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Harmonic Analysis of Single Phase Inverter

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ABSTRACT: This paper focus on modelling and simulation of single phase inverter as a frequency changer modulated by Pulse Width Modulation (PWM). An inverter is a circuit that converts DC sources to AC sources. Pulse Width Modulations a technique that use as a way to decrease total harmonic distortion in inverter circuit.
The model is implemented using MATLAB/Simulink software with the SimPower System Block Set based on computer simulation. Computer simulation plays an important role in the design, analysis, and evaluation of power electronic converter and their controller. MATLAB is an effective tool to analyze a PWM inverter.
Advantages of using MATLAB are the following: Faster response, availability of various simulation tools and functional blocks and the absence of convergence problems. Safe-commutation strategy want be implemented is to solve switching Transients. So, Insulated Gate Bipolar Transistor (IGBT) is use as switching devices. IGBT is preferable because it is easy to control and low losses. The result from Simulink was verified using matlab simulation prior to Experimental verifications.

KEYWORDS: PWM, Duty cycle,Harmonics,THD,MATLAB SIMULINK

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I.INTRODUCTION

The term harmonics referred to Power quality in ideal world would mean how pure the voltage is, how pure the current waveform is in its sinusoidal form. Power quality is very important to commercial and industrial power system designs. Ideally, the electrical supply should be a perfect sinusoidal waveform without any kind of distortion. If the current or voltage waveforms are distorted from its ideal form it will be termed as harmonic distortion. This harmonic distortion could result because of many reasons. In today's world, prime importance is given by the engineers to derive a method to reduce the harmonic distortion. Harmonic distortion was very less in the past when the designs of power systems were very simple and conservative. But, nowadays with the use of complex designs in the industry harmonic distortion has increased as well.
This project explains the effects of Harmonics in the Power System and steps to reduce the effects of Harmonics. This project will also explain how Harmonic distortion is one of the most important problems associated with power quality and creates several disturbances to the Power System. It includes the Harmonic reduction techniques to improve the power quality and it will also include the simulation for the same.
This project also explains different types of inverters that are used in the Power System. During the transformation from DC to AC, harmonics affect the the power quality a lot. How harmonic reduction will improve the power quality will be explained in detail.
Users (PUs). This opportunistic use of the spectrum leads to new challenges to the varying available spectrum. Using a Trust-Worthy algorithm, it improves the trustworthiness of the Spectrum sensing in CR-Networks.

II. II. LITERATURE SURVEY

2.1 Inverter

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line

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commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application.

Inverters can be broadly classified into two types based on their operation:

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

Voltage Source Inverters is one in which the DC source has small or negligible impedance. In other words VSI has stiff DC voltage source at its input terminals.

A current source inverter is fed with adjustable current from a DC source of high impedance, i.e. from a stiff DC current source. In a CSI fed with stiff current source, output current waves are not affected by the load. From view point of connections of semiconductor devices, inverters are classified as under

• Bridge Inverters
• Series Inverters
• Parallel Inverters Page

2.2 Single Phase Half Bridge and Full Bridge VSI Inverter:

It consists of two semiconductor switches T1 and T2.These switches may be BJT, Thyristor, IGBT etc with a commutation circuit. D1 and D2 are called Freewheeling diode also known as the Feedback diodes as they feedback the load reactive power.

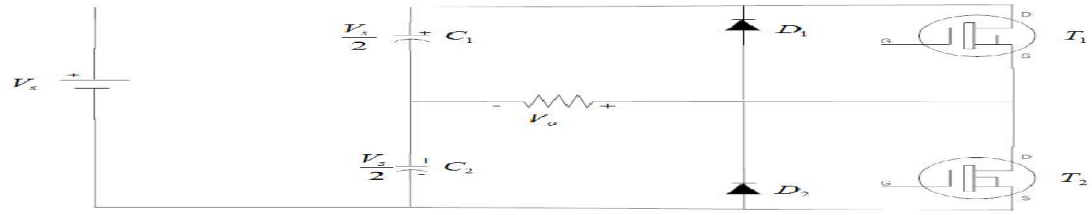

Fig1: Single Phase Half Bridge Inverter

T1	T2	Vo
ON	OFF	$+\frac{Vs}{2}$
OFF	ON	$-\frac{Vs}{2}$

Table-1: switching state

T1 is ON during the positive half cycle of the output voltage, which makes Vout=Vo/2 and T2 is ON during the negative half cycle which makes Vout= -Vo/2. The both switches must operate alternatively otherwise there may be a chance of short circuiting. In case of resistive load, the current waveform follows the voltage waveform but not in case of reactive load. The feedback diode operates for the reactive load when the voltage and current are of opposite polarities.

2.2.1. Single Phase Full wave Bridge Inverter:

It consists of two arms with a two semiconductor switches on both arms with anti parallel freewheeling diodes for discharging the reverse current. In case of resistive-inductive load, the reverse load current flow through these diodes. These diodes provide an alternate path to inductive current which continue so flow during the Turn OFF condition.

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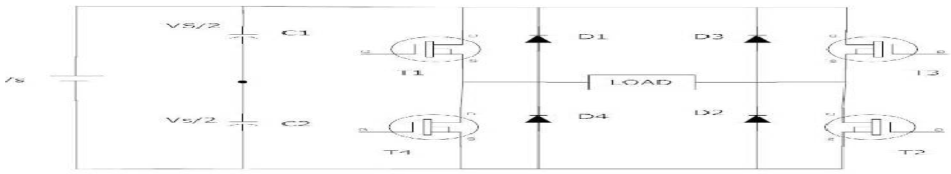

Fig2**:** Single Phase Full wave Bridge Inverter

T1	T2	T3	T4	V_A	V_B	V_{AB}
ON	OFF	OFF	ON	$\frac{Vs}{2}$	$-\frac{Vs}{2}$	V_S
OFF	ON	ON	OFF	$+\frac{Vs}{2}$	$+\frac{Vs}{2}$	$-V_S$
ON	OFF	ON	OFF	$\frac{Vs}{2}$	$-\frac{Vs}{2}$	0
OFF	ON	OFF	ON	$-\frac{Vs}{2}$	$+\frac{Vs}{2}$	0

Table-2: switching state

The switches are T1, T2, T3 and T4. The switches in each branch is operated alternatively so that they are not in same mode (ON /OFF) simultaneously .In practice they are both OFF for short period of time called blanking time, to avoid short circuiting. The switches T1 and T2 or T3 and T4 should operate in a pair to get the output.

These bridges legs are switched such that the output voltage is shifted from one to another and hence the change in polarity occurs in voltage waveform. If the shift angle is zero, the output voltage is also zero and maximal when shift angle is π.

2.3 APPLICATIONS

• DC POWER SOURCE UTILIZATION

Inverter designed to provide 115 VAC from the 12 VDC source provided in an automobile. The unit provides up to 1.2 Amps of alternating current, or just enough to power two sixty watt light bulbs. An inverter converts the DC electricity from sources such as batteries, solar panels, or fuel cells to AC electricity. The electricity can be at any required voltage; in particular it can operate AC equipment designed for mains operation, or rectified to produce DC at any desired voltage. Grid tie inverters can feed energy back into the distribution network because they produce alternating current with the same wave shape and frequency as supplied by the distribution system. They can also switch off automatically in the event of a blackout. Micro-inverters convert direct current from individual solar panels into alternating current for the electric grid.

• UNINTERRUPTIBLE POWER SUPPLIES

An uninterruptible power supply is a device which supplies the stored electrical power to the load in case of raw power cut-off or blackout. One type of UPS uses batteries to store power and an inverter to supply AC power from the batteries when main power is not available. When main power is restored, a rectifier is used to supply DC power to recharge the batteries. It is widely used at domestic and commercial level in countries facing Power outages.

• INDUCTION HEATING

Inverters convert low frequency main AC power to a higher frequency for use in induction heating. To do this, AC power is first rectified to provide DC power. The inverter then changes the DC power to high frequency AC power.

• HVDC POWER TRANSMISSION

With HVDC power transmission, AC power is rectified and high voltage DC power is transmitted to another location. At the receiving location, an inverter in a static inverter plant converts the power back to AC.

• VARIABLE-FREQUENCY DRIVES

A variable-frequency drive controls the operating speed of an AC motor by controlling the frequency and voltage of the power supplied to the motor. An inverter provides the controlled power. In most cases, the variable-frequency drive

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includes a rectifier so that DC power for the inverter can be provided from main AC power. Since an inverter is the key component, variable frequency drives are sometimes called inverter drives or just inverters.

• ELECTRIC VEHICLE DRIVES
Adjustable speed motor control inverters are currently used to power the traction motor in some electric locomotives and diesel-electric locomotives as well as some battery electric vehicles and hybrid electric highway vehicles such as the Toyota Prius. Various improvements in inverter technology are being developed specifically for electric vehicle applications.[2] In vehicles with regenerative braking, the inverter also takes power from the motor (now acting as a generator) and stores it in the batteries.

• THE GENERAL CASE
A transformer allows AC power to be converted to any desired voltage, but at the same frequency. Inverters, plus rectifiers for DC, can be designed to convert from any voltage, AC or DC, to any other voltage, also AC or DC, at any desired frequency. The output power can never exceed the input power, but efficiencies can be high, with a small proportion of the power dissipated as waste heat.

III.PWM (PULSE WIDTH MODULATION TECHNIQUE)

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs [8]. The applications of PWM are wide variety used like ranging from measurement and communications to power control and conversion.PWM provides a way to decrease the Total Harmonic Distortion (THD) of load current. The THD requirement can be met more easily when the output of PWM inverter is filtering. The unfiltered PWM output will have a relatively high THD, but the harmonic will be at the much higher frequencies than for a square wave, making filtering easily.
The total harmonic distortion, or THD, is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental .In analog circuit; analog signal has a continuously varying value, with infinite resolution in both time and magnitude. As an example of an analog device for 5 volt battery, output voltage is not precisely 5V, changes over time, and can take any real-numbered value. The amount of current drawn from a battery is not limited to a finite
Analog signals are distinguishable from digital signals because the latter always take values only from a finite set of predetermined possibilities, such as the set {0V, 5V}. Analog voltages and currents can be used to control things directly, like the volume of a car radio. In a simple analog radio, a knob is connected to a variable resistor. As the knob is turned, the resistance goes up or down. As that happens, the current flowing through the resistor increases or decreases. This changes the amount of current driving the speakers, thus increasing or decreasing the volume. An analog circuit is one, like the radio, whose output is linearly proportional to its input .The analog control system it is not always economically attractive or otherwise practical. Analog circuits tend to drift over time and can, therefore, be very difficult to tune. Precision analog circuits, which solve that problem, can be very large, heavy, and expensive. Analog circuits can also get very hot; the power dissipated is proportional to the voltage across the active elements multiplied by the current through them. Analog circuitry can also be sensitive to noise. Because of its infinite resolution, any perturbation or noise on an analog signal necessarily changes the current value. If the analog circuit is controlled digitally, the system costs and power consumption can be drastically reduced. Besides, there are many microcontrollers and DSPs already include on-chip PWM controllers, making implementation easy.PWM is a way of digitally encoding analog signal levels. The duty cycle of a square wave is modulated to encode a specific analog signal level by using the high-resolution counter. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the period during the supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM. Control of the switches for the sinusoidal PWM output requires a reference signal (modulating or control signal) which is a sinusoidal wave and a carrier signal which a triangular wave that control the switching frequency. There two type of the switching for PWM, unipolar
switching and bipolar switching.In a unipolar switching scheme for PWM, the output is switched from either high

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to zero or low to zero, rather than between high and low as in bipolar switching. The unipolar scheme has switch control as follow;
S_1 is on when $V_{sine} > V_{tri}$
S_2 is on when $-V_{sine} < V_{tri}$
S_3 is on when $-V_{sine} > V_{tri}$
S_4 is on when $V_{sine} < V_{tri}$
Another unipolar switching scheme has only one pair of switches operating at the carrier frequency while the other pair operates at reference frequency, thus having two high-frequency switches and two low-frequency switches.
S_1 is on when $V_{sine} > V_{tri}$
S_4 is on when $V_{sine} < V_{tri}$
S_2 is on when $V_{sine} > 0$
S_3 is on when $V_{sine} < 0$

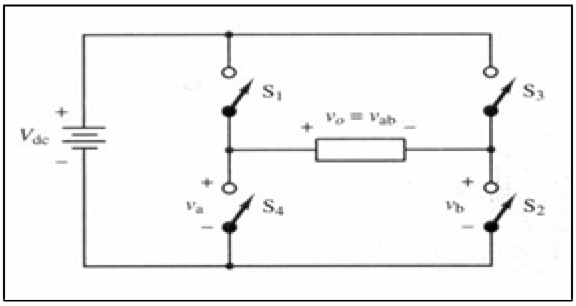

FIGURE 3: FULL-BRIDGE CONVERTER FOR UNIPOLAR PWM (HIGH FREQUENCY)

The benefit of choosing the PWM over analog control is increased noise immunity which the PWM is sometimes used for communication. Switching from an analog signal to PWM can increase the length of a communications channel dramatically. At the receiving end, a suitable RC (resistor-capacitor) or LC (inductor-capacitor) network can remove the modulating high frequency square wave and return the signal to analog form. So, the filter requirement can be reduced and the overall Inverter size can be reduced.
The disadvantages of PWM are like more complex circuit for the switching, higher switching loss due more to frequent switching, difficult to implement and more Electro Magnetic Interference (EMI) loss.

IV. HARMONICS

4.1 INTRODUCTION TO HARMONICS

Any periodic wave form can be represented by infinite series of sinusoids.

$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos(nwt) + b_n \sin(nwt))$$

Where $a_0 = \frac{1}{T}\int_0^T f(t)dt$

$$a_n = \frac{2}{T}\int_0^T f(t)\cos(nwt)\,dt$$

$$b_n = \frac{2}{T}\int_0^T f(t)\sin(nwt)\,dt$$

Harmonics has linear been more of an issue nowadays due to the increased usage of nonlinear loads which are the cause of harmonics. The non-linear loads here refer to loads which current is not proportional to the applied voltage. It must be noted that different non-linear loads will have different slight voltage current characteristics. Sometimes a slight increase in voltage can cause the current to double.
Any periodic, distorted waveform can be expressed as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency (50Hz for Australia). This multiple is called harmonic of

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the fundamental. Harmonic are normally analyzed up to the 40th multiple or component but the few odd, earlier harmonic components (3rd, 5th, 7th) are the ones that have significant effect on the system. What differentiate a distorted harmonic waveform and any waveform distortion is that those caused by harmonics are periodic and can be split into harmonics components.

4.2 VOLTAGE AND CURRENT DISTORTION

Nonlinear loads are the sources of harmonic current causing distorted current waveforms. Voltage distortion is the result of distorted currents passing through the linear, series impedance of the power delivery system. Therefore, it is always the current distortion that results in voltage distortion. Nevertheless, it must be noted that loads have distortion no control over the voltage distortion. The same load in two different locations on the power system will result in two different voltage distortion values.

4.2.1 EVEN HARMONICS

Even harmonics (2nd, 4th, and 6th) are less likely to occur at levels detrimental to electrical systems. This is because non-linear loads normally generate odd harmonics rather than even harmonics. Furthermore, when both the positive and negative half cycles of a waveform are similar in shape, the Fourier series contain only odd harmonics.

4.2.2 ODD HARMONICS

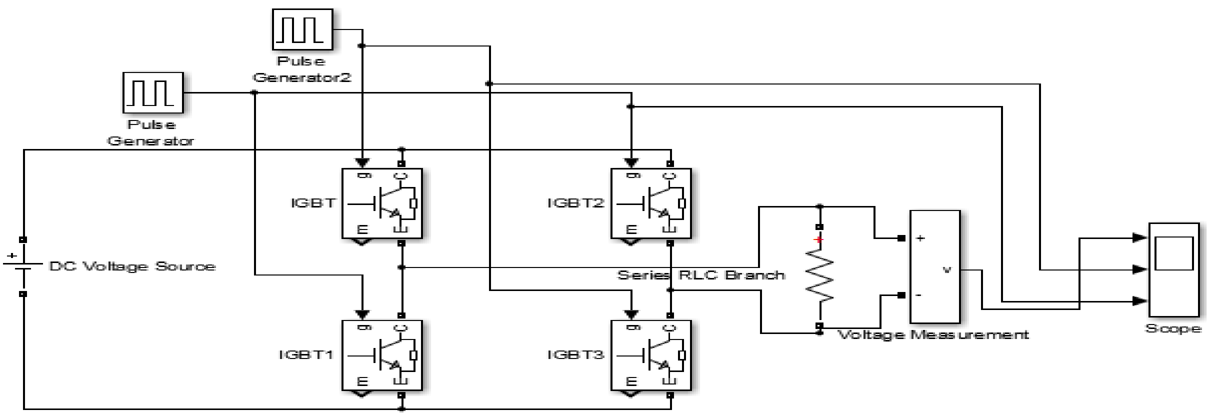
Odd harmonics (3rd, 5th, and 7th) are more common in power systems and are the ones which lead to severe consequences if they are not controlled. Each odd harmonic is associated with one of the sequence component (positive, negative or zero). The phase sequence is very important because it determines the effect of the harmonic on the operation of the electrical equipment. Table 1 shows the harmonics with their associated phase sequence.

4.3 CAUSES OF HARMONICS

- Harmonics are caused by non-linear loads that is loads that draw a non- sinusoidal current from a sinusoidal voltage source.
- Some examples of harmonic producing loads are
  - electric arc furnaces
  - static VAR compensators
  - Inverters
  - DC converters
  - switch-mode power supplies
  - and AC or DC motor drives.

V. SIMULATION STUDY & RESULT ANALYSIS

5.1.1 SINGLE PHASE INVERTER WITH HARMONICS



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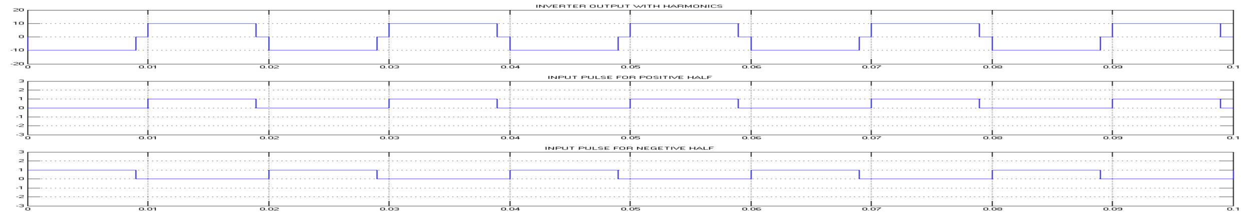
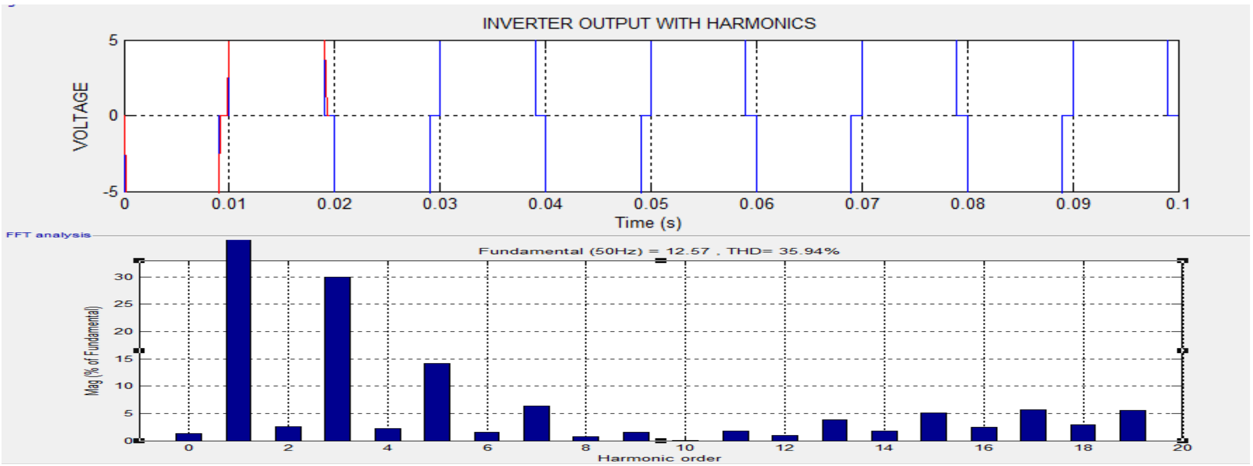
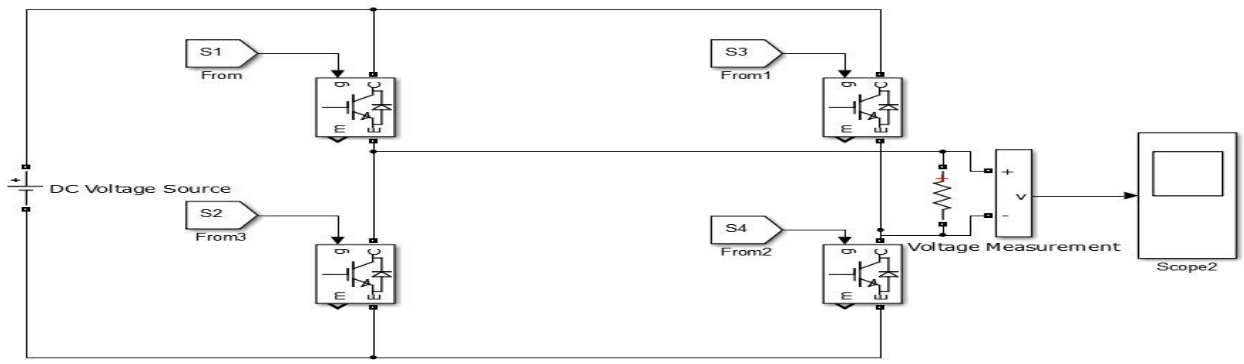
5.1.2 Output wave form of inverter with harmonics



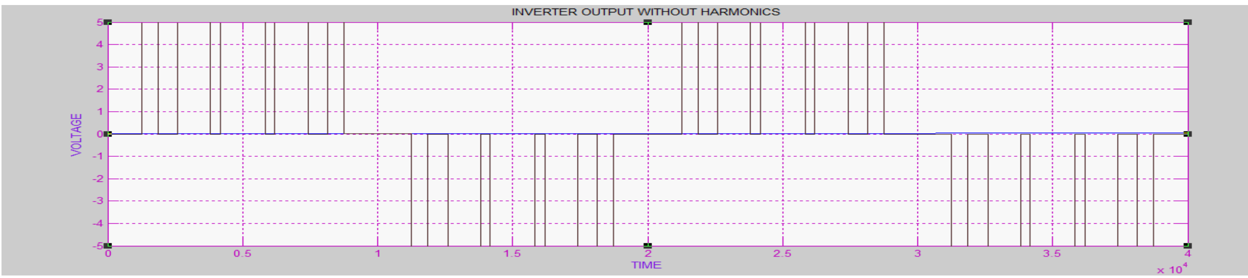
5.1.3 FFT analysis of inverter output with Harmonics



5.1.4 Single phase Inverter without Harmonics



5.1.5 Output wave form of inverter without harmonics



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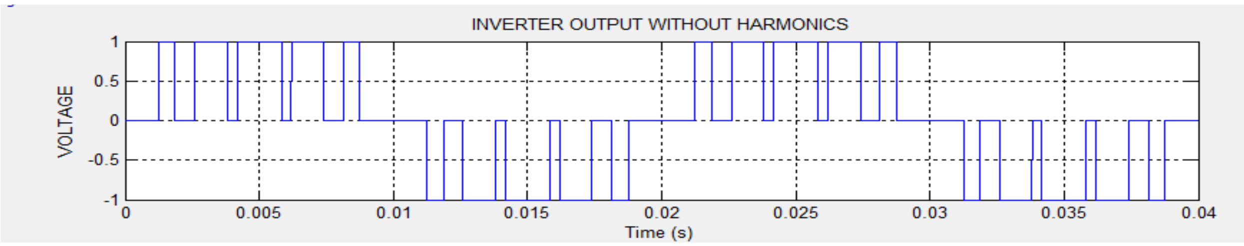
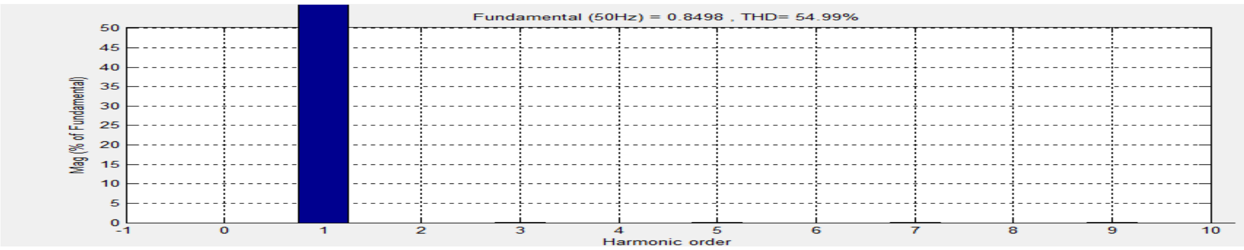
5.1.6 FFT of inverter without harmonics





VI.CONCLUSION AND FUTURE WORK

This chapter summarizes the whole thesis in a single paragraph. The main outcomes of the thesis are presented in this chapter. Finally the future work is being stated.

6.1 CONCLUSION

This project Report deals with the Harmonic analysis of Single Phase inverter wih Pulse Width Modulation (PWM). It includes both simple and practical inverter. The Simulink model for both simple and practical inverter has been simulated in MATLAB. Its various parameters such as R,C and Filter design. These parameters are varied and the resulting voltage and current graphs has been studied.

6.2 SCOPE FOR FUTURE WORK

The future work includes improving the stability of the system and also to study various instability in PWM with harmonic analysis in Three phase and ways to eliminate it and to design an actual household PWM-VSI with a better controller design.

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