Harmonic Compensation in Grid Integrated Distribution System Using Active Power Filter

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***Abstract* - In this paper, a new control method is presented for active power filter (APF). APF is connected in parallel to the distribution network to reduce harmonics. The total harmonic distortions measured at source to check the harmonic level. Combination of linear and nonlinear loads produces harmonics. Active filter consists of converter and controller. Controller provides reverse harmonics to the converter in terms of a pulse and the converter injects harmonics wit 180 degrees phase shift. To generate current magnitude PI and ANN controllers are used. PI and ANN techniques are compared and simulated using matlab simulink software.**

***Index Terms* - Shunt active power filter (SAPF),Voltage source inverter (VSI), Power Quality (PQ), Total harmonic distortion (THD), Voltage source converter (VSC), Artificial neural networks (ANN), Pulse Width Modulation (PWM).**

1.INTRODUCTION

There is a disturbance in the electrical network due to the excessive use of these power electronic devices. The disturbances are due to the use of nonlinear devices. These will introduce harmonics in the power system thereby causing equipment overheating, damage devices, EMI related problems etc. Harmonics is considered as one of the most essential problems in electrical power systems. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency.
For example, if the fundamental frequency 50Hz, then 3^{rd} is 150Hz,5^{th} is 250Hz.Ideally,Voltage and current waveforms are perfect sinusoids. However, because of increased popularity of electronic and nonlinear loads, these waveforms become distorted. This deviation from a perfect sine wave can be represented by harmonic components having a frequency that is an integral multiple of the fundamental frequency.

2.POWER QUALITY PROBLEMS AND SOLUTIONS

Power Quality(PQ) is generally defined as any change in power(voltage, current, or frequency) that interferes with the normal operation of electrical. Power quality may also be defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment.
Power quality problems concerning frequency deviation are the presence of harmonics and other departures from the intended frequency of alternating supply voltage. On the other hand, Power quality problems concerning voltage magnitude deviations can be in the form of voltage fluctuations, especially those causing flicker.
2.1 Power quality disturbances
Harmonics are a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. These harmonics interact with the fundamental frequency waveform and each other to produce a distorted waveform which can cause significant damage to power system components.

Total harmonic distortion:
According to IEEE-519, total harmonic distortion is defined as the summation of the effective value of the harmonic components in the distorted waveform related to the fundamental component.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{n_{max}} (I_h)^2}}{I_1}$$

Where Ih is the RMS value of current harmonics component.

The IEEE Standard 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power systems specifies the limits of harmonic voltage and current at the point of common coupling between end user and distribution utilities. The approach adopted in this standard requires the participation of both end users and utilites.

2.2 Modeling of the system

Description of the proposed system

The proposed system is Three Phase Four wire which consists of shunt active power filter connected to the dc-link of a grid-interfacing inverter as shown in Fig.3.1. The voltage source inverter is a key element of a PV system as it interfaces the renewable energy source to the grid and delivers the generated power. The active power filter is connected to grid with an inverter coupled to dc-link. The dc-capacitor decouples the Photovoltaic system from grid and also allows independent control of converters on either side of dc-link [17].

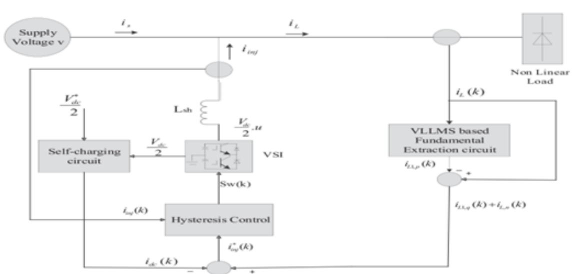

Figure 1. Proposed Three Phase Four Wire System

3.CONTROL TECHNIQUE USED FOR INTERFACING INVERTER TO ACT AS SHUNT APF

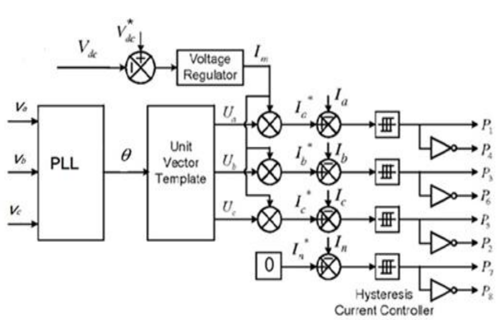

Figure 2: Control scheme

The reference current templates (Ia*, Ib*, and Ic*) are obtained by multiplying this peak value (Im) by the three-unit sine vectors (Ua, Ub and Uc) in phase with the three source voltages. These unit sine vectors are obtained from the three sensed line to neutral voltages. The reference grid neutral current (In*) is set to zero, being the instantaneous sum of balanced grid currents. Multiplication of magnitude Im with phases (Ua, Ub, and Uc) results in the three phase reference supply currents (Ia*, Ib*, and Ic*).

4. HYSTERESIS CURRENT CONTROL

The hysteresis current control (HCC) is the easiest control method to implement; it was developed by Brod and Novotny in 1985. The shunt APF is implemented with three phase current controlled VSI and is connected to the ac mains for compensating the current harmonics. The VSI gate control signals are brought out from hysteresis band current controller.

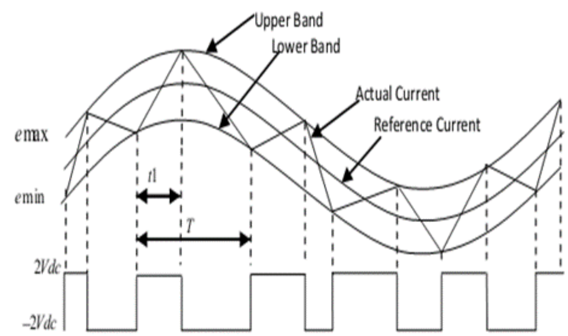

Figure 3. Waveform of hysterisis current control

5. SIMULINK MODEL OF HYSTERESIS CURRENT CONTROL

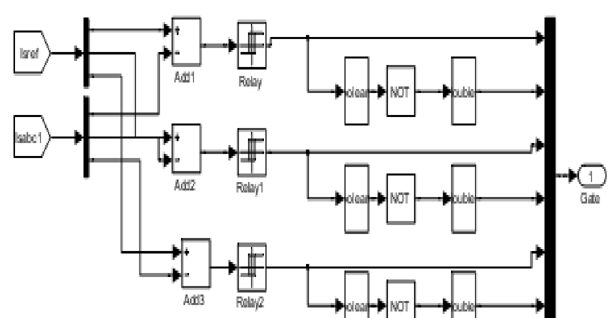

Figure 4: Simulink Model of Hysteresis Current Control

6. MATLAB /SIMULINK MODEL OF PI CONTROL

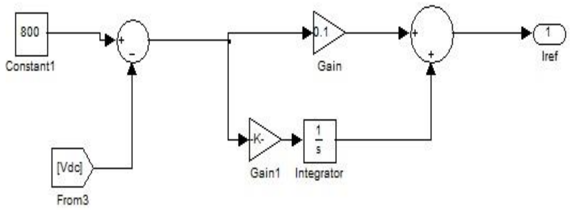

Figure 5. Matlab /Simulink Model of Pi Control

7.LOADS

7.1 NON-LINEAR LOAD: A three phase four leg diode rectifier feeding an RL load is considered as a non-linear load. The load is modeled in Simulink by using diodes.

7.2 BALANCED LOAD: The three impedance values are connected to the three phases of the source. The load is modeled in Simulink by using resistors.

7.3 UNBALANCED LOAD: The three different impedance of value is connected to the three phases of the source. The load is modeled in Simulink by using resistors and inductors.

8.MATLAB/SIMULINK MODEL OF THE PROPOSED SYSTEM

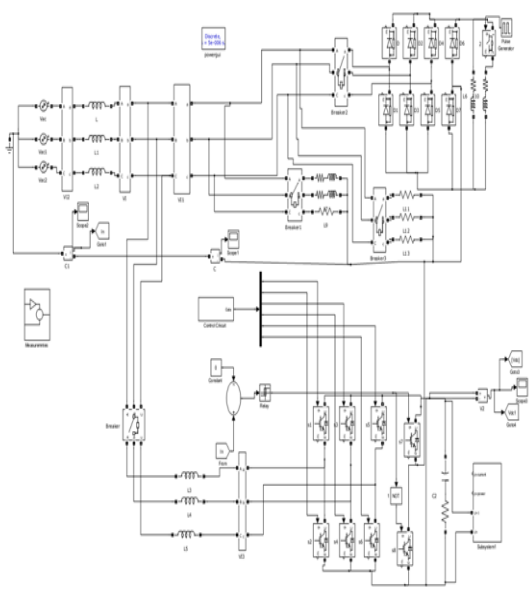

Figure 6: Matlab/Simulink Model of the Proposed System

9.ARTIFICIAL NEURAL NETWORKS

Artificial Neural Networks are relatively crude electronic models based on the neural structure of the brain. The brain basically learns from experiences. It is natural proof that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modeling also promises a less technical way to develop machine solutions. These biologically inspired methods of computing are thought to be the next major advancement in the computing industry. Even simple animal brains are capable of functions that are currently impossible for computers. Computers do rote things well, like keeping ledgers or performing complex math. But computers have trouble recognizing even simple patterns much less generalizing those patterns of the past into action of the future.

Now, advance in biological research promise an initial understanding of the natural thinking mechanism. This research shows that brain stores information, as patterns. Some of these patterns are very complicated and allow us the ability to recognize individual faces from any different angles. This process of storing information as patterns, utilizing those patterns, and then solving problems encompasses a new field in computing. This field does not utilize traditional programming but involves the creation of massively parallel networks and the training of those networks to solve specific problems. This field also utilizes words very different from traditional computing, words like behave, react, self-organize, learn, generalize, and forgot. An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. A neural network is an interconnected group of nodes, akin to the vast network of neurons in the human brain.

10.CASE STUDIES, RESULTS AND ANALYSIS

The performance of the proposed structure is assessed by a computer simulation that uses MATLAB Software. The parameters of the proposed system are given in the tables below. The performance of the system with proposed control scheme is discussed, which includes the following case studies.

Here Simulation results are presented for six cases.
Case 1: Non-Linear Load.
Case 2: Unbalanced Load.
Case 3: Unbalanced Nonlinear Load.
Case 4: Balanced Nonlinear Load.
Case 5: THD Analysis for Various Hysteresis Bands.
Case 6: THD Analysis for Different Percentage of Unbalanced Nonlinear Load

10.1 CASE 1: NONLINEAR LOAD

a. SOURCE CURRENT

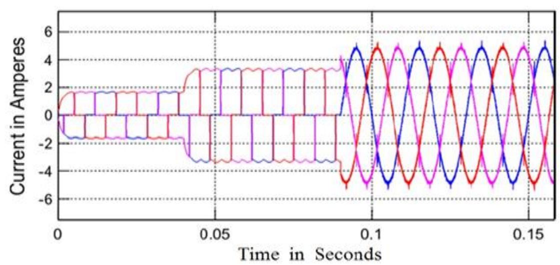

figure 8: SOURCE CURRENT

b. LOAD CURRENT

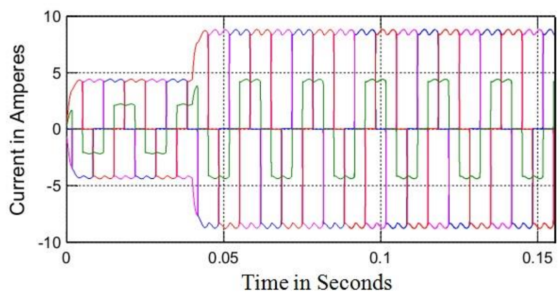

figure 9: LOAD CURRENT

C. INVERTER CURRENT

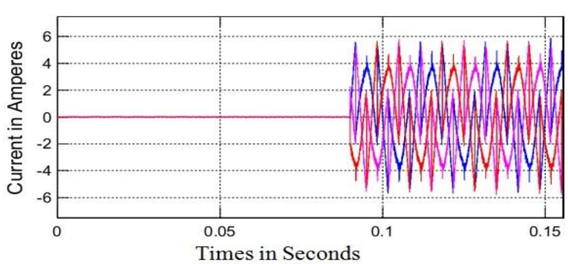

figure 10: INVERTER CURRENT

10.2 THD ANALYSIS FOR NON-LINEAR LOAD

10.2.1 THD OF SOURCE CURRENT BEFORE COMPENSATION

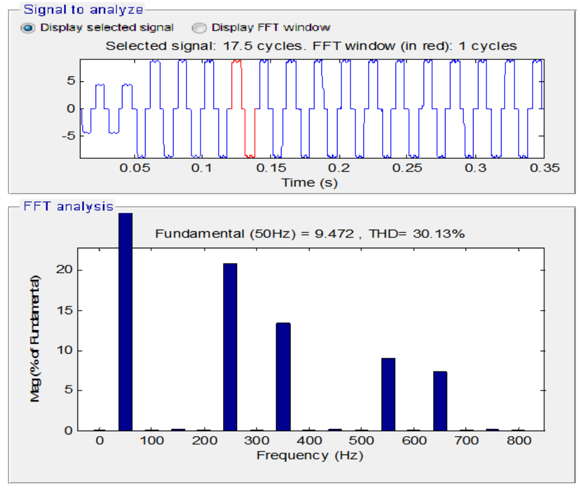

Figure 11: THD of Source Current before Compensation

Total Harmonic Distortion of Source Current after Compensation = 3.20%

10.1.1.2 THD OF SOURCE CURRENT AFTER COMPENSATION

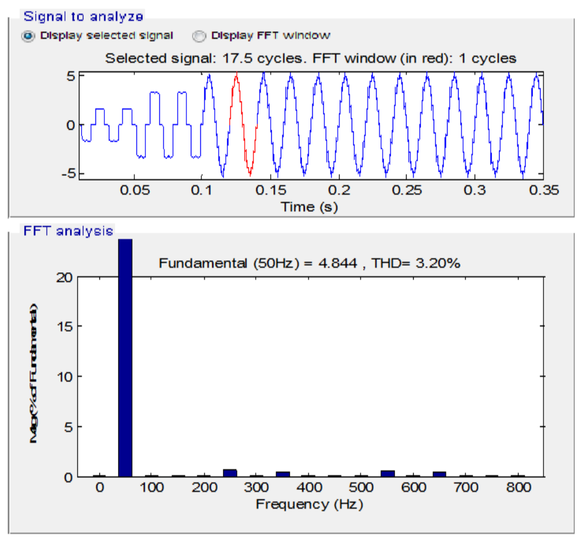

Figure 12: THD of Source Current after Compensation

Total Harmonic Distortion of Source Current after Compensation = 3.20%

Figure 12 gives the simulation result of three phase four wire shunt active power filter under nonlinear load condition. After compensation, THD of the source is reduced from 30.13% to 3.20% which is well below the recommended 5% limit.

10.2 CASE 2: UNBALANCED LOAD

a. SOURCE CURRENT

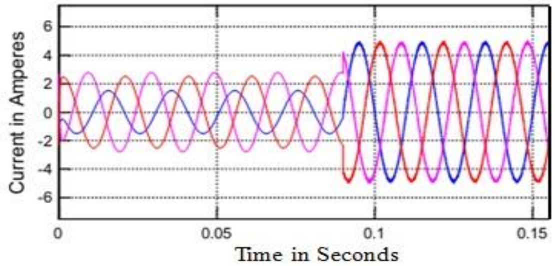

Figure 13: source current

b. LOAD CURRENT

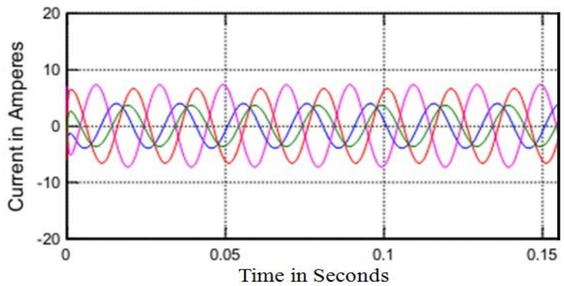

Figure 14: Load current

c. INVERTER CURRENT

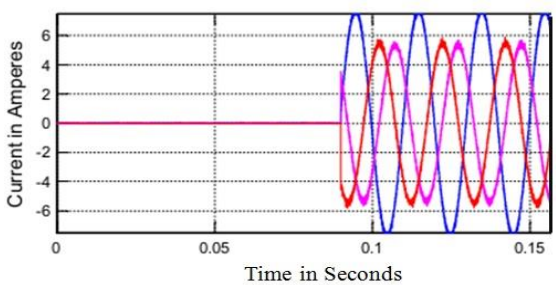

figure 15: Inverter current

10.3 CASE 3: BALANCED NONLINEAR LOAD

a. SOURCE CURRENT

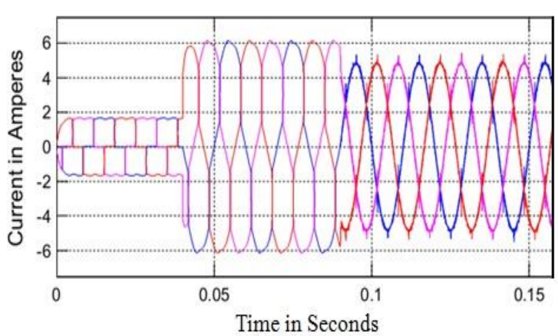

Figure 16: source current

b. LOAD CURRENT

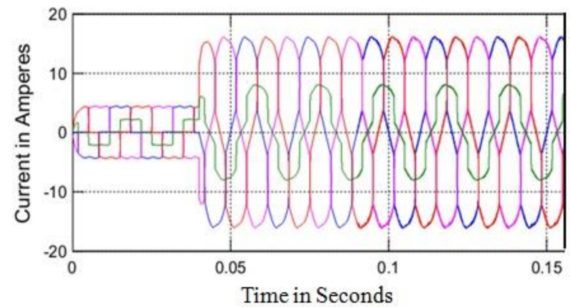

Figure 17: Load current

c. INVERTER CURRENT

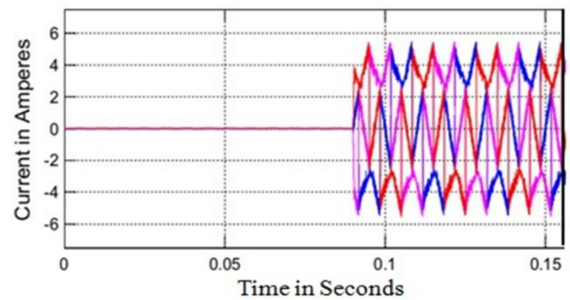

figure 18: Inverter current

10.3.1 THD ANALYSIS OF BALANCED NONLINEAR LOAD

10.3.1.1 THD OF SOURCE CURRENT BEFORE COMPENSATION

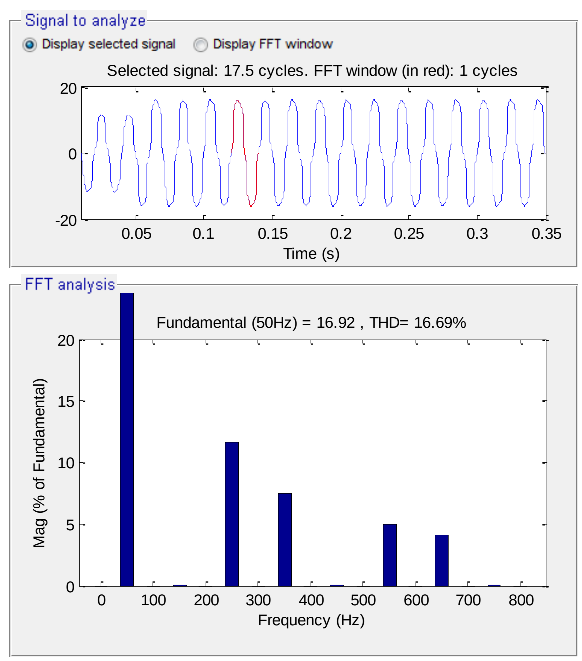

Figure 19: THD of Source Current before Compensation

Total Harmonic Distortion of Source Current before Compensation =14.69%

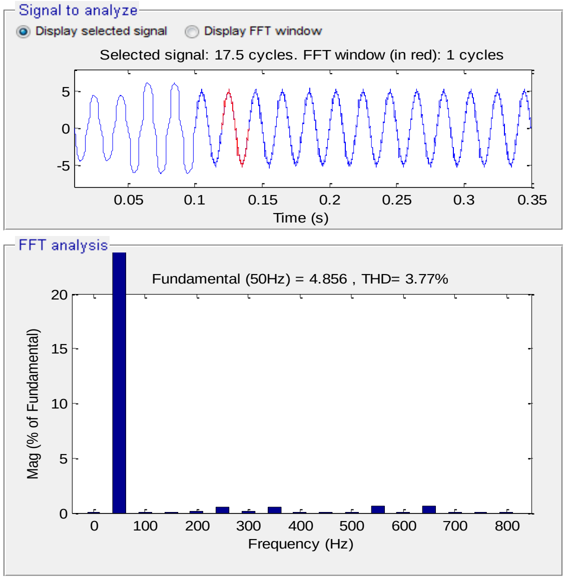

Figure 20: THD of Source Current after Compensation

Total Harmonic Distortion of Source Current after Compensation =3.77%

Figure 20 gives the simulation result of three phase four wire shunt active power filter under Balanced Nonlinear Load condition. After compensation, THD of the source is reduced from 14.6% to 3.77% which is well below the recommended 5% limit.

CASE 4: UNBALANCED NONLINEAR LOAD

a. SOURCE CURRENT

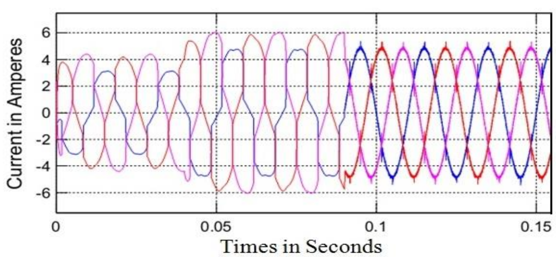

figure 21:source current

b. LOAD CURRENT

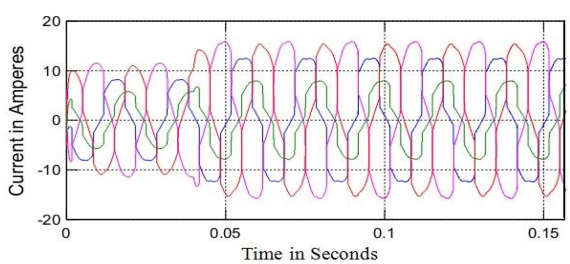

Figure 22: Load current

c. INVERTER CURRENT

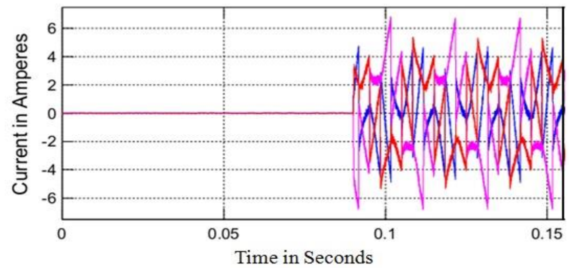

Figure 23: Inverter current

Figure 23: shows the source current, load current, inverter compensating current respectively. The inverter is turned on at o.1 seconds. Figure 23 (a): it clearly indicates the source current from 0 to 0.1 sec represents the unbalance and non-sinusoidal nature due to the presence of unbalance nonlinear load. At 0.1 seconds the nature of waveform is sinusoidal this represents the inverter compensated both unbalance and non-sinusoidal wave to balanced sinusoidal wave. The load current waveform is shown in Figure 23 (b). The inverter supplies the compensating current that is shown in Figure 23 (c).

THD ANALYSIS OF UNBALANCED NONLINEAR LOAD

THD OF SOURCE CURRENT BEFORE COMPENSATION

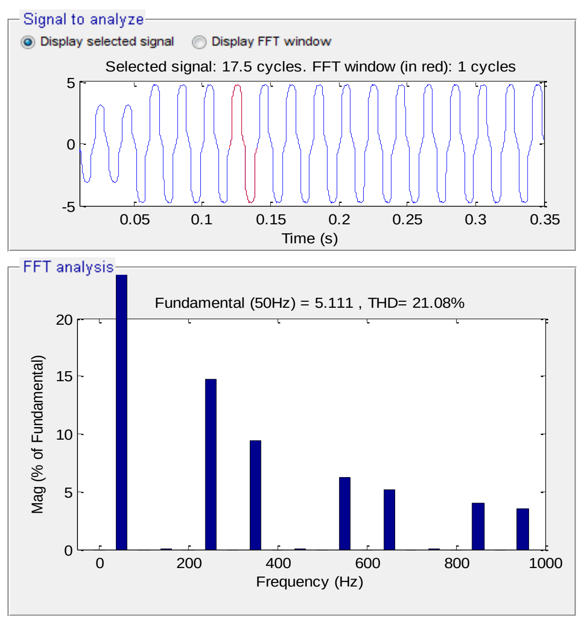

Figure24: THD of Source Current before Compensation

Total Harmonic Distortion of Source Current before Compensation =21.08%

10.3.1.2 THD OF SOURCE CURRENT AFTER COMPENSATION

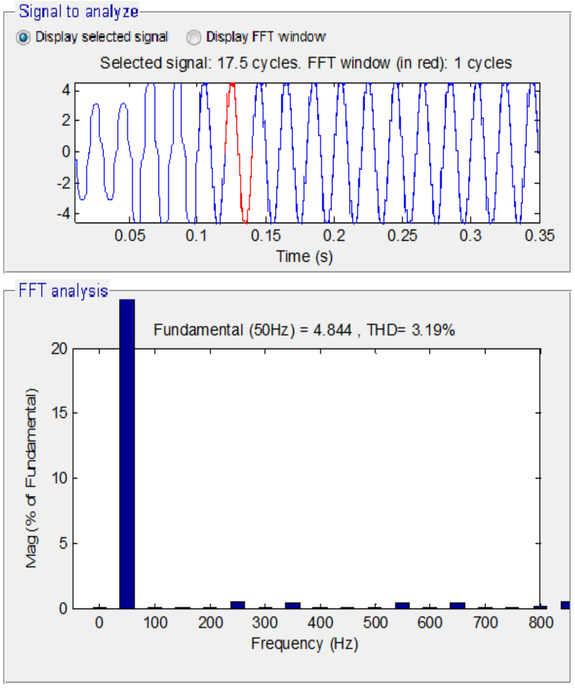

Figure 25 THD of Source Current after Compensation

Total Harmonic Distortion of Source Current after Compensation = 3.19%

Figure 25 gives the simulation result of three phase four wire shunt active power filter under Unbalanced Nonlinear Load condition. After compensation, THD of the source is reduced from 21.08% to 3.19% which is well below the recommended 5% limit.

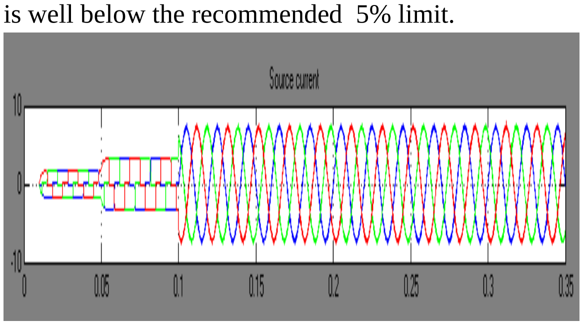

Figure 26 Source Current after Compensation USING ANN

THD ANALYSIS OF UNBALANCED NONLINEAR LOAD

THD OF SOURCE CURRENT BEFORE COMPENSATION

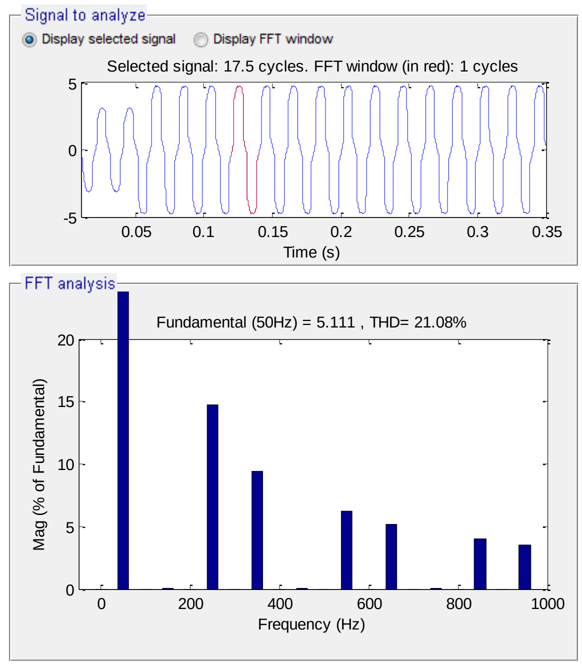

Figure 28: THD of Source Current before Compensation

Total Harmonic Distortion of Source Current before Compensation =21.08%

10.3.1.2 THD OF SOURCE CURRENT AFTER COMPENSATION

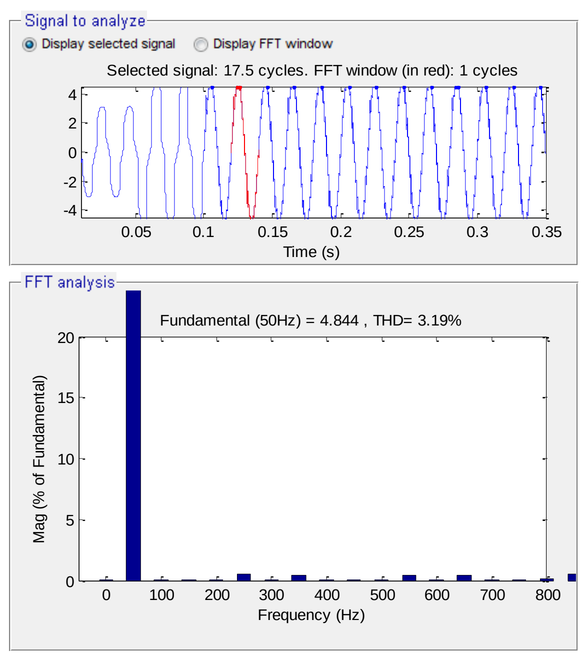

Figure 29 THD of Source Current after Compensation

Total Harmonic Distortion of Source Current after Compensation = 3.19%

Figure 29 gives the simulation result of three phase four wire shunt active power filter under Unbalanced Nonlinear Load condition. After compensation, THD of the source is reduced from 21.08% to 3.19% which is well below the recommended 5% limit.

11.CONCLUSION

1. Shunt active power filter is modeled and connected to three phase four wire distribution system through an inverter.
2. From the results, it can be concluded that the grid interfacing inverter is functioning as a conventional inverter as well as an Active Power Filter.
3. It can also be concluded that the grid interfacing inverter is maintaining sinusoidal source current by reducing THD in supply under various load conditions.
4. PI controller and ANN controllers are used for Inverter current control. It is better to use ANN controller by replacing pi controller.

12.SCOPE FOR FUTURE WORK

In this thesis, the inverter is utilized to work as shunt active power filter as well as conventional inverter by using PI control with hysteresis current control technique.

This work can be extended by

1. By changing control scheme like fuzzy network, PID control techniques.
2. By using load side control technique like PQ theory.

13.ACKNOWLEDGMENT

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