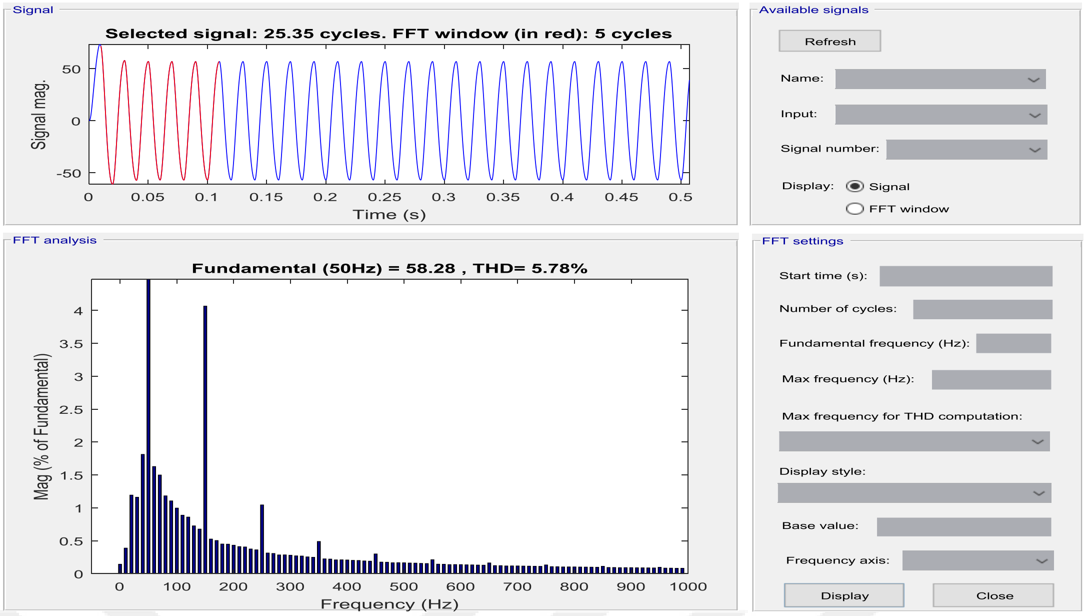


Figure 4. 21: FFT analysis and THD analysis of Proportional controlled based Single-Phase Inverter for Kp=0.7.

Finally, the Kp value is set to 0.7 as shown in Figure 4.21, which is a higher value, and the current and voltage responses of the system are investigated. As a result, it is observed that the Kp coefficient of the Proportional-based single phase inverter is shortened and the desired current and reference are reached faster. However, it is observed that the THD value increases in a certain range and remains constant after a certain level.

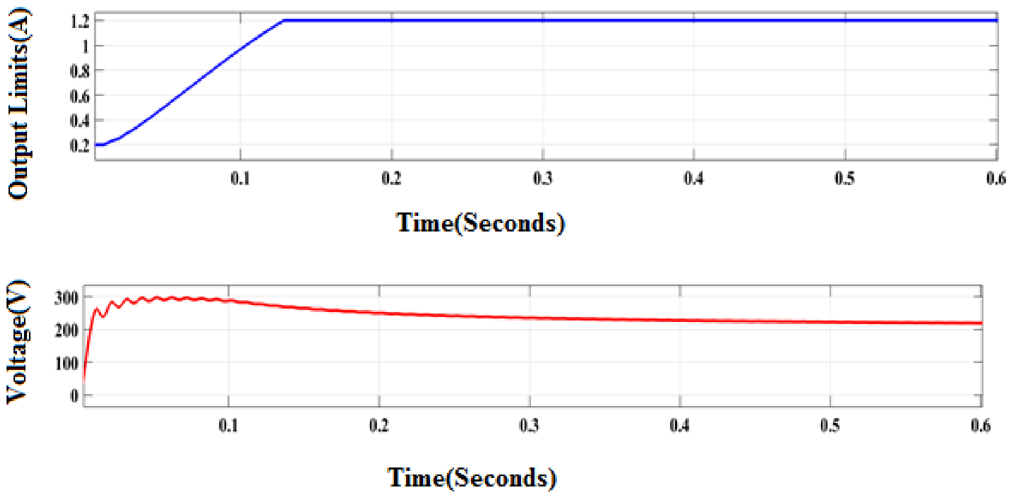


Figure 4. 22: Integrative controller based Single phase inverter for Ki=0.1.

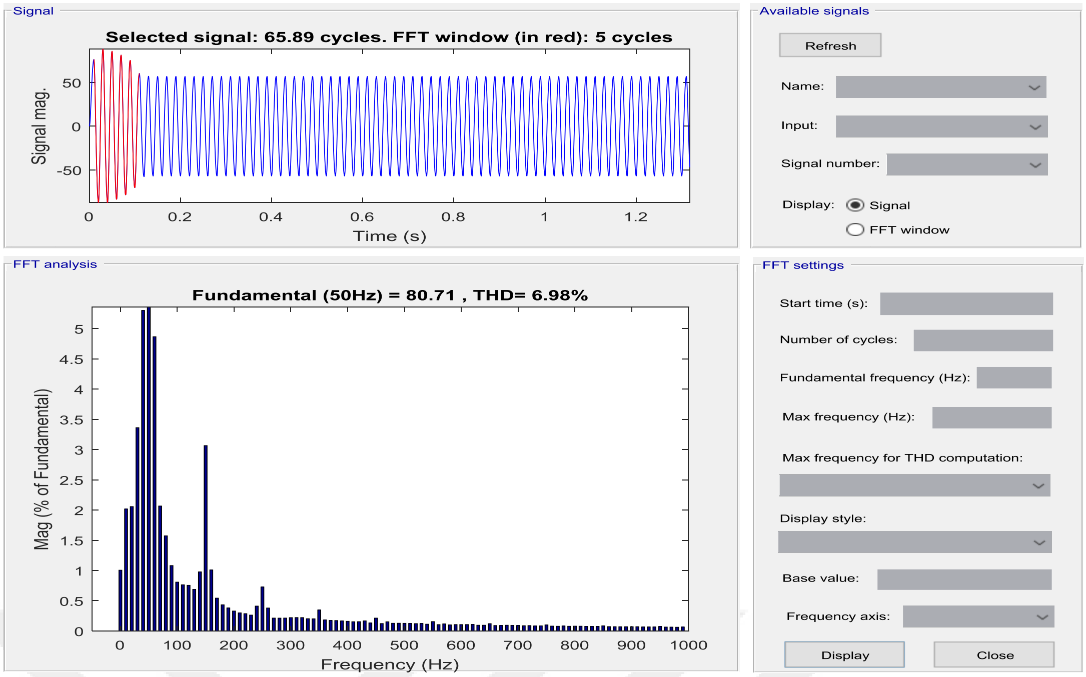


Figure 4. 23: FFT analysis and THD analysis of Integrative controlled based Single Phase Inverter for Ki=0.1

Finally, the Kp value is set to 0.7(Figure 4.22 and 4.23), which is a higher value, and the current and voltage responses of the system are investigated. As a result, it is observed that the Kp coefficient of the Proportional-based single phase inverter is shortened and the desired current and reference are reached faster. However, it is observed that the THD value increases in a certain range and remains constant after a certain level. When the Ki coefficient is set to 0.1, the desired reference strain cannot be achieved in the integrative-base single-phase inverter, and the THD value is 8.98, which is very high, as opposed to the desired value.

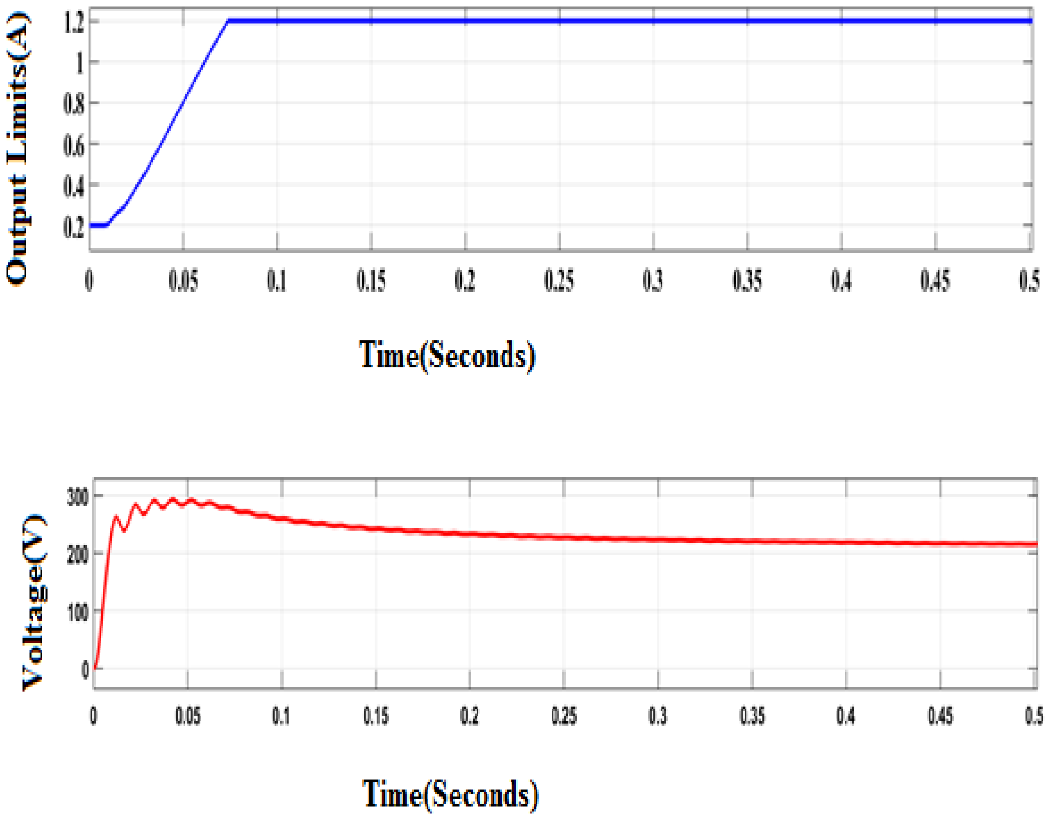


Figure 4. 24: Integrative controller based Single phase inverter for Ki=0.2.

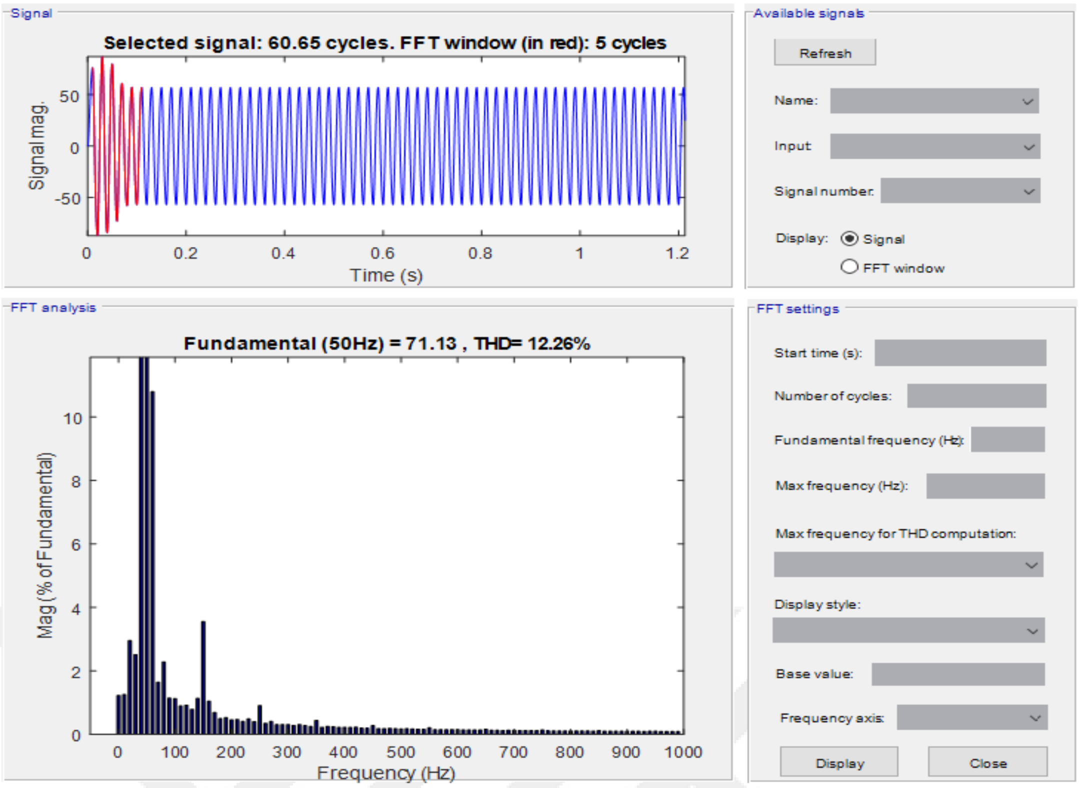


Figure 4. 25: FFT analysis and THD analysis of Integrative controlled based Single Phase Inverter for Ki=0.2

When the Ki coefficient is set to 0.2, the reference strain can not be achieved in the integrative-base single-phase inverter, and THD value is further degraded to 12.28. When the integrative value was raised and the reference voltage was not reached, the output limits were reduced. THD is very high.

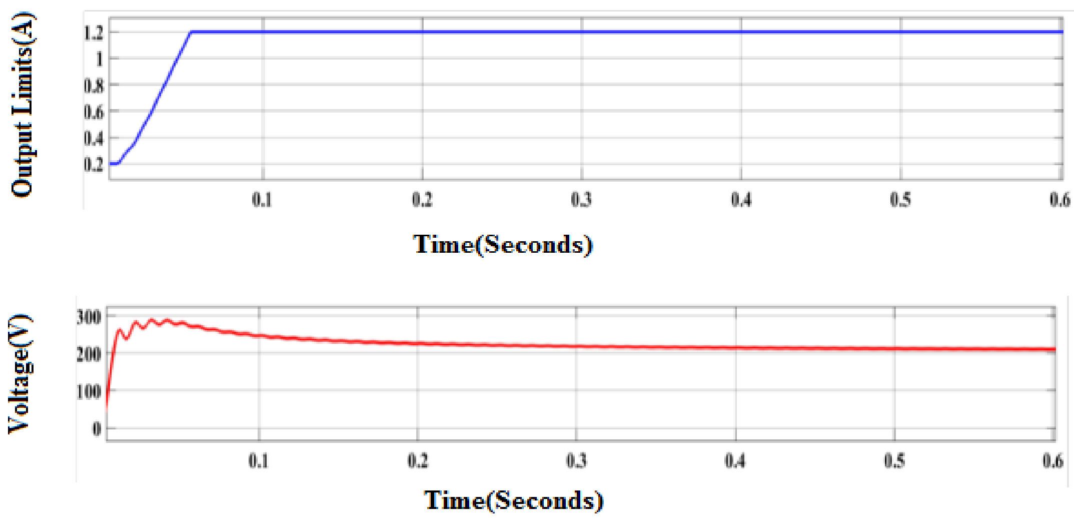


Figure 4. 26: Integrative controller based Single phase inverter for Ki=0.3.

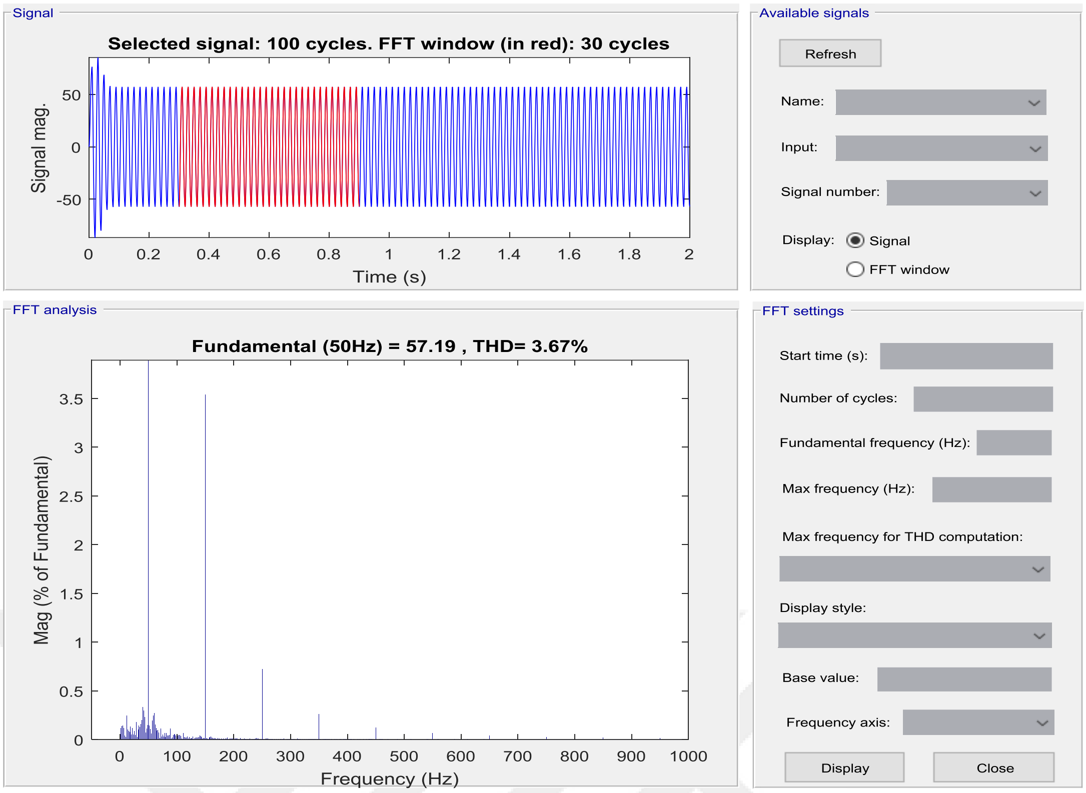


Figure 4. 27: FFT analysis and THD analysis of Integrative controlled based Single Phase Inverter for Ki=0.3.

When the Ki coefficient is set to 0.3, the integrator-based single-phase inverter achieves the desired voltage, 200V, with a high ovrshoot value after oscillation and the THD value is 3.67% at the desired value.

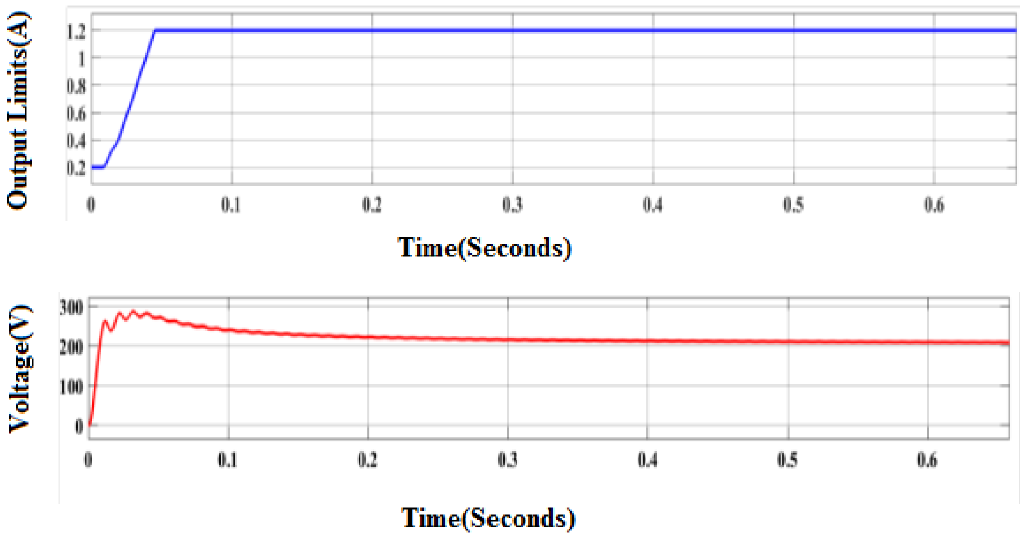


Figure 4. 28: Integrative controller based Single phase inverter for Ki=0.4.

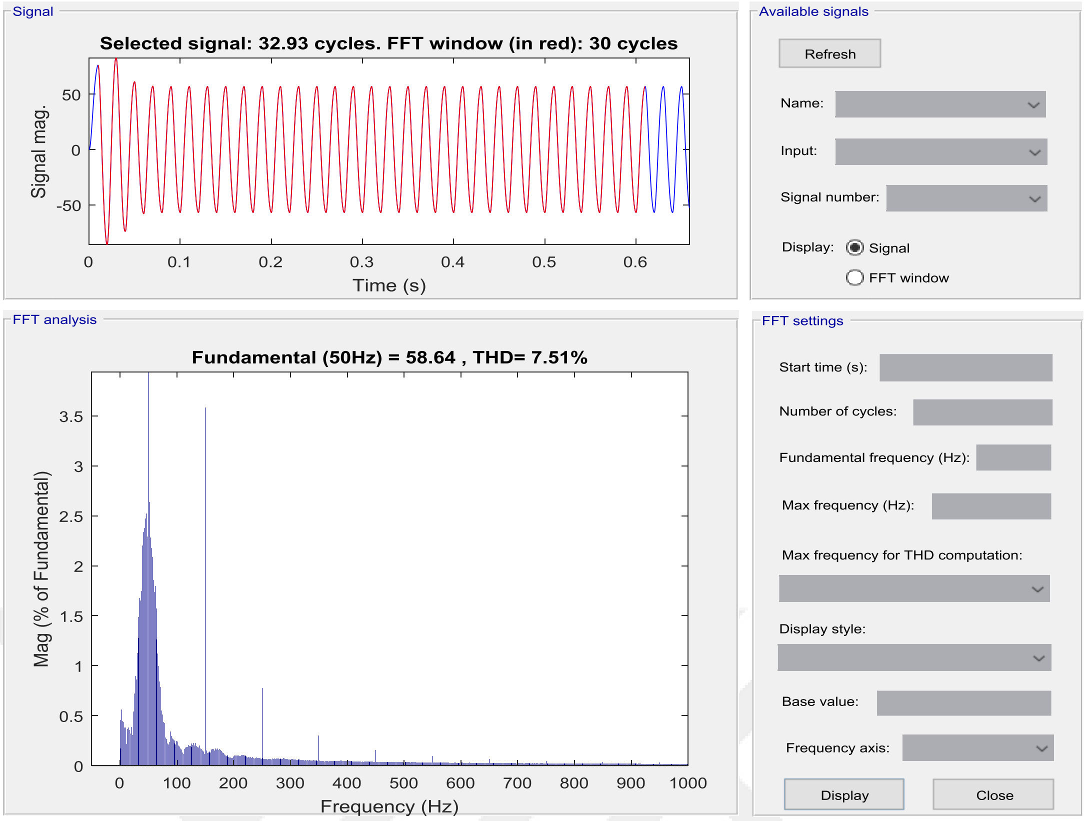


Figure 4. 29: FFT analysis and THD analysis of Integrative controlled based Single Phase Inverter for Ki=0.4.

When the Ki coefficient is set to 0.4, the harmonic quantity increases and the THD is 7.51%, though the desired voltage and voltage can be achieved in the integrative single-phase inverter. The response time at the output limit is again reduced and the overshoot value is reduced, but the THD again exceeds 5%, which is not a desired result.

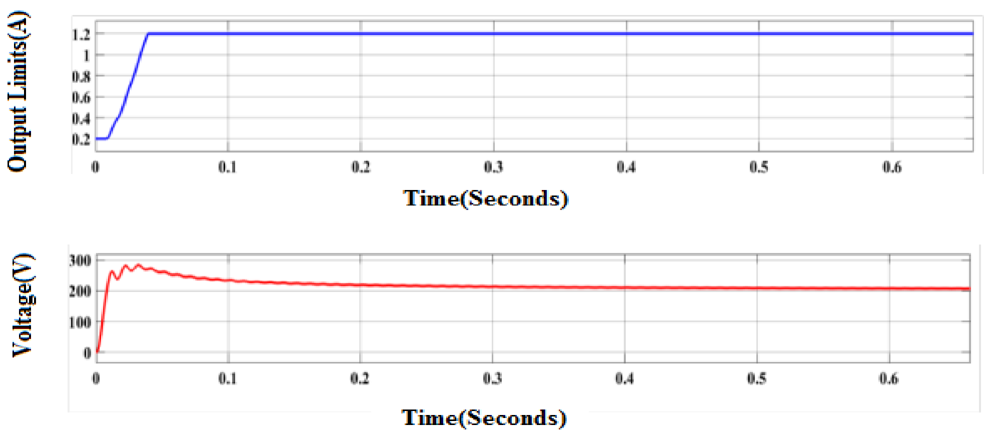


Figure 4. 30: Integrative controller based Single phase inverter for Ki=0.5.

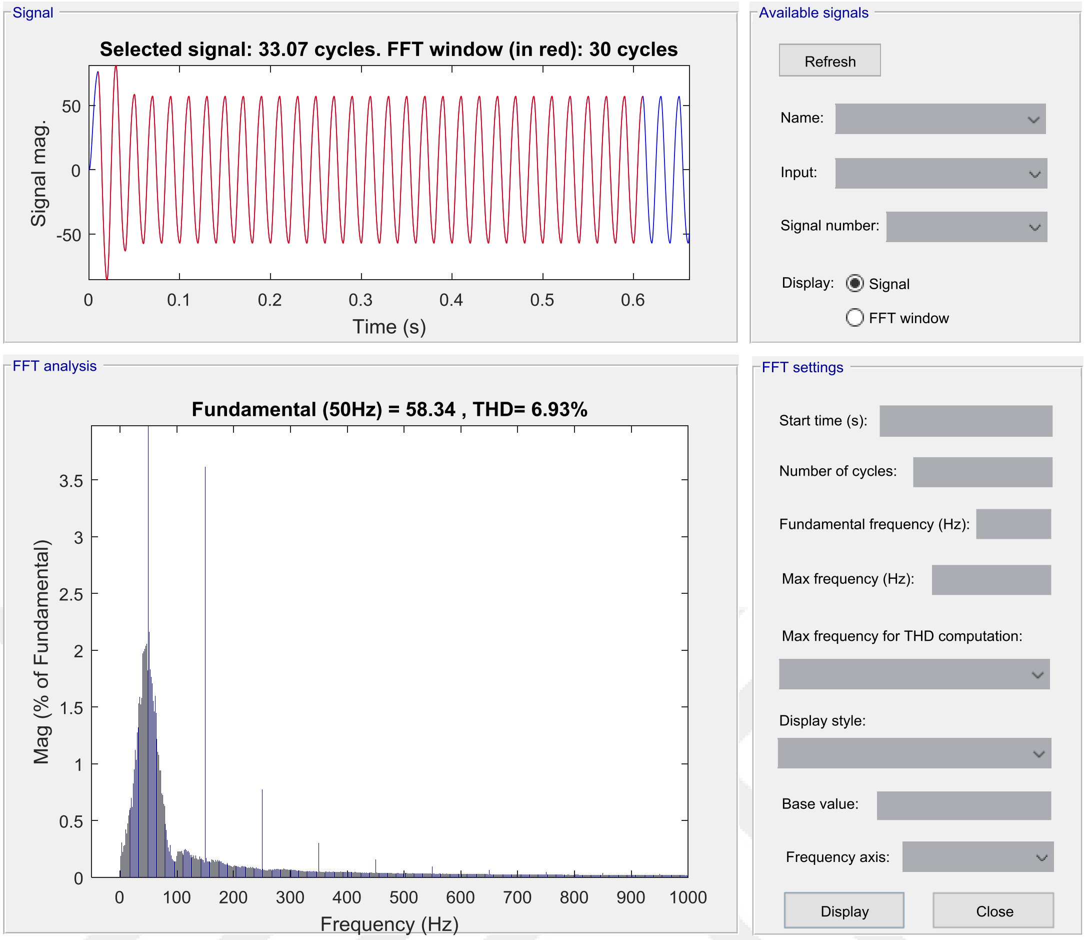


Figure 4. 31: FFT analysis and THD analysis of Proportional controlled based Single Phase Inverter for Ki=0.5.

When the Ki coefficient is set to 0.5, the desired voltage and voltage is achieved in the integrative-base single-phase inverter, and the harmonic quantity is slightly lower than the previous one, resulting in a THD of 6.93%. In the result,t he response time to the output limits and the time to reach the reference value have decreased but the THD is not at the desired value.

When the results of the inverters designed with Proportional and Integrative Controllers are examined, it is understood that it is appropriate to use a single phase inverter with a PI controller base by choosing the most suitable parameters of these two devices alone. In this system, $K_p = 0.2$ and $K_i = 0.3$ are adjusted according to control scope and the result of the proportional and integrative controller based single phase inverter (Figure 4.32) results which is shown in Figure 4.33 and 4.34. If we set the reference voltage to 300 V instead of 200 V, the results are as shown in Figure 4.35 and 4.36. As a result, the newly set reference voltage reaches the inverter quickly thanks to the PI control. When the above figure is examined, the time to reach the reference voltage of the PI-controlled inverter decreases as the voltage increases. On the other hand, when reaching the reference voltage above 300, the system creates a time delay due to the design of the inverter.

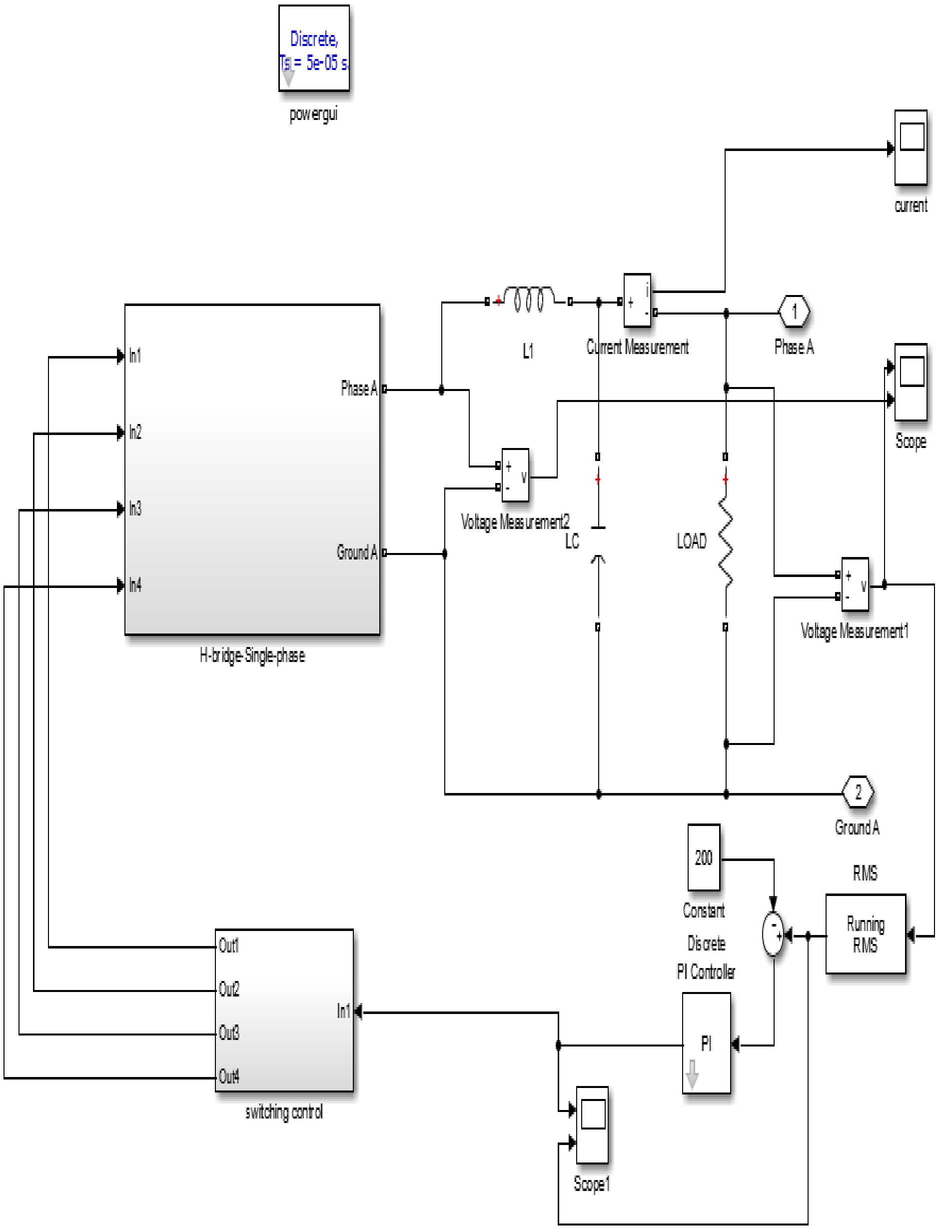


Figure 4. 32: PI control system for optimum gating signal to reduce harmonics

In the PI controller, the control has been eliminated by adding the permanent state error integrative controller.

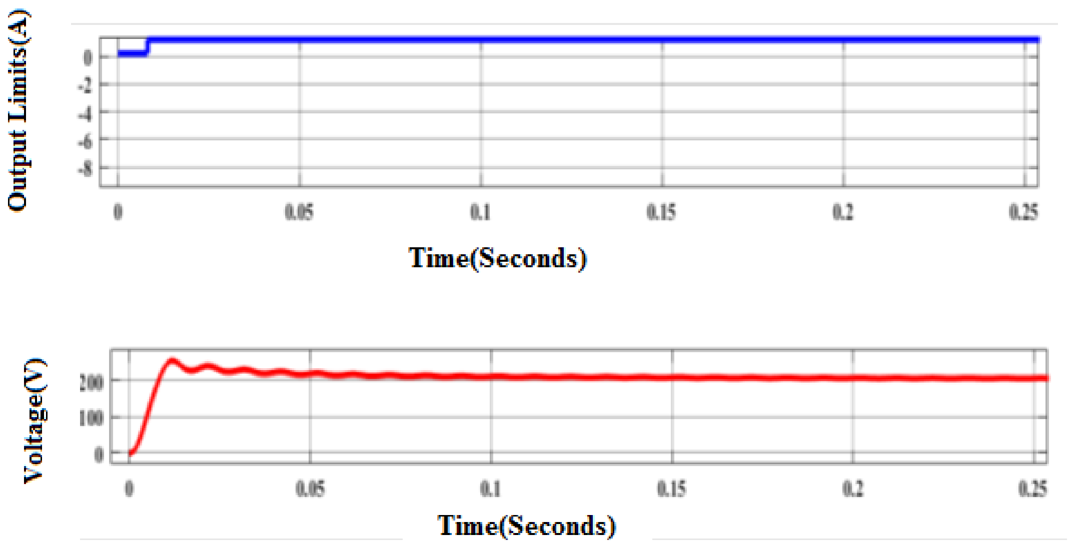


Figure 4. 33: The current and voltage output of PI Controlled Single phase H-Bridge Inverter for Kp=0.2and Ki=0.3

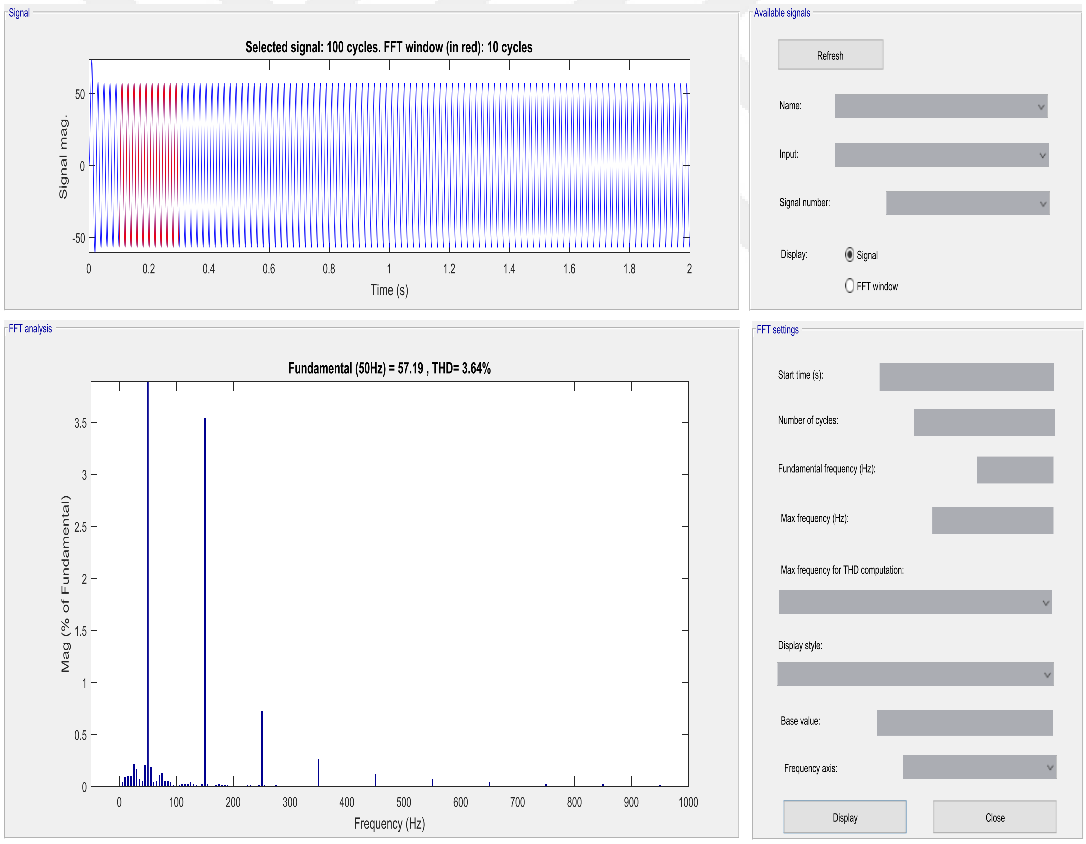


Figure 4. 34: FFT analysis and THD analysis of Proportional-Integrative controlled based Single Phase Inverter for Kp=0.2and Ki=0.3.

The Kp and Kd values reached the desired current and frequency in the fastest way in the system's response in the best-yielding values previously examined.

When the reference voltage was set to 300V, the system response was faster and the harmonic distortion was further reduced to 3.29%. However, undesirable oscillations have been observed in the current of the system.

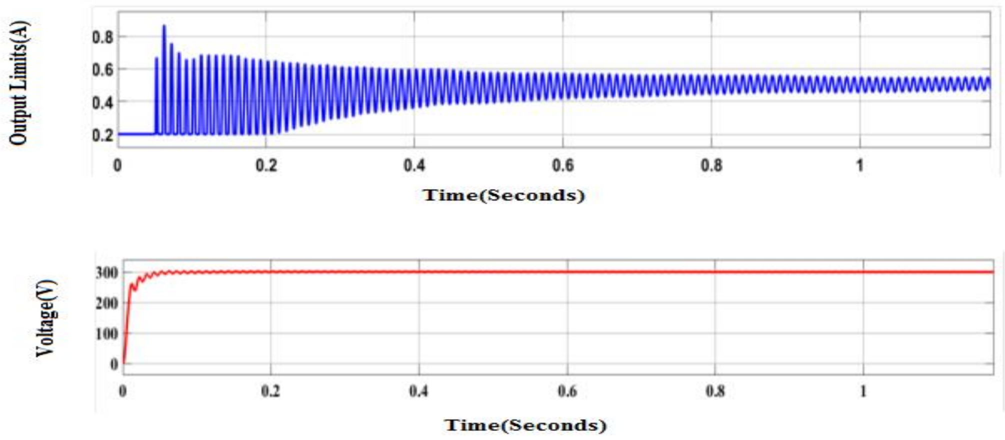


Figure 4. 35: The current and voltage output of PI Controlled Single phase H-Bridge Inverter for reference voltage 300V.

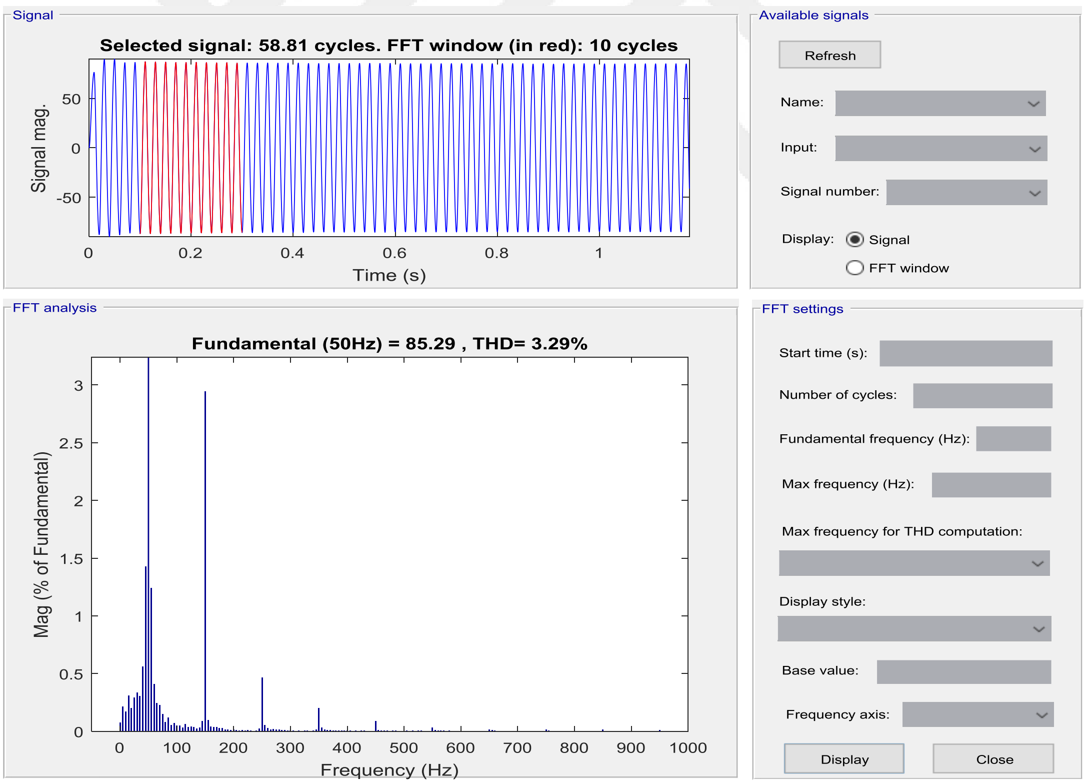


Figure 4. 36: FFT analysis and THD analysis of Proportional-Integrative controlled based Single Phase Inverter for Kp=0.2and Ki=0.3.

The PI controller operation was used to reduce the total harmonic distortion and the total harmonic distortion was reduced by 3.64 % for reference voltage equal to 200V. (Figure 4.36). The value of the PI controller is very small, as stated in the IEEE standard for inverter design. THD is calculated using the FFT toolbox in the Simulink. In this study, it has been seen that the system has overstepped too much of the proportional coefficient and the integral proportion cannot suppress it completely, so derivative control to the proportional control is added to suppress the system overrun. First, the effect of the derivative controller was studied in a single-phase inverter to design the Proportional Derivative controller. For this purpose, the proportional coefficient is set to 0.2 in the PID controller while the derivative coefficient is set to 0.1, 0.2, 0.3, 0.4, 0.5.

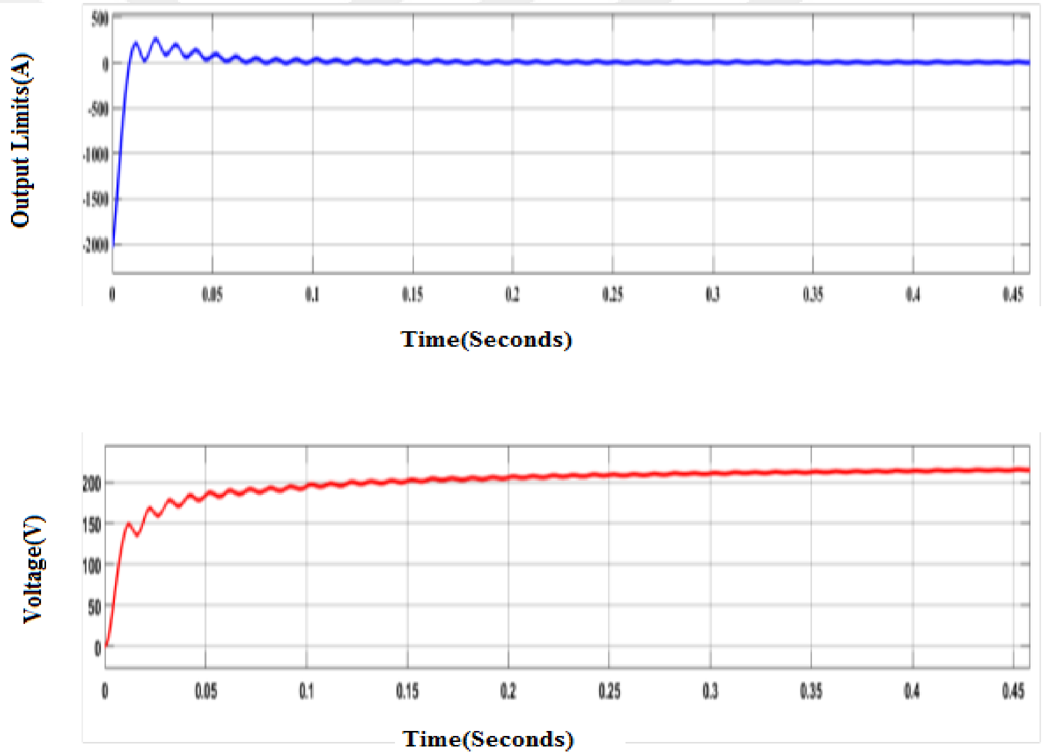


Figure 4. 37: The current and voltage output of PD Controlled Single phase H-Bridge Inverter for Kp=0.2 and Kd=0.1.

The output limit is set to zero at the PD control, as shown in Figure 4.37, so the output itself is zero at the reference point. The maximum overshoot problem seen in the Pi control was removed from here and thus the THD value was reduced.

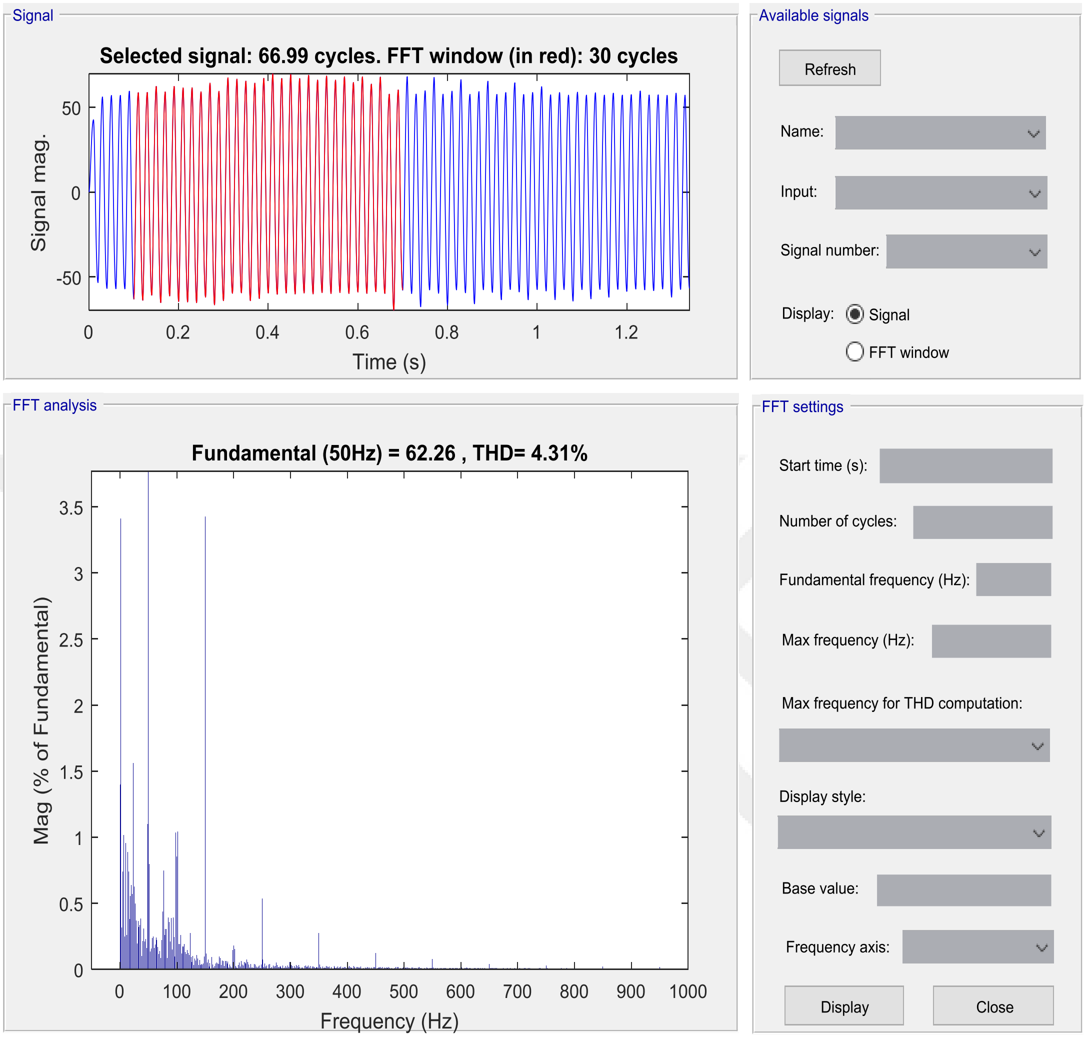


Figure 4. 38: FFT analysis and THD analysis of Proportional-Derivative controlled based Single Phase Inverter for Kp=0.2 and Kd=0.1.

When the Kp coefficient is fixed, when the Kd coefficient is set to 0.1, it is observed that the total harmonic distortion is reduced to conform to the 5% inverter THD standard. Here the overshoot and oscillation disadvantage of the proportional coefficient is solved by applying the derivative coefficient to the control.

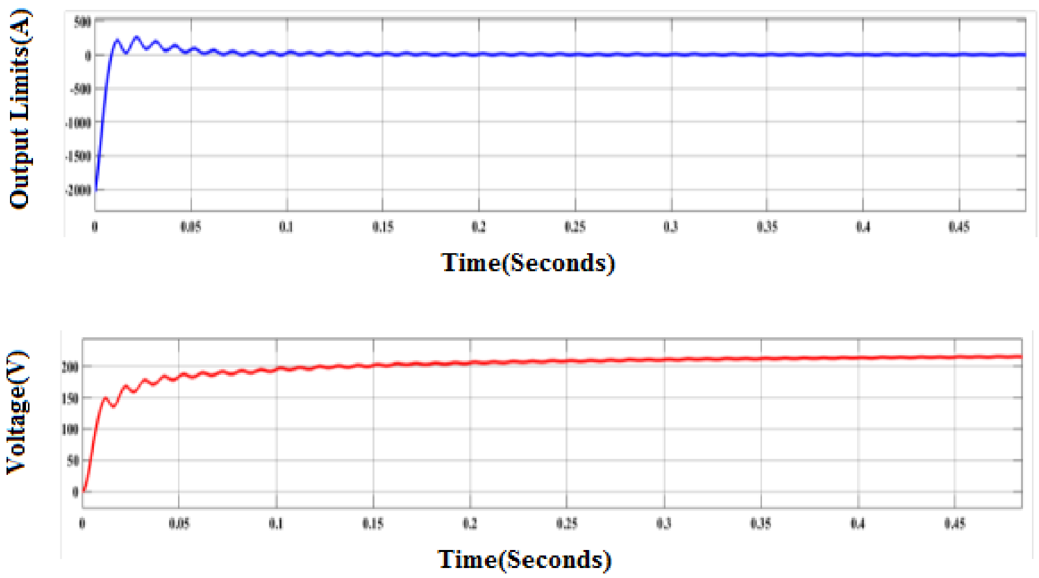


Figure 4. 39: The current and voltage output of PD Controlled Single phase H-Bridge Inverter for Kp=0.2 and Kd=0.2.

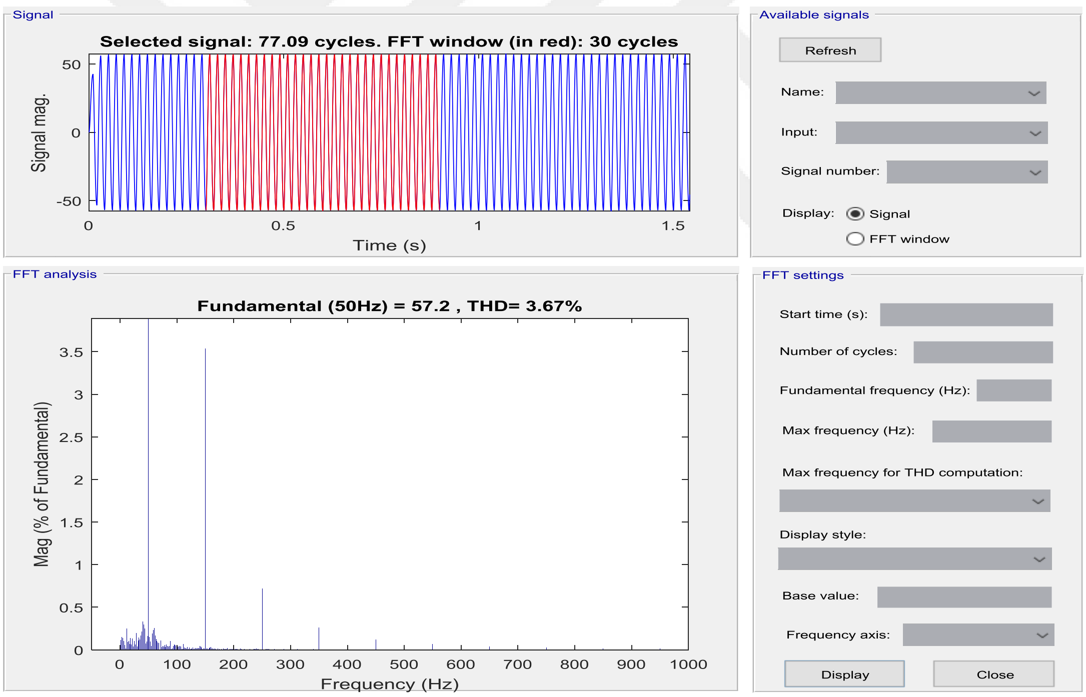


Figure 4. 40: FFT analysis and THD analysis of Proportional-Derivative controlled based Single Phase Inverter for Kp=0.2 and Kd=0.2.

When the Kd parameter was increased, it was observed that the THD harmonics decreased by 0.2. It is observed here that the reference value reached 0.15 s while the THD value dropped to 3.67, which is a desired feature for the inverter design because it is below 5%.

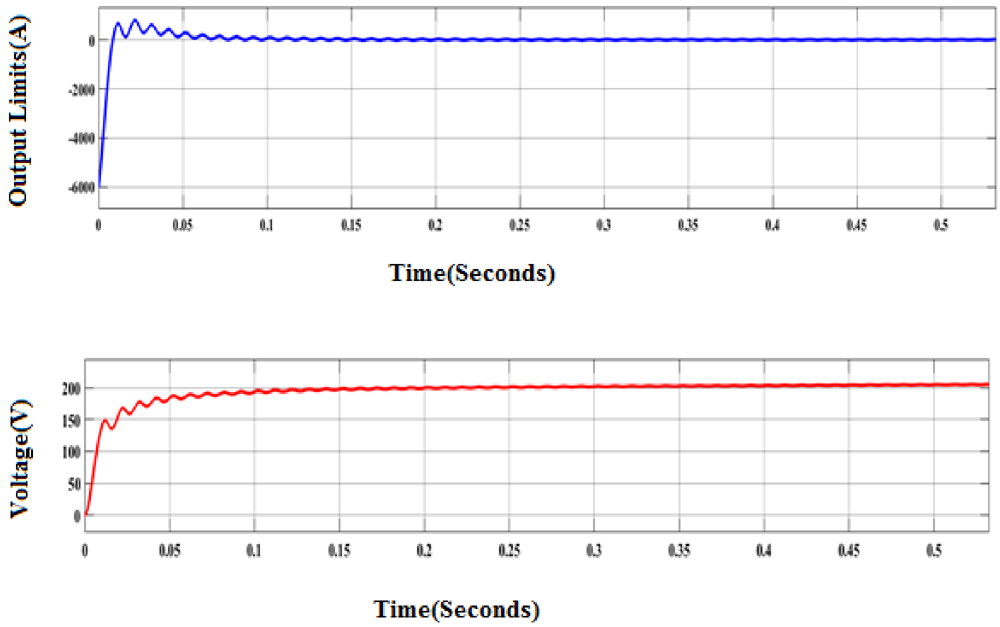


Figure 4. 41: The current and voltage output of PD Controlled Single phase H-Bridge Inverter for Kp=0.2 and Kd=0.3.

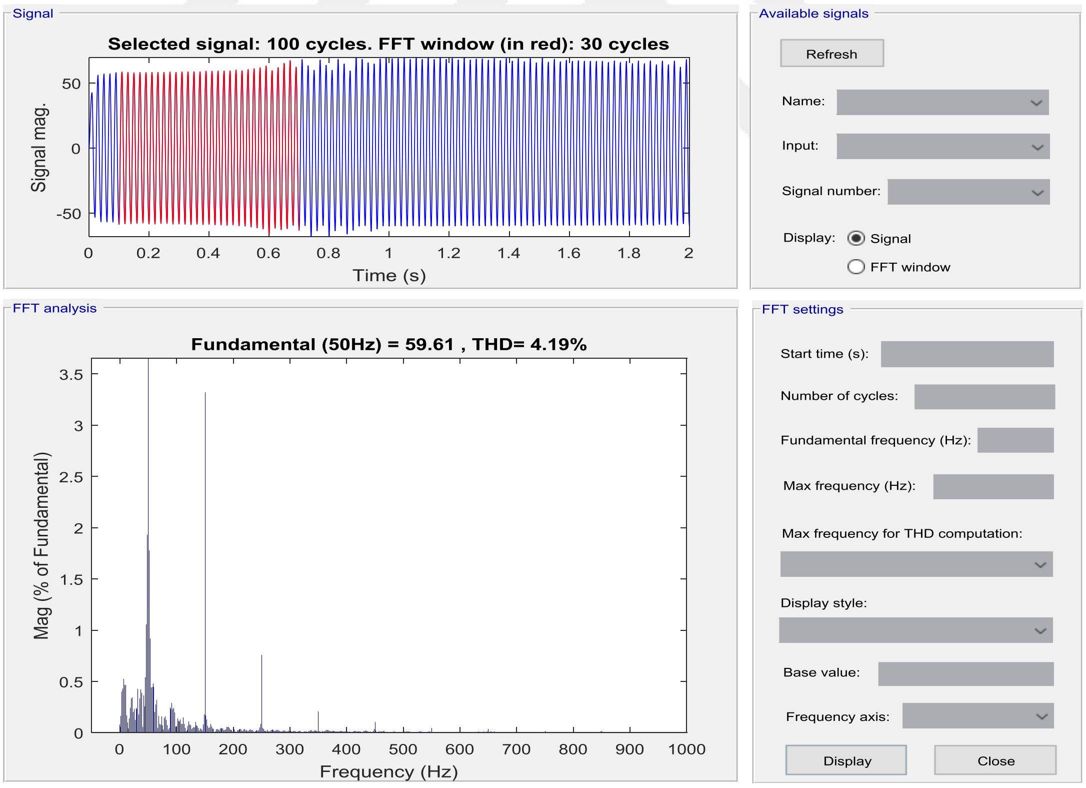


Figure 4. 42: FFT analysis and THD analysis of Proportional-Derivative controlled based Single Phase Inverter for Kp=0.2 and Kd=0.3.

When the Kd value is set to 0.3, it is observed that the THD value of the system increases even though the system responds faster and reaches the desired reference value faster by 0.1 sec.

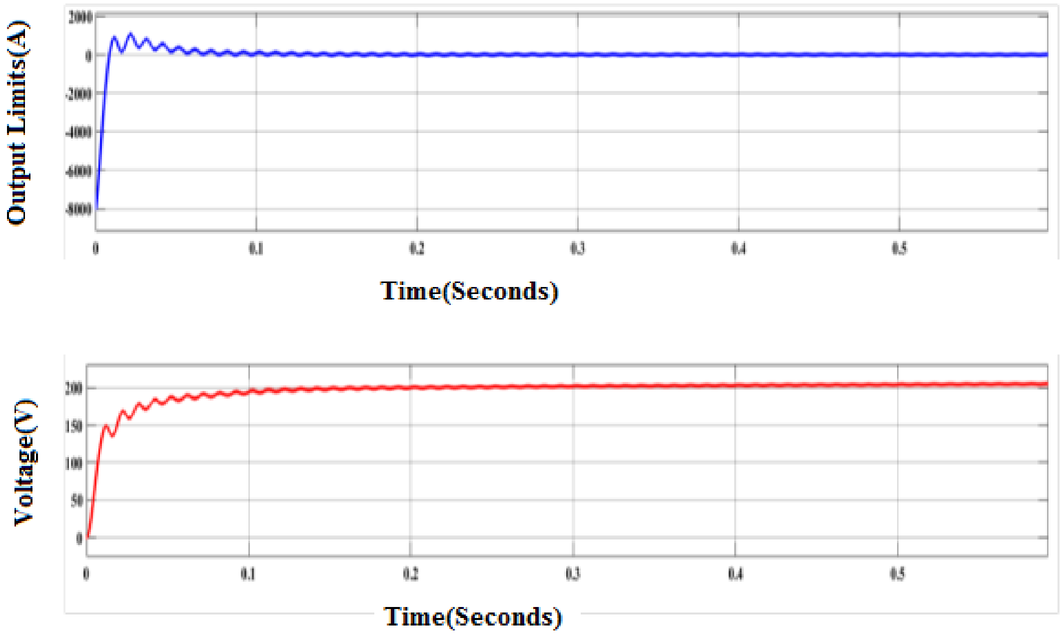


Figure 4. 43: The current and voltage output of PD Controlled Single phase H-Bridge Inverter for Kp=0.2 and Kd=0.4.

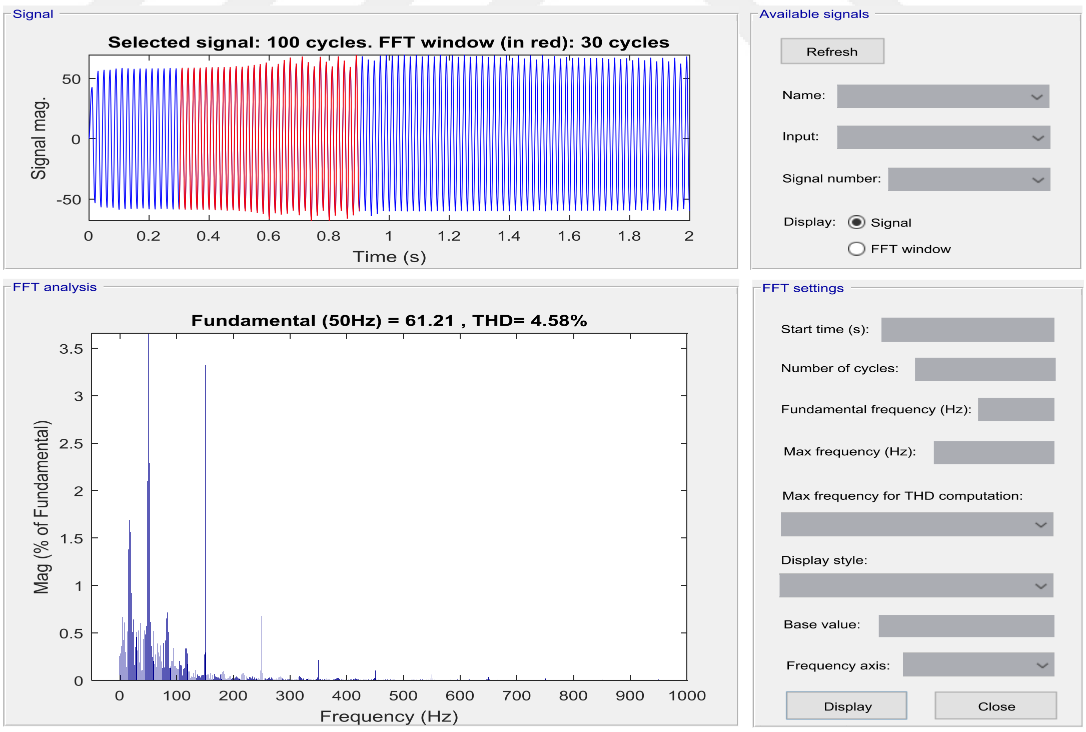


Figure 4. 44: FFT analysis and THD analysis of Proportional-Derivative controlled based Single Phase Inverter for Kp=0.2 and Kd=0.4.

When the Kd parameter is increased to 0.4, THD is slightly increased.

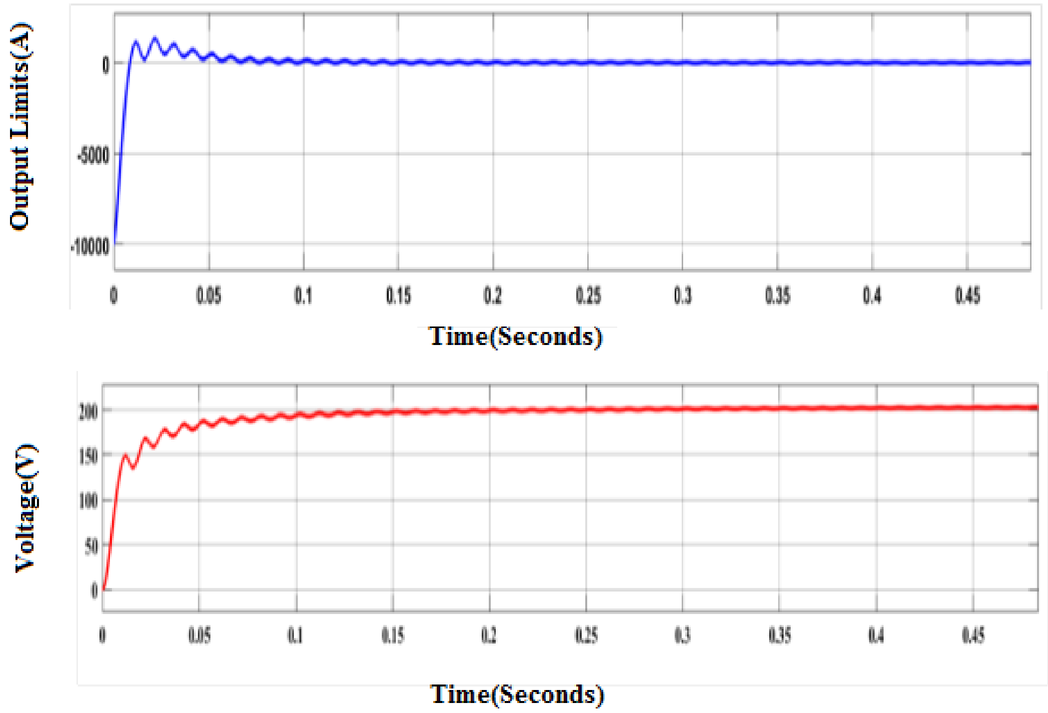


Figure 4. 45: The current and voltage output of PD Controlled Single phase H-Bridge Inverter for Kp=0.2 and Kd=0.5.

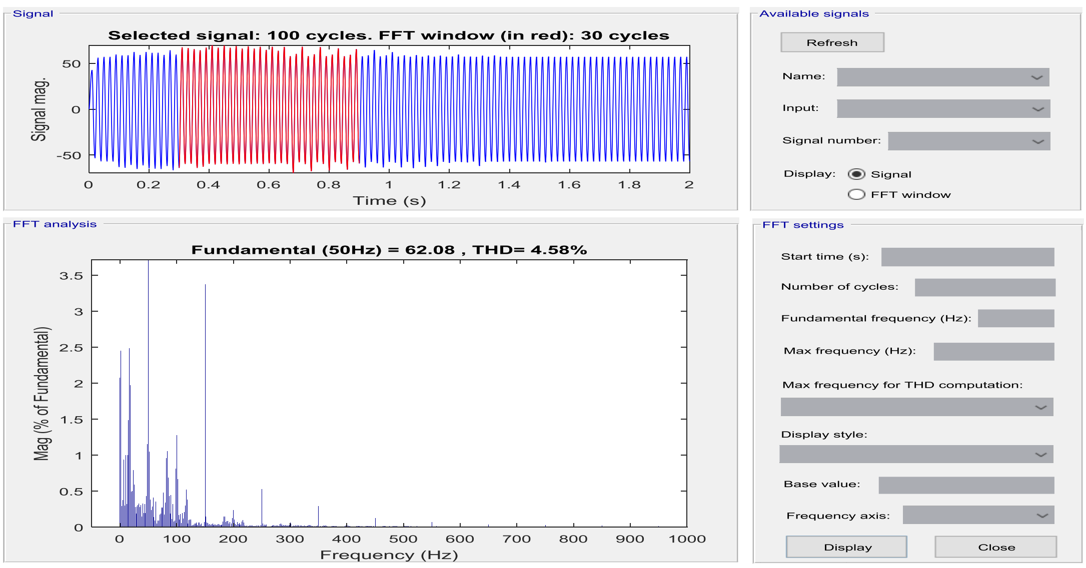


Figure 4. 46: FFT analysis and THD analysis of Proportional-Derivative controlled based Single Phase Inverter for Kp=0.2 and Kd=0.5.

When the Kd parameter is increased to 0.5, THD is slightly increased. From the results, the THD value of the inverter control changes at every value of Kp and Kd, and the optimal solution is not found. Therefore, it has been found to be more appropriate to have the parameters of the system with an optimization.

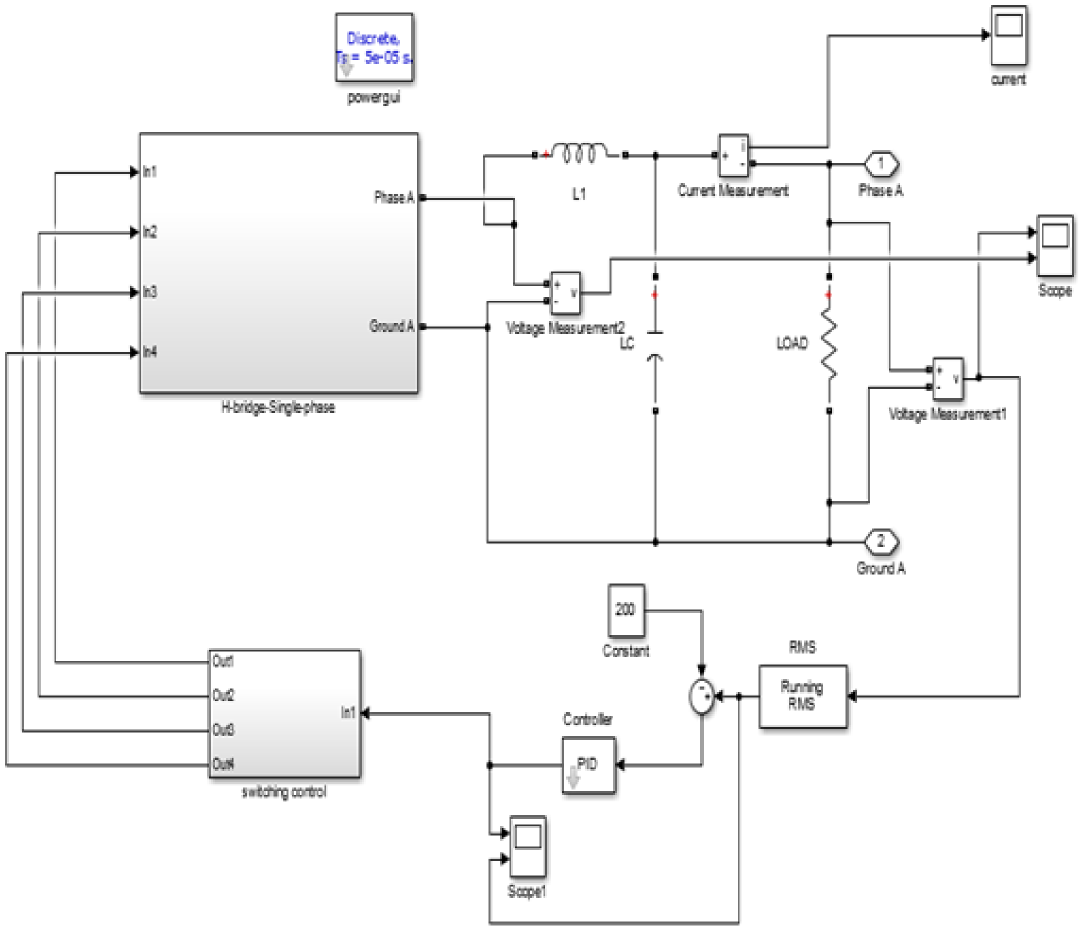


Figure 4. 47: PSO-PD controlled Single Phase H-Bridge inverter.

The Optimist function is prepared as Matlab Programming which is used PSO algorithm automatically and turned into a block diagram with a program fragment so that the PSO can automatically adjust the Kp and Kd parameters if the reference voltage is changed. PSO algorithm was used to calculate the optimal Kp and Kd parameters and Ki parameter is set as zero or ineffective. After the reference value for the PSO has been set to a certain voltage value, the range of the system to the voltage is considered as an error. As a result, the outputs current and voltage graph is obtained as Figure 4.48.

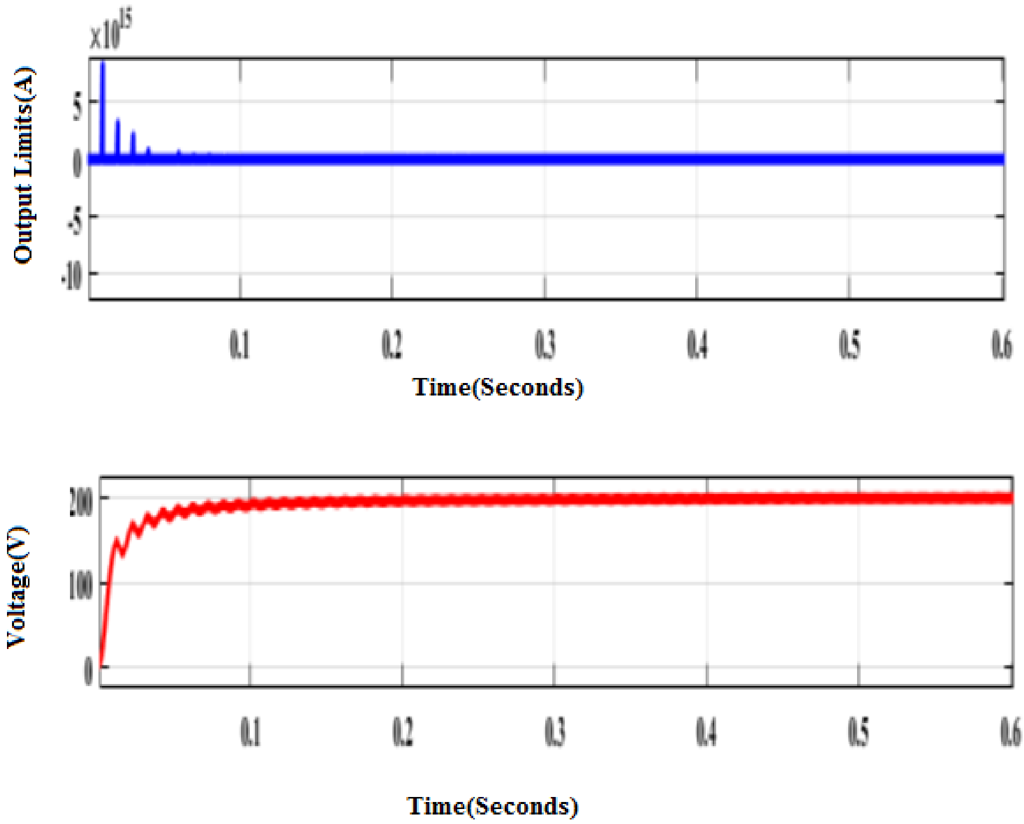


Figure 4. 48: The output current and voltage of PSO-PD controlled inverter.

When the above Figure is examined, it has been seen that the system provides very good results thanks to the PSO algorithm and optimization of Kp and Kd parameters. The total Harmonic Distortion in the system appears to decrease rapidly and effectively. This result can be reached by performing FFT analysis toolbox in Matlab Simulink. With comparing the PI control with the PSO-PD, the developed PSO-PD method showed better results than the PI control, and the desired output current and voltage at 50Hz frequency reached faster than the PI control. In the single phase H bridge inverter with PSO-PD control, THD is obtained lower than PI controlled inverter, and this designed inverter is seen to be effective in reducing harmonics and achieving desired voltage and frequency.

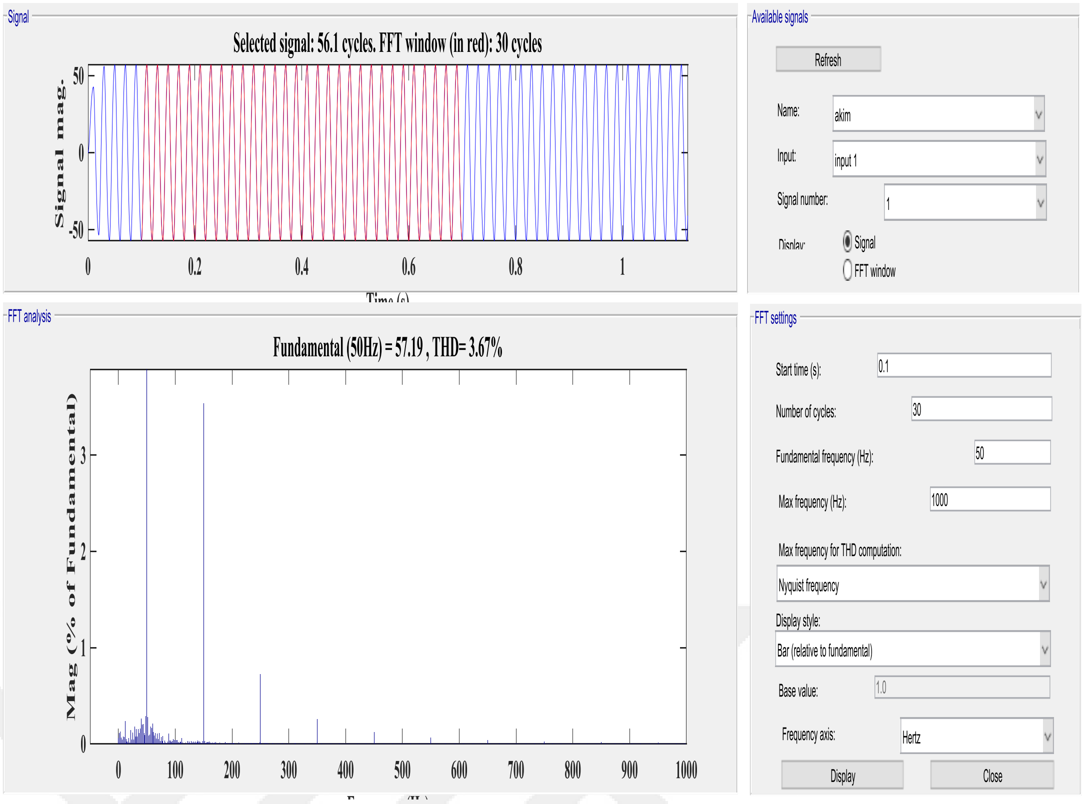


Figure 4. 49: The THD output of PSO-PD controlled single phase H-Bridge inverter.

CHAPTER FIVE

5. CONCLUSION & FUTURE WORK

Single phase inverters are a device that used everywhere from home appliances to industrial where AC signals with converting DC signals. The design of the inverters is as important as the least use of the correct harmonic effect. For this purpose, H bridge type single-phase inverter is designed in Matlab Simulink environment in this thesis. The DC signal was obtained by comparing the triangle and sinus signal in a comparison circuit.

An LC filter is designed to reduce the harmonics of the system after the single-phase inverter is obtained. The first PI controller is designed so that after the LC filtration the signal reaches the desired frequency in the most efficient way. The PD controller was first used for this purpose because the oscillation in the PI controller is excessive and the desired reference voltage is too high. The PD controller is designed because the PD controller is a bit closer to the desired result. The most optimal controller is obtained by calculating P and D parameters using the PSO algorithms. In the future studies, the switching techniques can be developed with new learning based and adaptive methods.

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APPENDICES

Appendix-A:

Particle Swarm Optimization Code in Matlab

```
%Egemen thesis programme
%


%% Initialization
clear
clc
n = 50;             % Size of the swarm " no of birds "
bird_setp  =50;     % Maximum number of "birds steps"
dim = 2;            % Dimension of the problem

c2 =1.2;            % PSO parameter C1
c1 = 0.12;          % PSO parameter C2
w =0.9;             % pso momentum or inertia
fitness=0*ones(n,bird_setp);

                                        %-----------------------------%
                                        %    initialize the parameter %
                                        %-----------------------------%


R1 = rand(dim, n);
R2 = rand(dim, n);
current_fitness =0*ones(n,1);


                                 %-----------------------------------------
--------%
                                 %  Initializing  swarm  and  velocities  and
position %
                                 %-----------------------------------------
--------%

current_position = 10*(rand(dim, n)-.5);
velocity = .3*randn(dim, n) ;
local_best_position  = current_position ;
```

```
                                %-----------------------------------------
--%
                                %            Evaluate  initial  population
%
                                %-----------------------------------------
--%

for i = 1:n
    current_fitness(i) = tracklsq(current_position(:,i));
end


local_best_fitness  = current_fitness ;
[global_best_fitness,g] = min(local_best_fitness) ;

for i=1:n
    globl_best_position(:,i) = local_best_position(:,g) ;
end
                                              %--------------------%
                                              %   VELOCITY UPDATE  %
                                              %--------------------%

velocity = w *velocity + c1*(R1.*(local_best_position-current_position)) +
c2*(R2.*(globl_best_position-current_position));

                                              %-------------------%
                                              %    SWARMUPDATE    %
                                              %-------------------%


current_position = current_position + velocity ;

                                              %-------------------------%
                                              %  evaluate anew swarm    %
                                              %-------------------------%


%% Main Loop
```

```
iter = 0 ;          % Iterations'counter
while  ( iter < bird_setp )
iter = iter + 1;

for i = 1:n,
current_fitness(i) = tracklsq(current_position(:,i)) ;
end


for i = 1 : n
        if current_fitness(i) < local_best_fitness(i)
           local_best_fitness(i)  = current_fitness(i);
           local_best_position(:,i) = current_position(:,i)    ;
        end
 end


 [current_global_best_fitness,g] = min(local_best_fitness);


if current_global_best_fitness < global_best_fitness
   global_best_fitness = current_global_best_fitness;

    for i=1:n
        globl_best_position(:,i) = local_best_position(:,g);
    end

end


 velocity = w *velocity + c1*(R1.*(local_best_position-current_position)) +
c2*(R2.*(globl_best_position-current_position));
 current_position = current_position + velocity;

 sprintf('The value of interation iter %3.0f ', iter );
```

```
end % end of while loop its mean the end of all step that the birds move it

            xx=fitness(:,50);
            [Y,I] = min(xx);
            current_position(:,I)

%
```

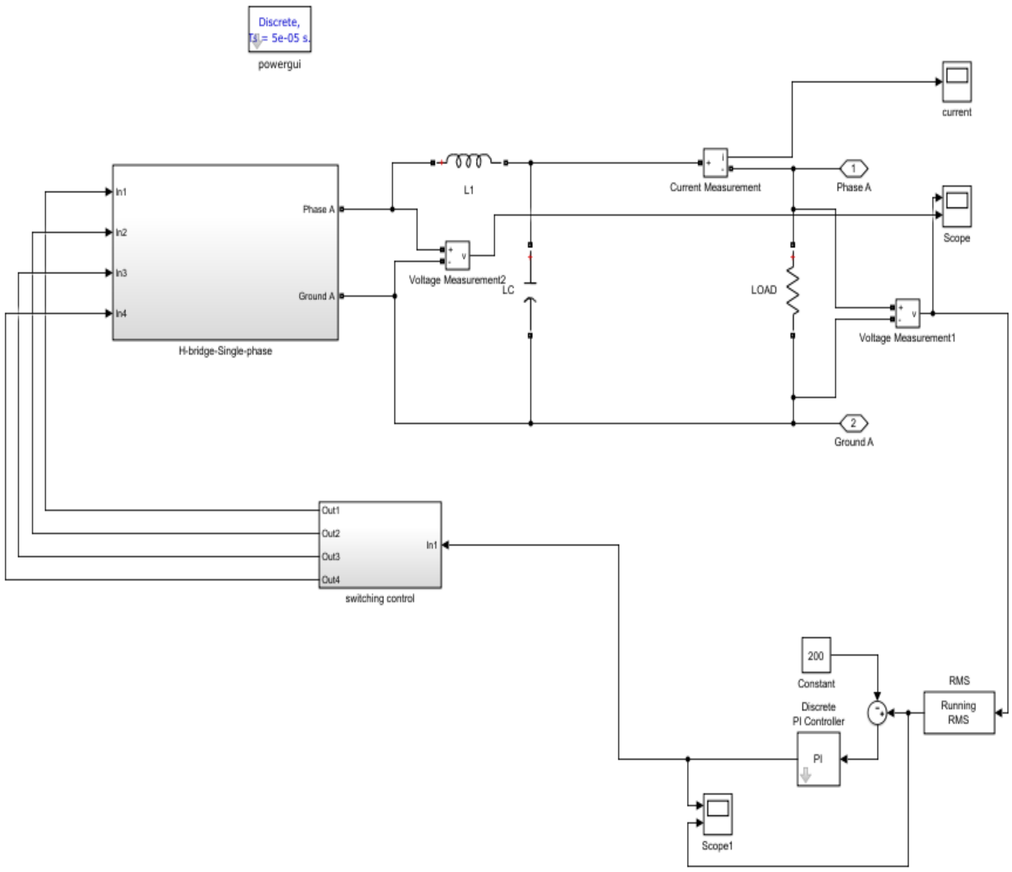
Appendix B-

Optimization program for PD controller with Simulink Application

```
function F = tracklsq(pid)
         % Track the output of optimal to a signal of 1

         % Variables a1 and a2 are shared with RUNTRACKLSQ
         Kp = pid(1);
         Kd = 0;
         Ki = pid(2);

         sprintf('The  value  of  interation  Kp=  %3.0f,  Kd=  %3.0f',
pid(1),pid(2));
         % Compute function value
         simopt                                                     =
simset('solver','ode5','SrcWorkspace','Current','DstWorkspace','Current');
% Initialize sim options
         [tout,xout,yout] = sim('optsim1',[0 100],simopt);
         e=yout-1 ;  % compute the error
         sys_overshoot=max(yout)-1; % compute the overshoot

      alpha=10;beta=10;
      F=e2*beta+sys_overshoot*alpha;

    end
```

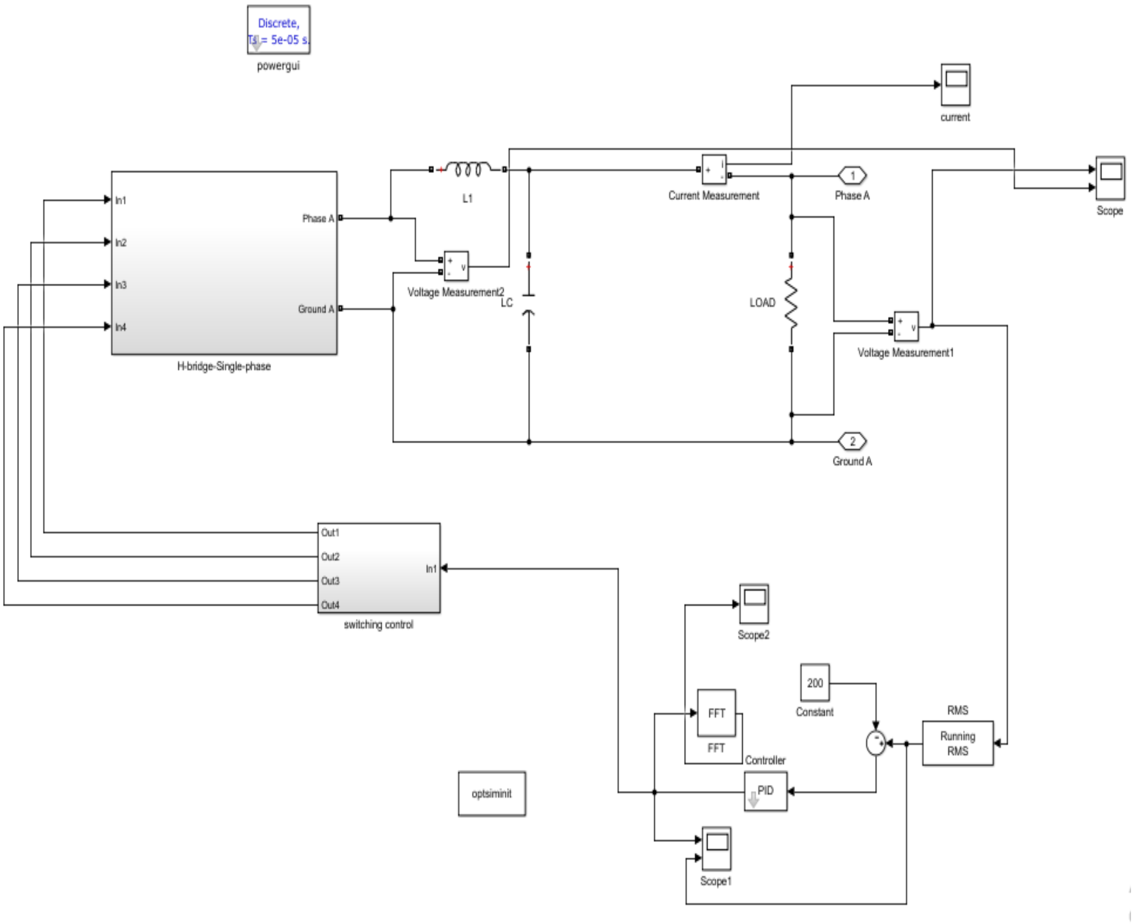
Appendix-C:

PI Controlled Based Single Phase Inverter Circuit in Simulink



Appendix-D:

PSO-PD Control Based Single Phase H Bridge Inverter in Simulink



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High School	Beşikdüzü Atatürk High School/Science	2007

University thesis

" RF and PIC Controlled LED Dot Matrix Driver Circuit", European University of LEFKE , Electrical Electronic Engineering

Training Period

Turkish Radio and Television Electronic and Communication Department (30 labor day)

Work Experience

Yıl	Yer	Görev

Foreign Language

English

Computer Skills

Programming Languages; C,C++, Matlab, Proteus, Autocad

Office Programs; Microsoft Word, Excel, Powerpoint.

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References

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