Mitigation of Harmonic in Non-Linear Load using PWM Techniques with Shunt Passive Power Filter

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Abstract — **This paper presents an analysis to mitigate harmonic in nonlinear load using three phase pulse width modulation (PWM) techniques with shunt active power filter. PWM signal and the voltage inverter are used with the shunt passive power filter (PPF) to reduce the value of total harmonic distortion (THD). The conduction mode angle of three phase PWM are varied form 20° to 180°. The advantages of PWM is the output voltage is nearly sinusoidal, better power factor and better transient response. The analysis is to observe that harmonic can be reduced comply with IEEE 802 regulation standard. The simulation result was carried out using Matlab/Simulink R2012a.**

Keywords-power quality; PWM; shunt passive power filter; total harmonic distortion THD; inverter

I. INTRODUCTION

In recent years, there has been an increased emphasis on, the quality of power delivered to factories, and residences. This is due to the preponderance of harmonic creating the systems. Adjustable speed drives, switching power supplies, arc furnaces, electronic fluorescent lamp ballasts, and other harmonic generating equipment all contribute to the harmonic burden in the system. In addition, utility switching and fault clearing produce disturbances that affect the quality of delivered power. In addressing this problem, the Institute of Electrical and Electronics Engineers (IEEE) has done significant work on the definition, detection, and mitigation of power quality events.

Harmonic pollution on a power line can be quantified by a measure known as total harmonic distortion. Total harmonic distortion or THD is a measure of how much harmonic content there is in a waveform. The total harmonic distortion of a waveform is

$$\text{THD} = \sqrt{\frac{V_{\text{rms}}^2 - V_{1,\text{rms}}^2}{V_{1,\text{rms}}^2}}$$

Where V_{RMS} is the rms value of the total waveform, and $V_{1\ RMS}$ is the rms value of the first harmonic. The THD of a sine wave is 0 percent, and the THD of a square wave is 48 percent.

High harmonic distortion can negatively impact a facility electric distribution system, and can generate excessive heat in motors, causing early failures. Heat also builds up in wire insulation causing breakdown and failure. Increased operating temperatures can affect other equipment as well, resulting in malfunctions and early failure. In addition, harmonics on the power line can prompt computers to restart and adversely affect other sensitive analog circuits. [5]

The increased use of nonlinear equipment has caused harmonics to become more common. An analysis of the sine wave architecture provides an understanding of the basic anatomy of harmonics. Harmonics are integral multiples of the fundamental frequency of the sine wave that is, harmonics are multiples of the 60 Hz fundamental voltage and current. The adding to the fundamental 60 Hz waveform and distort it. They can be 2, 3, 4, 5, 6 or 7 times the fundamental.

To handle with these harmonic problems many alternative methods are proposed in the past. One of the well-known methods is the PWM control technique. The advantages of PWM control technique is the output current or voltage waveforms is nearly sinusoidal, better input power factor, better transient response, elimination of the low order harmonics and, consequently, smaller input output filter parameters.

The objective of this project is to investigate mitigation of harmonics using PWM technique on the nonlinear load. The PWM is connected to inverter and shunt PFF in order to reduce the harmonics effects cause by the nonlinear load. The modulation angle is varies to give a better output.

II. THEORYTICAL BACKGROUND

A. Harmonic

Harmonics always present in power systems. Lately, due to the common use of power electronic systems has increased harmonic and is a crucial concern in installations. Harmonic disturbances arise commonly from equipment with a non-linear voltage or current characteristic. Non-linear loads represent a large percentage of the total loads. In these situations, THD may become very high and so risky for the system. Harmonic distortion can be considered as a type of contamination of the electric system which can cause

problems if the sum of the harmonic currents exceeds certain parameters. Understanding of electromagnetic disturbances related with this phenomenon is still developing.

Figure 2.1 below shows the voltage waveform signal. The yellow and blue line is the normal sinusoidal voltage waveform and the other line is waveform that has been distorted by harmonic.

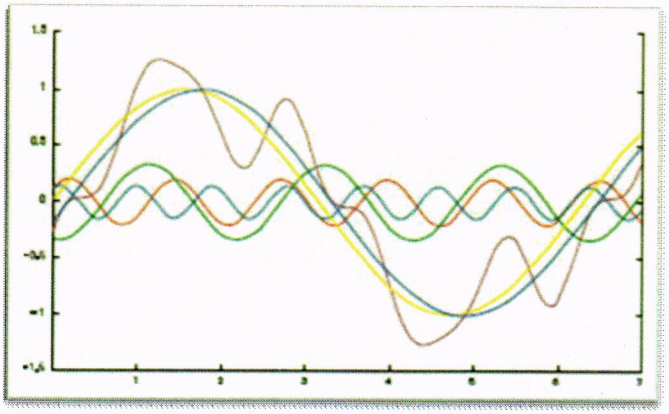

Figure 2.1: Electrical waveform with harmonic distortion

B. *Pulse Witdh Modulation (PWM)*

Pulse-width modulation is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. The usual value of voltage and current fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off period, the higher the power is supplied to the load. The development of fast switching device and microprocessors permits the producing of PWM technique to improve the performance of the system. The performance in terms of THD obtained from this PWM is better than that of phase control technique. The applications of PWM ranging from measurement and communications are to power control and conversion. PWM provides a way to decrease the THD of load current. The THD requirement can be met more easily when the output of PWM inverter is filtered. [8].

Figure 2.2 is the sinusoidal and triangle waveform used to produce a PWM signal. The signal that has been produce is single phase PWM.

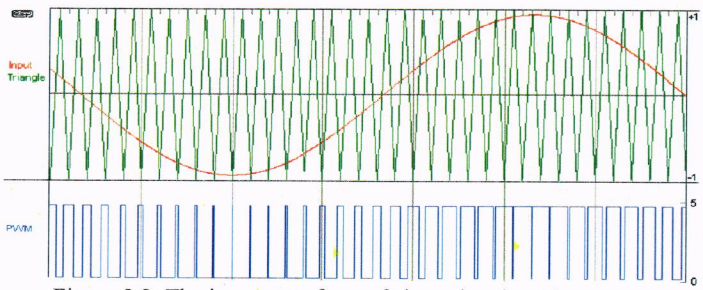

Figure 2.2: The input waveform of sine, triangle and output waveform of PWM.

C. *Shunt Passive Power Filter*

The shunt PPF circuit consists of capacitor coupled in series with a reactor tuned to a certain harmonic frequency. Shunt PPF is connected in parallel with the load. Since the impedance of the filter is close to zero at the alteration frequency, the harmonic is absorbed by the filter and jointly with the natural resistance of the circuit.

The figure 2.3 is the circuit diagram of Passive Power Filter. The diagram consists of the source, non-linear load and Passive Power.

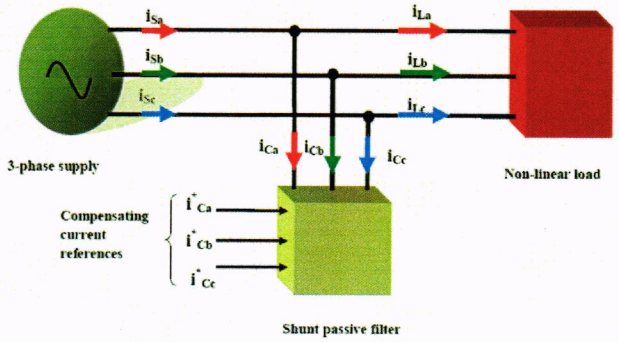

Figure 2.3: The Shunt Passive Filter

III. METHODOLOGY

Figure 3.1 shows the flow chart of the overall project. In this project MATLAB software is used to simulate the circuit. The circuit includes PWM inverter, shunt PPF and nonlinear load.

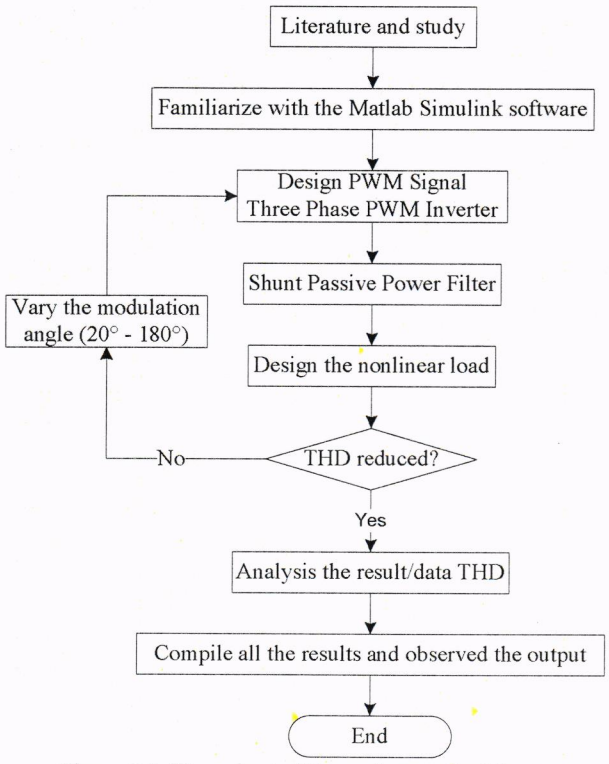

Figure 3.1: Flow chart of the project methodology.

A. *Design PWM circuit*

Power electronic circuits manage the flow of electrical energy between the source and the load. [7] The concept of PWM is central to all switch mode power converters. PWM refers to the control of the average value of a switching variable by controlling or modulating its pulse width. Some of basic concepts and definitions are necessary to understand PWM such as *Duty Ratio* and *Averaging*. Other than that is the concept of steady state because the analysis of steady-state operation is essential to determine the ratings and the design of the power stage components. The components are the converter, power semiconductor devices, inductor, capacitors, and transformers. Important concepts that enable steady-state analysis from a circuit view point are steady-state averages of inductor voltage and capacitor current, power balance and Kirchoff Laws for averages. It should be remembered that these are only valid during steady-state operation. Plus the characteristic that need to consider when design the circuit is the power loss in the bi-positional switch. The power loss can be divided into two, conduction loss and switching loss [6].

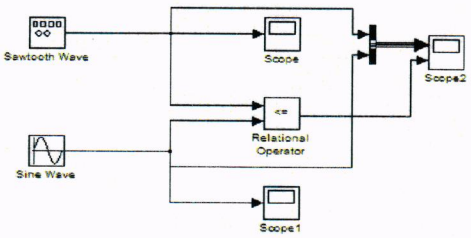

Figure 3.2: Circuit Diagram of Single Phase PWM

Figure 3.2 shows the circuit diagram of single phase PWM. The process happens by comparing the signal of saw-tooth wave with sine wave. Thus, the signal will compare using the relational operator that TRUE if the first input is less than or equal to the second input.

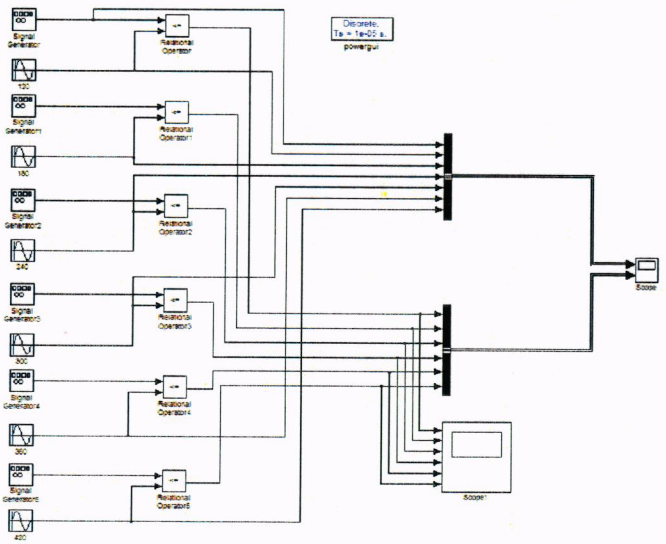

Figure 3.3: Circuit Diagram of Three Phase PWM

Figure 3.3 shows the circuit diagram of three phase PWM signal. The process happens by comparing the signal of saw-tooth wave with three phase sine wave. Thus, the signal will compare using the relational operator that TRUE if the first input is less than or equal to the second input.

B. *Design inverter circuit*

Figure 3.4 shows the circuit diagram of an Inverter Bridge using IGBT to generate the PWM signal. The pulse signal that produces from the three phase signal will be inject to each IGBT Bridge.

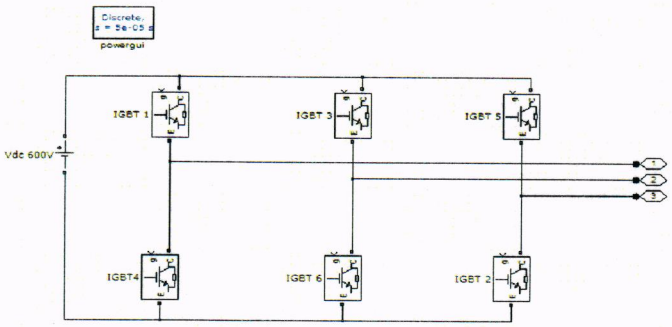

Figure 3.4: Circuit Diagram of PWM using IGBT Inverter

C. *Design PWM with inverter and shunt PPF connected to Non-Linear Load*

This stage is similar to the design of the signal except that the circuits of the signal include the non-linear load. The characteristic has to be the same as designing PWM signal stage. The improvements of the power quality are measured.

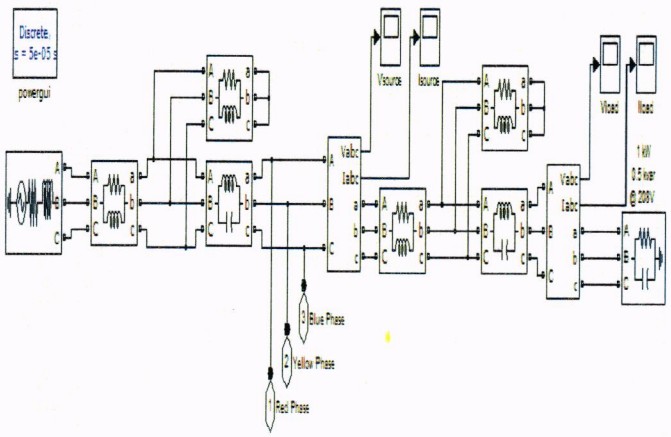

Figure 3.5: Circuit Diagram of Non Linear Load

Figure 3.5 above shows the nonlinear load circuit with the shunt PPF not connected to the PWM circuit. The addition of shunt PFF makes the waveform smoother.

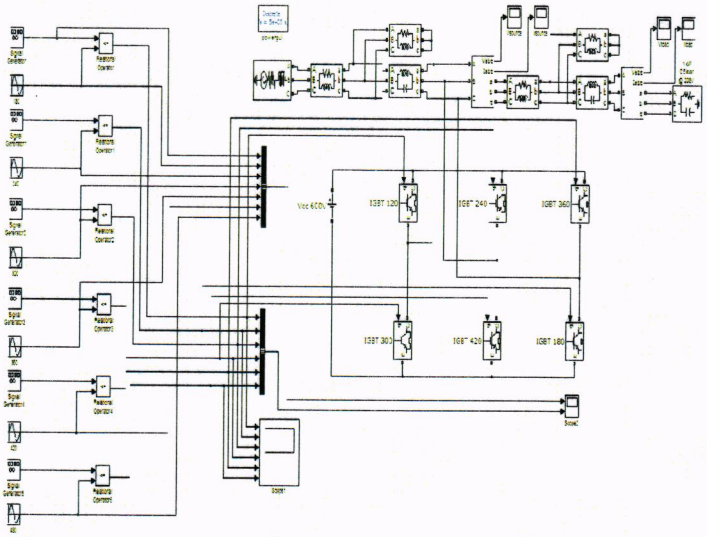

Figure 3.6: Circuit Diagram of Three Phase PWM with IGBT Inverter and shunt PPF connected to Non Linear Load

Figure 3.6 shows the circuit diagram of Inverter Bridge with shunt PFF connected to the non-linear load.

The parameter of shunt PFF and nonlinear load is shown at table 3.1 and 3.2 below.

Table 3.1 shunt PFF parameter

Parameters	Value
Capacitor	300uF
Inductor	10mH
Resistor	0.9Ω

Table 3.2 Nonlinear load parameter

Parameters	Value
Phase to phase voltage	208 V_{RMS}
Nominal frequency	60 Hz
Active power	1000 W
Capacitive reactive power	500 VAR

IV. RESULTS AND DISCUSSION

The simulation results are observed. Each waveform produce in the simulation and the value of the THD are analysed. From the waveform obtained it can be seen that after inserting shunt PFF to the circuit the harmonic is reduced.

A. Voltage waveform

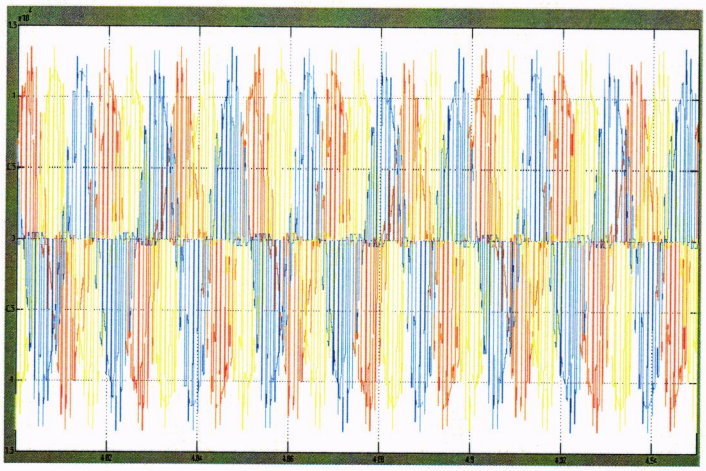

Figure 4.1: Waveform of three phase input signal before filter

The waveform of figure 4.1 is the input waveform of three phases PWM IGBT Inverter before it is filtered.

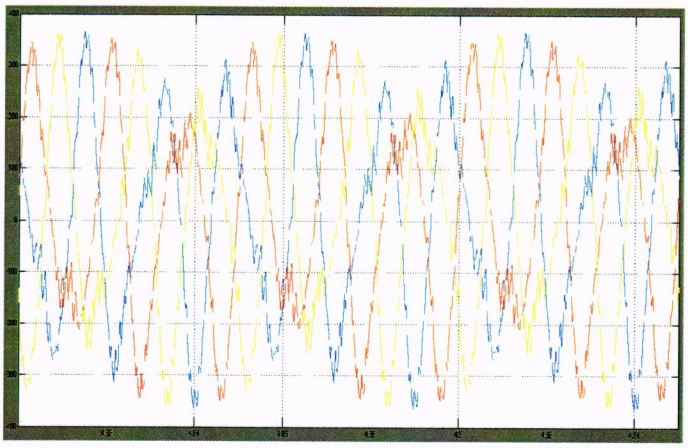

Figure 4.2: Waveform of three phase output signal after filter

Figure 4.2 shows the output waveform of three phases PWM IGBT Inverter after it is filtered.

B. Applying PWM techique with shunt PFF to nonlinear load

The PWM technique with shunt PFF is applied to the nonlinear load. The conduction mode angle of PWM is varied to get the best THD result. The THD is measured before the filter and after the filter circuit.

I. 20° conduction mode

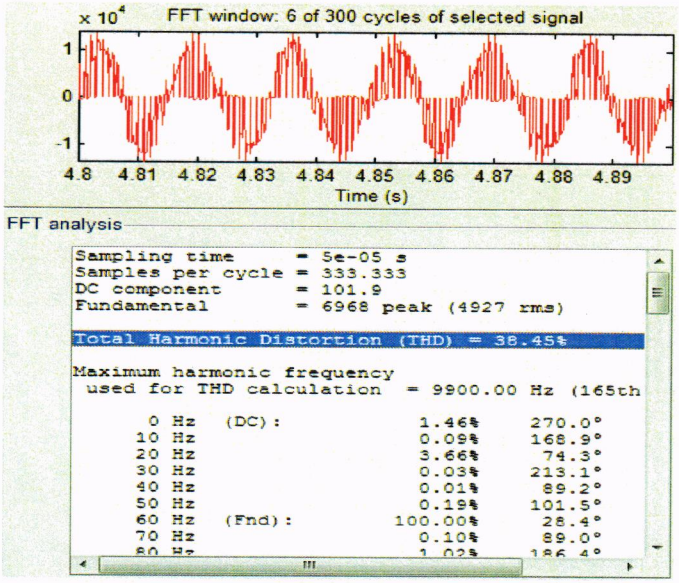

Figure 4.3: Percentage of harmonic input to filter when conduction mode is 20°

Figure 4.3 shows the waveform and THD input to filter when conduction mode is 20°. The THD 38.45% of harmonic occur.

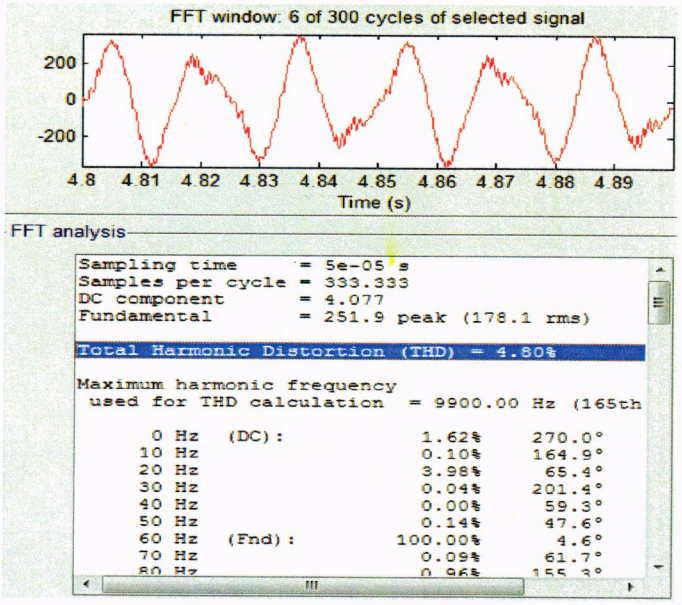

Figure 4.4: Percentage of harmonic after filter when conduction mode is 20°

Figure 4.4 shows the result after the filter circuit, input of the load. In this result is based on the PWM three phase 20° conduction mode. The THD 4.80% of harmonic occur. The values of the harmonic occur is decreasing and comply the standard of IEEE.

II. 100° conduction

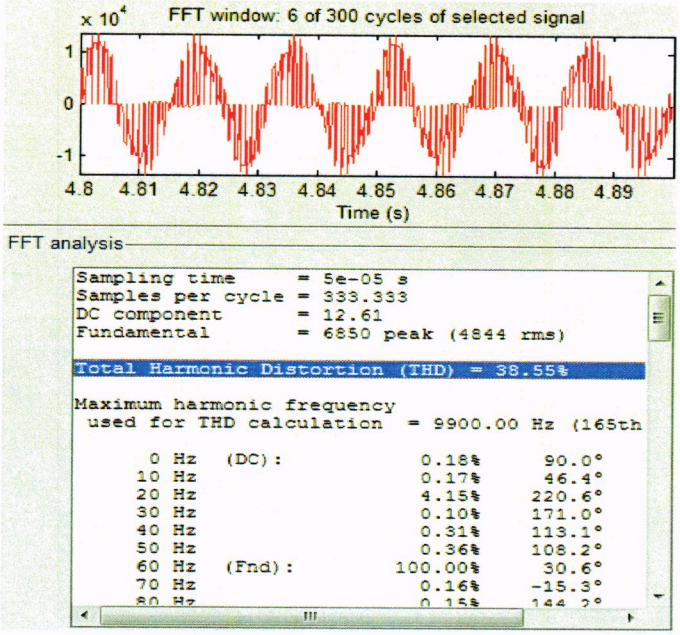

Figure 4.5: Percentage of harmonic input to filter when conduction mode is 100°

Figure 4.5 shows the waveform and THD input to filter when conduction mode is 100°. The THD 38.55% of harmonic occur.

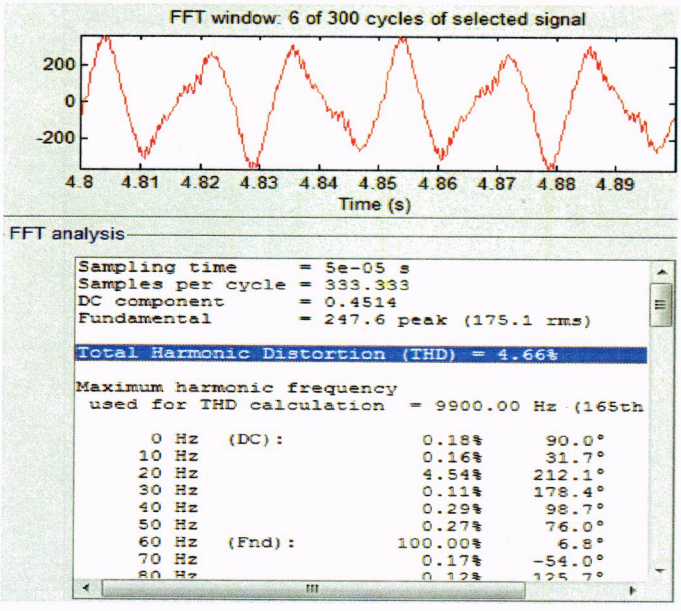

Figure 4.6: Percentage of harmonic after filter when conduction mode is 100°

Figure 4.6 shows the result after the filter circuit, input of the load. In this result is based on the PWM three phase 100° conduction mode. The THD 4.66% of harmonic occur. The values of the harmonic occur is decreasing and comply the standard of IEEE.

III. 180° conduction mode

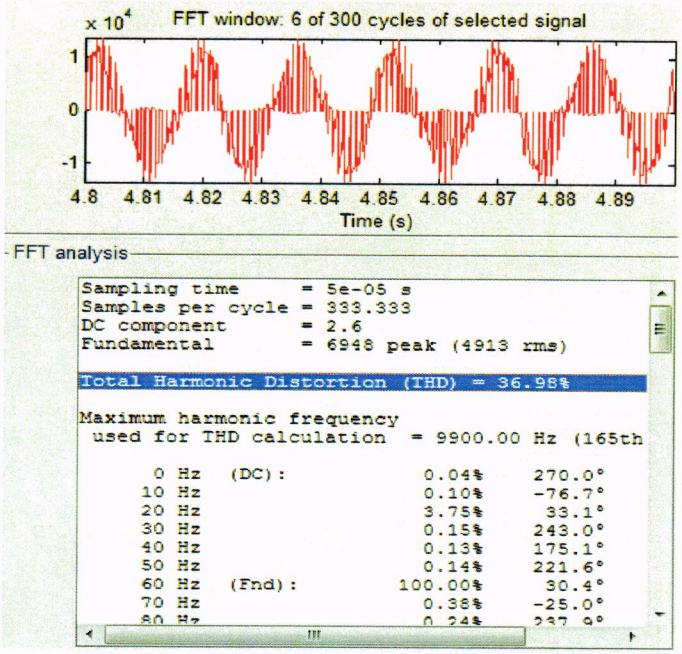

Figure 4.7: Percentage of harmonic input to filter when conduction mode is 180°

Figure 4.7 shows the waveform and THD input to filter when conduction mode is 180°. The THD 36.98% of harmonic occur.

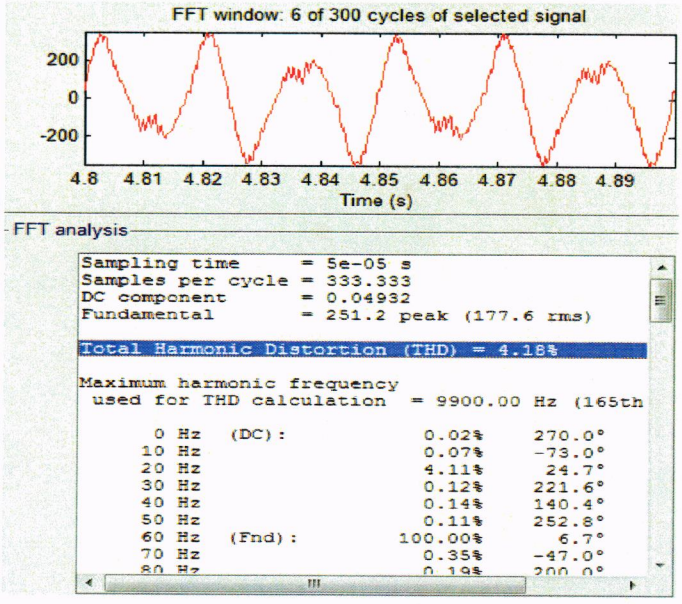

Figure 4.8: Percentage of harmonic after filter when conduction mode is 180°

Figure 4.8 shows the result after the filter circuit, input of the load. In this result is based on the PWM three phase 180° conduction mode. The THD 4.18% of harmonic occur. The values of the harmonic occur is decreasing and comply the standard of IEEE.

From the result obtained it can be seen the THD reduced after entering the filter circuit. The THD comply with IEEE 519 standard which is shows in table 4.1 below.

Table 4.1: THD input to filter and after the filter when conduction mode is varies.

PWM conduction mode	THD	
	Input to filter	After Filter
20°	38.45%	4.80%
40°	37.51%	4.37%
60°	37.92%	4.36%
80°	37.72%	4.35%
100°	38.55%	4.66%
120°	37.03%	4.40%
140°	38.71%	4.51%
160°	36.75%	4.45%
180°	36.98%	4.18%

V. CONCLUSION

The project can be conclude that PWM techniques can mitigate the harmonic in the non-linear load. By using the three phase PWM IGBT Inverter Bridge with shunt PFF the presence of the harmonic has decreased comply with IEEE 802 standards. The conduction mode also affects the THD. The best conduction mode is when angle is 180°. The project will resolve the problem of power quality especially harmonic problem that is common problem in electrical system..

For future recommendation, different types of filter could be connected and studied.

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