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HARMONIC IDENTIFICATION AND COMPENSATION IN DISTRIBUTION SYSTEM WITH NON-LINEAR AND LINEAR LOADS USING SHUNT APF

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ABSTRACT

The shunt active power filter has proved to be a useful device to eliminate harmonic currents and to compensate reactive power for linear/nonlinear loads. This paper presents harmonic identification and compensation for harmonics using shunt active filter. With load consisting of linear and non-linear loads, harmonics are induced in source components and affect the other sensitive loads connected at point of common coupling. Harmonics in source components insists for mitigation. Shunt active power filter is a custom power device used to compensate harmonics in power system source components. The work concentrates on identification of harmonics when non-linear loads are placed at different nodes of power system and their mitigation using shunt APF. Total Harmonic Power method/Active Compensation method is used for identification of harmonics. This paper proposes a new constant hysteresis current controlled objective for shunt active power filter which maintains a fixed switching frequency. In this control technique, the hysteresis bandwidth need not be specified in entire control objective. The operating principle of the proposed technique is proposed in this paper and implemented. Proposed work is simulated using MATLAB/SIMULINK and results are presented.

Keywords: shunt APF, compensation, harmonics, linear, non-Linear, load.

INTRODUCTION

General developed and comprehensively used three phase power electronic conversion topologies are highly utilized in various commercial/residential applications for processing the energy levels. Their operating principles are dependent on the high-speed range power switching components in such a way their wave-shapes are characterized so as to engage the power transfer between the two sides. In fact, usage of such high range devices at acute frequencies than the fundamental switching frequency by necessarily originates the undesired harmonized components [1-3]. These harmonized components are annoying the power supplies particularly in responsive electronic loads. For minimization of these harmonized components in three phase distribution systems using several ways. In that, identification of harmonics acts as a primary task and then, compensation takes place as a secondary task. Harmonics can be generated by loads as well as source only or both. Before harmonic compensation, measurement of harmonic is one of the familiar aspects of the power quality monitoring and effective control. Total Harmonic Power method/Active Compensation method is more convenient & advanced schemes and implemented in a three phase power distributed systems considering as a both linear load & non-linear load placed at a two node formation as load shifting at conferred source node with respect to RL.

The active filters are merely used to suppress the harmonic distortions in power distribution systems over the LC filters. The active filters [4-6] utilize the power semiconductor devices so as to inject harmonics into the system that may cancel out the harmonics in the supply current is affected by non-linear loads. The shunt/parallel active filter comprises of sensor, control schemes, gate pulse generators, voltage source inverter, and DC link capacitor, line interfacing inductor, and interfacing in shunt/parallel with the load. The switches of the VSI in active power filter are powered by specific compensation scheme is attained.

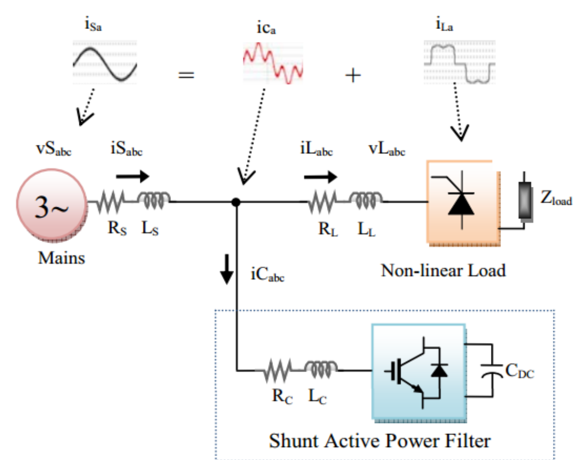

Figure-1. Block diagram of shunt APF.

Figure-1 shows the block diagram of shunt active power filter (APF). The work concentrates on identification of harmonics when non-linear loads are placed at different nodes of power system and their mitigation using shunt APF [7-8]. This paper proposes a new constant hysteresis current controlled objective for shunt active power filter which maintains a fixed switching frequency. In this control technique, the hysteresis bandwidth need not be specified in entire control objective. The operating principle of the proposed technique is proposed in this paper and implemented. Proposed concept is simulated using MATLAB/SIMULINK and results are presented.

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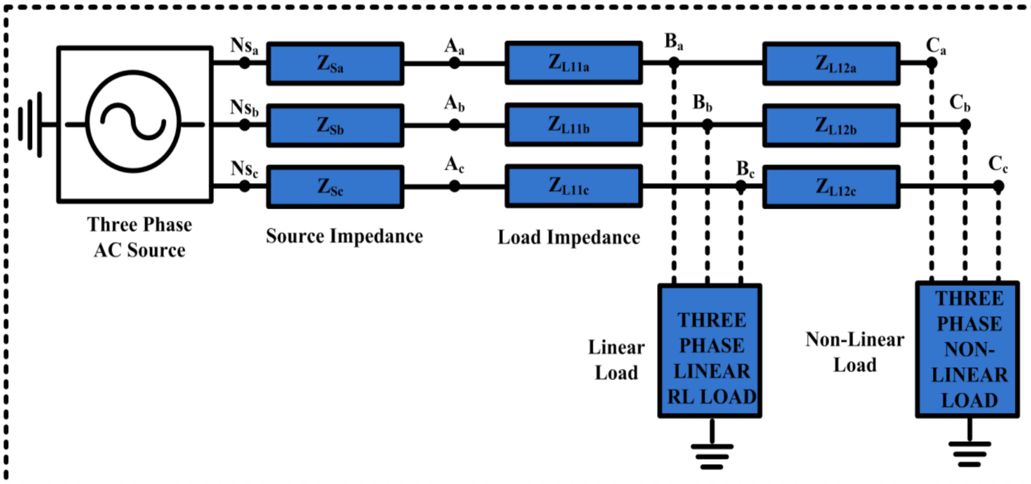
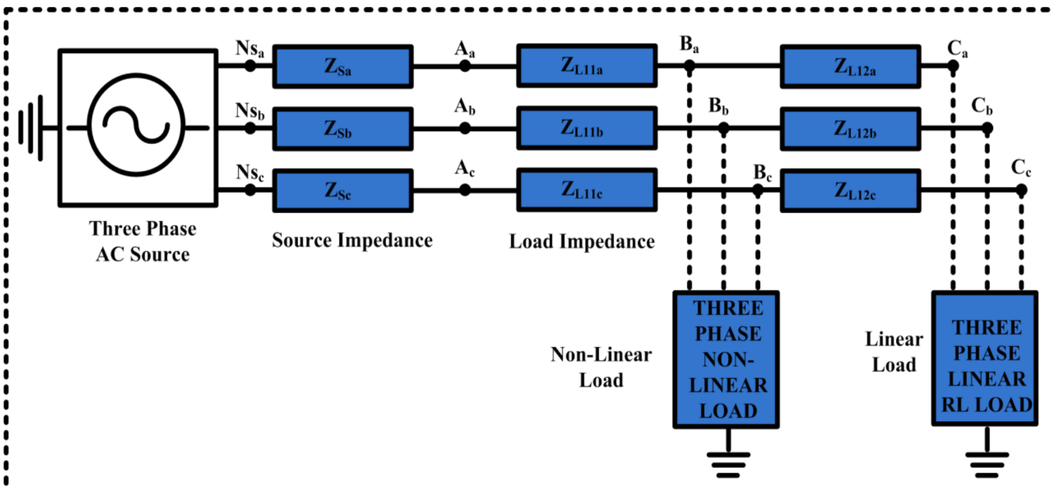


(a) Three phase non-linear load placed at load side with specific load impedance at node C



(b) Three phase non-linear load placed at source side with specific load impedance at node B

Figure-2. Consisting of three phase linear & nonlinear load with RL-load as load shifting by load/source side with specific load impedances at node C & B.

HARMONIC IDENTIFICATION WITH TOTAL HARMONIC POWER (THP) SCHEME

The fundamentals of the THP technique are often illustrated by using the circuit shown in Figure-2. Consisting of three-phased linear & three phase nonlinear load with DC RL-load with load shifting by load/source side with specific load impedances at node C & B, a perfect sinusoidal three phase voltage source is connected to a nonlinear load through the three phase system impedance. The nonlinear load generates harmonic currents that flow within the system inflicting voltage distortion at PCC. This voltage distortion depends on each the three phase harmonic currents and the system electrical phenomenon at harmonic frequencies.

The THP method suggests at a specific node is indicated for the existence of a polluting load. Although, the power sign can be used to identify the location of the polluting load in radial systems as follows:

If P_H positive at a certain point in the system, then a harmonic source exists upstream of this point and the harmonic power is received from the source side.

If P_H is negative, then a harmonic source exists downstream of the node under study, and the harmonic power is received from the load side.

A dual condition is studied for these cases: first; three phase Non-linear load is placed at Node C &three phase Linear load is placed at Node B with a source impedance is placed at node A, this scheme is named as load side node technique & second; three phase Non-linear load is placed at Node B & three phase Linear load is placed at Node C, this scheme is named as Source side node technique. The fundamental power P1 is positive at nodes B and C decreases from the supply to the load side. The THP P_H and each individual harmonic power are all negative at node A for both conditions. Thus, the source of harmonic pollution is downstream with respect to this node (load side).

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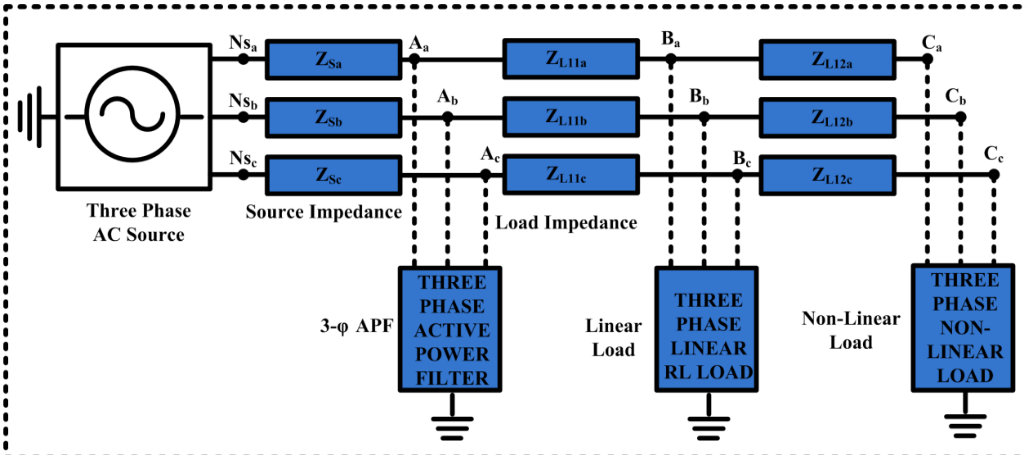
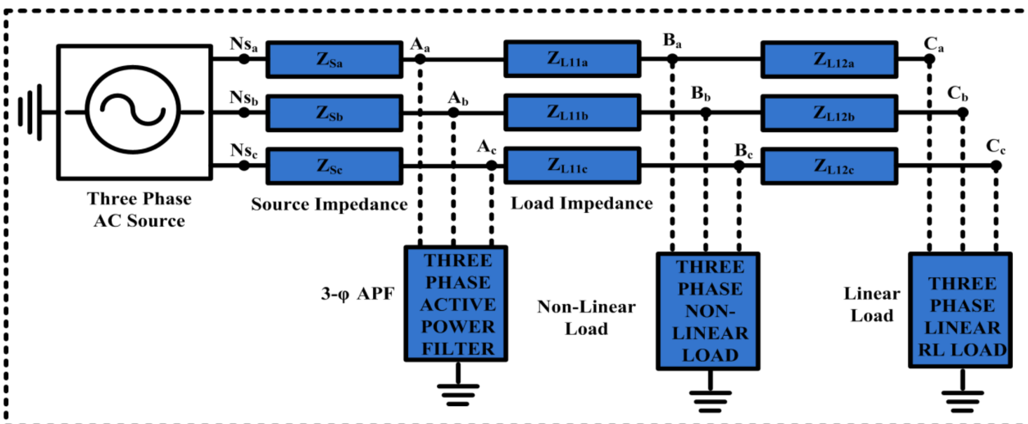
For case 1, the THP P_H and each individual harmonic power are all negative at node, indicating that the polluting source is downstream with respect to this node. On the other hand, these powers are positive at node, indicating that the polluting source is upstream with respect to this node.



(a) Three phase non-linear load placed at load side with specific load impedance at node C, the three-phase APF is interfaced at A node.



(b) Three phase non-linear load placed at source side with specific load impedance at node B, the three phase APF is interfaced at a node.

Figure-3. Consisting of the three phase active compensation of three phased linear & nonlinear load with RL-load with load shifting by load/source side node C & B.

Therefore, it can be concluded that the load connected at node C (nonlinear) is a harmonic polluting load. For case 2, the signs of the harmonic powers at nodes B and C are opposite of those obtained for condition 1 and, thus, it can be concluded that the load at node C (nonlinear) is a harmonic polluting load.

HARMONIC COMPENSATION WITH APF

Harmonic identification acts as the primary task for giving better suggestion to harmonic compensation. In three phase system THP theory is used to identify the 5^{th} & 7^{th} harmonics only due to consideration of inter-harmonics and calculated for whole harmonics. Several harmonic identification schemes, proposed THP scheme is very accurate & more reliable performances. In that, harmonic compensation acts as the secondary task to acquire low harmonic profile, qualified voltage-current wave shapes, low THD content by using active power filtering technology. The active power filtering technology have been implemented, characterised and priced in several past years ago. Mostly, they are highlighted as compensation of voltage and current reflected distortions like voltage harmonics, voltage swells & sags, flickers and current harmonics, elimination of neutral current, reactive power control, etc. Moreover, active filters are comprised of two categorized as three phase, single phase filtering systems. Single phased filtering technique is highly used to enhance power quality concerns which are related to single phase loads.

The selection of APF is merely recognized by depending of compensation principle, in that shunt APF is more capable of harmonic eradication from the

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source/PCC level with respect to effective control objective. The main principle of active compensation is to make a VSI by sinusoidal subtraction of load harmonics which is greatly recognized to regulate the particular load harmonized components. The compensation principle of three phased VSI-APF is based on reference current generation by advanced instantaneous Real (P) & Reactive (Q) power theory; it supports better compensation characteristics in transient & steady states. It will generates the required reference currents to minimize the current harmonics, maintain required DC bus capacitor voltage as constant and reactive control action. Figure-3 shows the Three Phase Active Compensation of Three Phased Linear & Nonlinear Load with RL-Load with Load Shifting by Load/Source Side Node C & B.

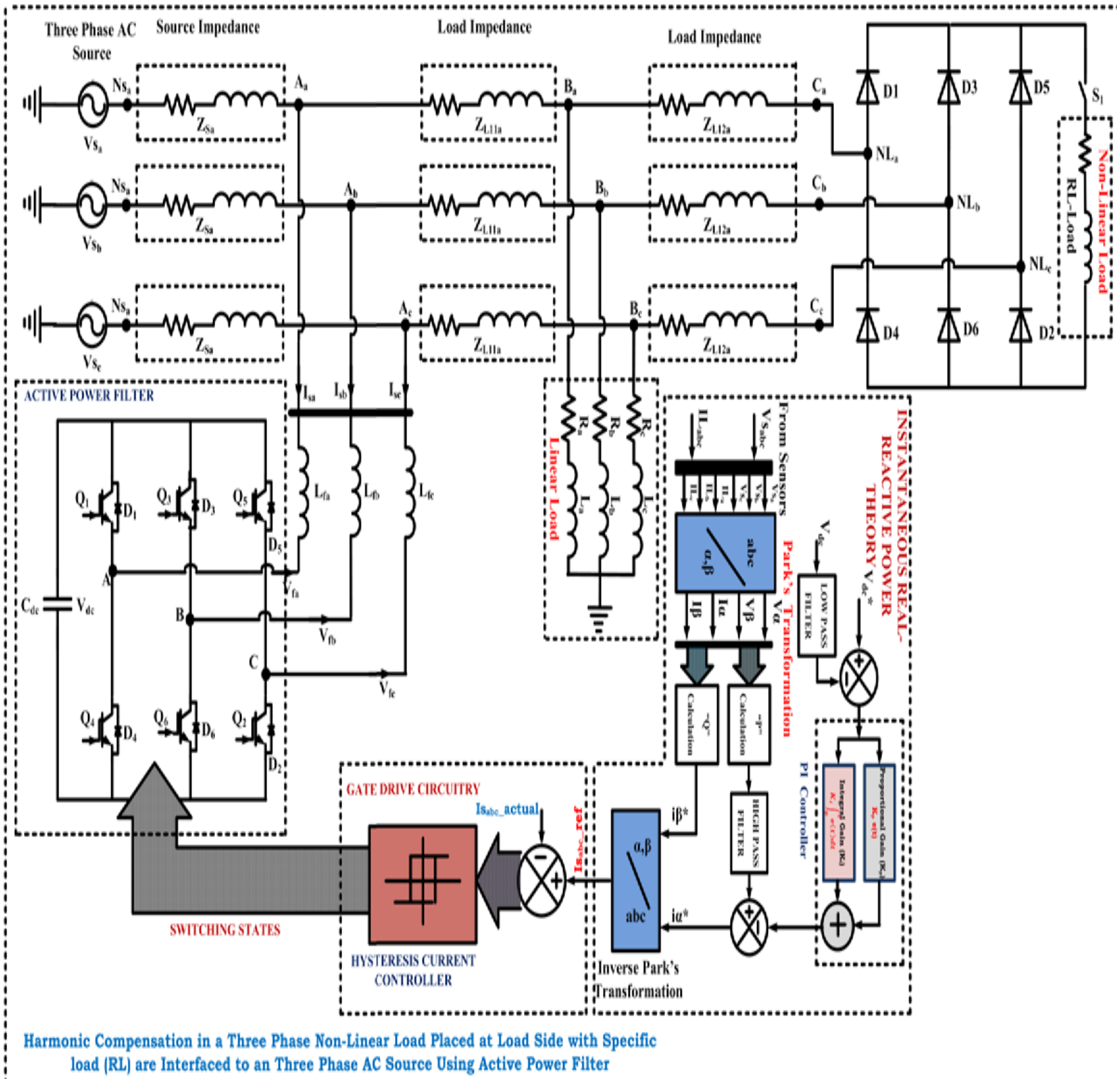

Figure-4. Schematic diagram of harmonic compensation in a three phase non-linear load placed at load side with specific load (RL) are interfaced to a three phase AC source using active power filter.

CONTROL OF SHUNT APF

Figure-4 shows the Schematic Diagram of Harmonic Compensation in a Three Phase Non-Linear Load Placed at Load side with Specific Load (RL) are interfaced to a Three Phase AC Source using Active Power Filter controlled with instantaneous reactive power theory. The important characteristic of this IRP theory is very simple calculations, which supports only algebraic calculations.

The reference currents coming from IRP theory is transform to actual currents to make sufficient reference signal to the gate drive circuitry. Several gate drive circuits are used to generate switching states to VSI for attaining good compensation characteristics, in that hysteresis current controller (HCC) is best suited for three phase active filtering technique. The HCC generates the switching states which are operated on limitation of upper/lower hysteresis current loop with respect to reference current signal. The attained switching states are

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transforming to VSI for the firing of voltage source inverter. This VSI eradicates the harmonics coming from the non-linear load and maintain PCC terms are qualified RMS nature & limitation of harmonics as in IEEE standards.

RESULTS AND DISCUSSIONS

Table-1. System parameters.

Parameters	Value
Source Voltage	415 V
Fundamental Frequency	50 Hz
Source Impedance	(0.1 +j0.9) Ω
Load Impedance	(0.5 +j12.56) Ω
DC Link Capacitor	1500 μF
Linear Load	(100 +j62.8) Ω

The simulation analysis is carried under the effectiveness of the Total Harmonic Power Scheme with active compensation scheme for harmonic mitigation in dual load two node conditions. Table-1 indicates the system parameters considered for system design.

Case 1: THP Identification Scheme Incorporated of Both Loads with Three Phased Linear & Non-Linear Load placed at Load Side with RL-Load

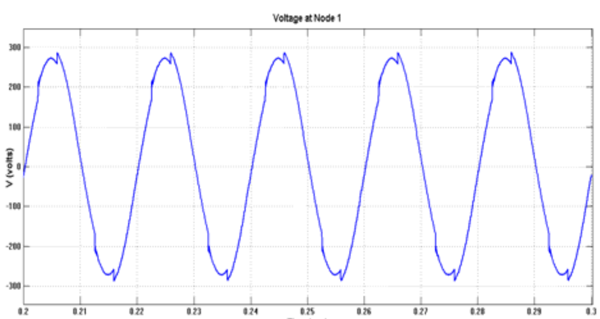

Figure-5. Source voltage at node A.

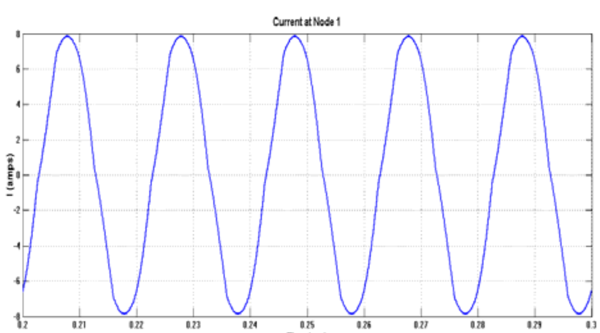

Figure-6. Source current at node A.

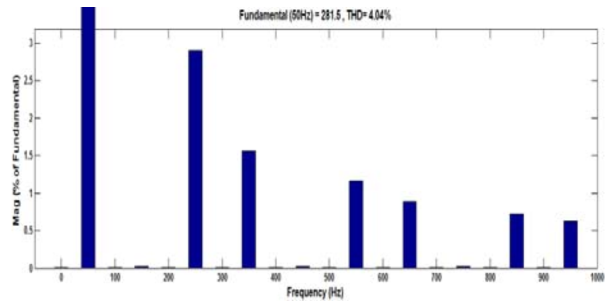

Figure-7. THD of the source voltage at node A.

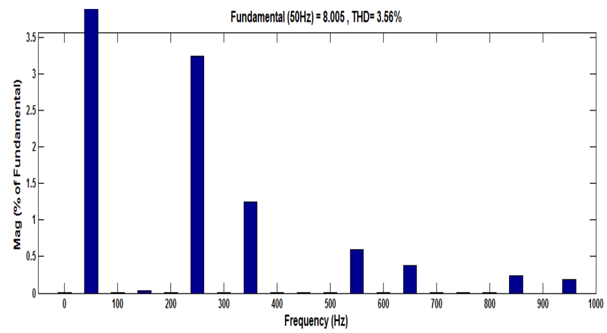

Figure-8. THD of source current at node A.

Figure-5 shows the source voltage and Figure-6 shows the source current at node A. Both source voltage and source current are un-distorted and maintained nearer sinusoidal in shape. Total harmonic distortion at node A is identified using THP scheme and identified to 4% in source voltage and 3.5% in source current as shown in Figure-7 and Figure-8.

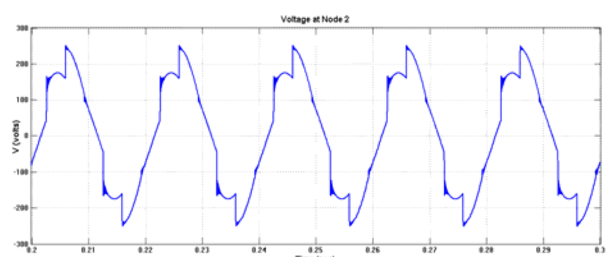

Figure-9. Voltage at node B.

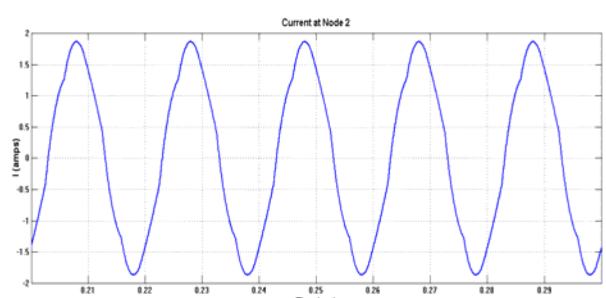

Figure-10. Current at node B.

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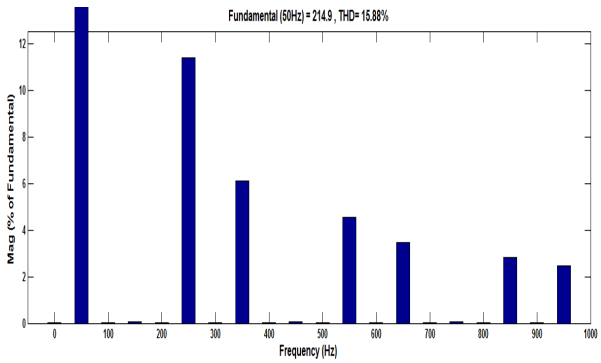

Figure-11. THD of voltage at node B.

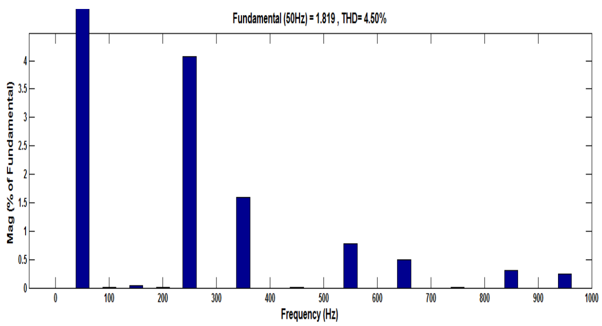

Figure-12. THD of current at node B.

Figure-9 shows the source voltage and Figure-10 shows the source current at node B. Source voltage is distorted and source current is nearer sinusoidal. Total harmonic distortion at node B is identified using THP scheme and identified to 15.8% in source voltage and 4.5% in source current as shown in Figure-11 and Figure-12.

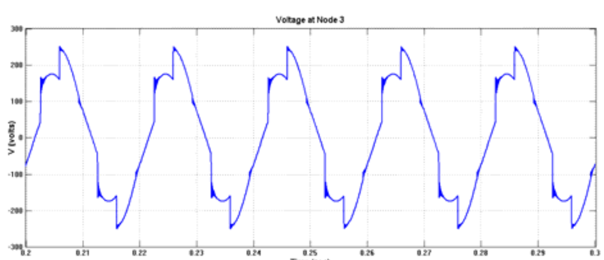

Figure-13. Voltage at node C.

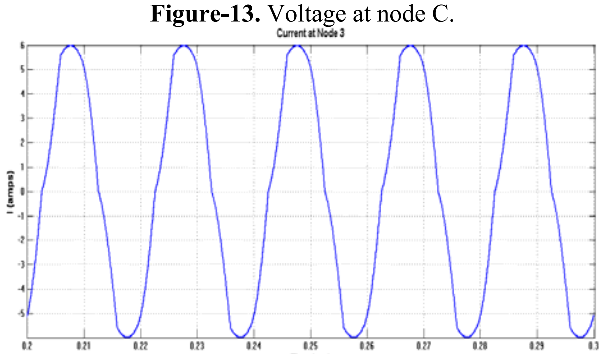

Figure-14. Current at node C.

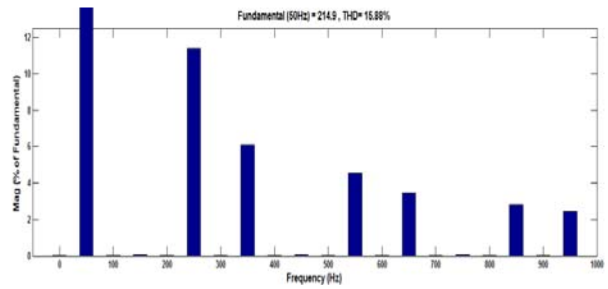

Figure-15. THD of voltage at node C.

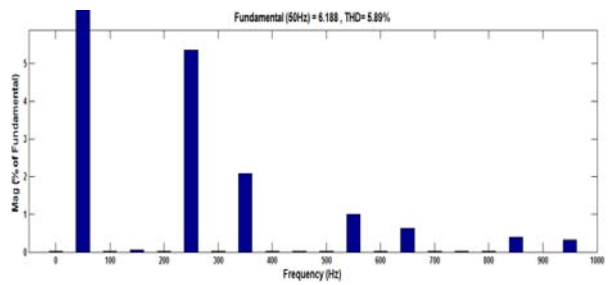

Figure-16. THD of current at node C.

Figure-13 shows the source voltage and Figure-14 shows the source current at node C. Source voltage is distorted and source current is nearer sinusoidal. Total harmonic distortion at node C is identified using THP scheme and identified to 15.8% in source voltage and 5.8% in source current as shown in Figure-15 and Figure-16.

Case 1: THP Identification Scheme Incorporated of Both Loads with Three Phased Linear & Non-Linear Load placed at source Side with RL-Load

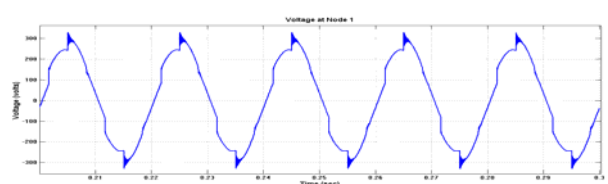

Figure-17. Source voltage at node A.

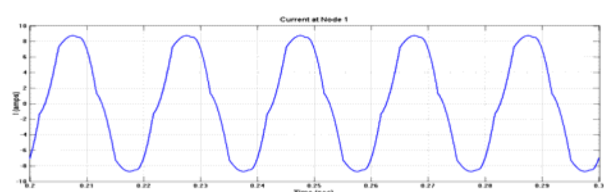

Figure-18. Source current at node A.

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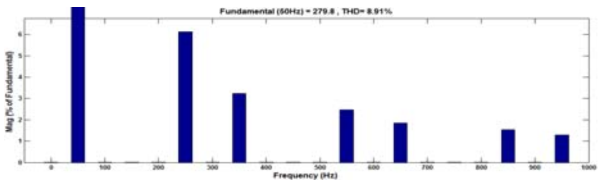

Figure-19. THD of the source voltage at node A.

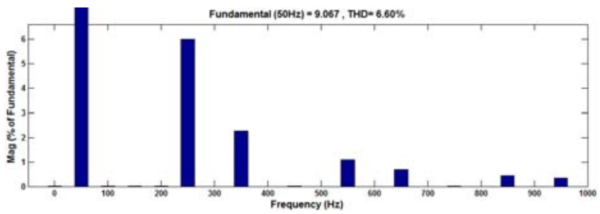

Figure-20. THD of source current at node A.

Figure-17 shows the source voltage and Figure-18 shows the source current at node A. Both source voltage and source current are distorted. Total harmonic distortion at node A is identified using THP scheme and identified to 8.9% in source voltage and 6.6% in source current as shown in Figure-19 and Figure-20.

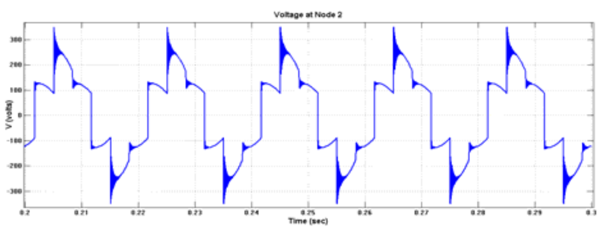

Figure-21. Voltage at node B.

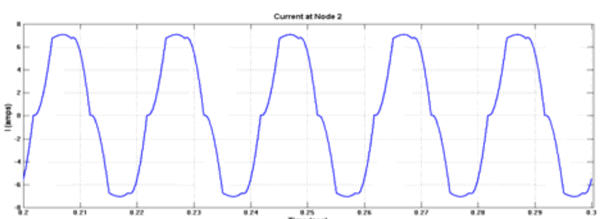

Figure-22. Current at node B.

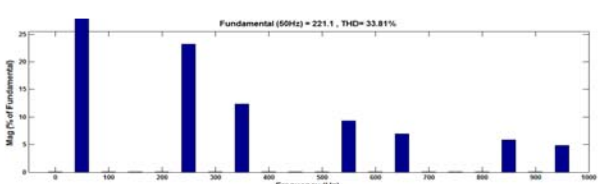

Figure-23. THD of voltage at node B.

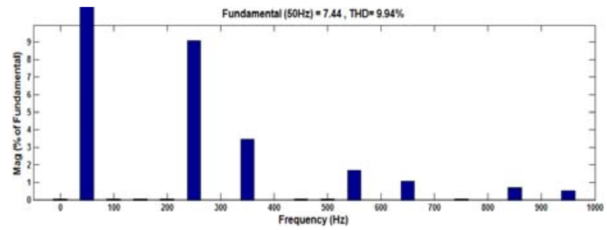

Figure-24. THD of current at node B.

Figure-21 shows the source voltage and Figure-22 shows the source current at node B. Source voltage is distorted and source current is also distorted. Total harmonic distortion at node B is identified using THP scheme and identified to 33.8% in source voltage and 9.9% in source current as shown in Figure-23 and Figure-24.

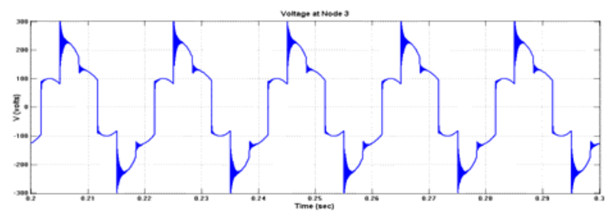

Figure-25. Voltage at node C.

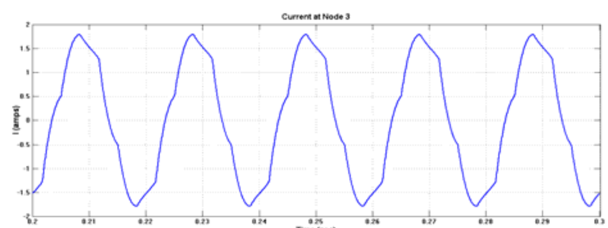

Figure-26. Current at node C.

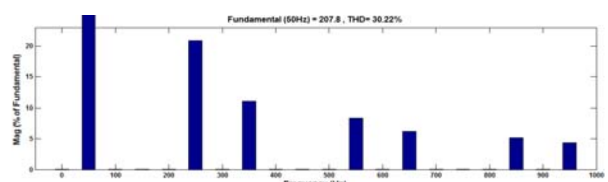

Figure-27. THD of voltage at node C.

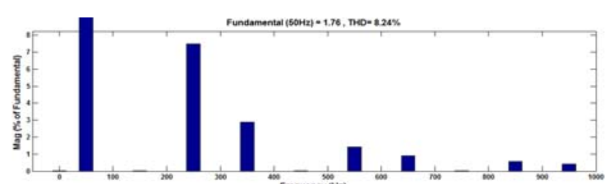

Figure-28. THD of current at node C.

Figure-25 shows the source voltage and Figure-26 shows the source current at node C. Source voltage and currents are distorted. Total harmonic distortion at node C is identified using THP scheme and identified to 30.2% in

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source voltage and 8.84% in source current as shown in Figure-27 and Figure-28.

Case 3: Three-Phase Active Compensation Scheme Incorporated of both loads as Three Phase Linear & Non-Linear Load Placed at Load side with RL-Load

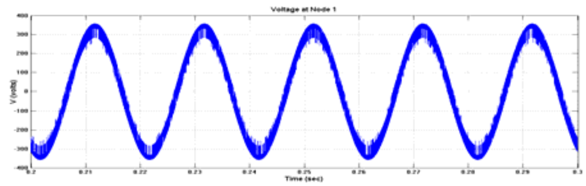

Figure-29. Source voltage at node A.

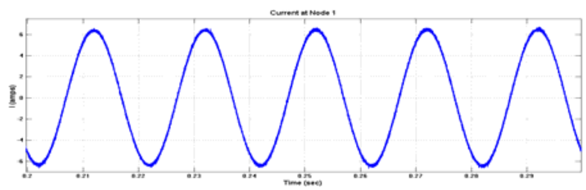

Figure-30. Source current at node A.

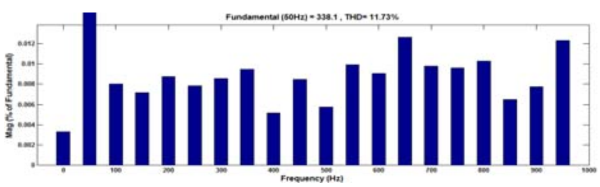

Figure-31. THD of the source voltage at node A.

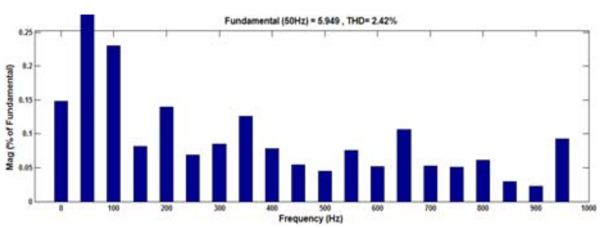

Figure-32. THD of source current at node A.

Figure-29 shows the source voltage and Figure-30 shows the source current at node A. Source voltage is distorted and source current is un-distorted. Total harmonic distortion at node A is identified using THP scheme and identified to 11.7% in source voltage and 2.4% in source current as shown in Figure-31 and Figure-32.

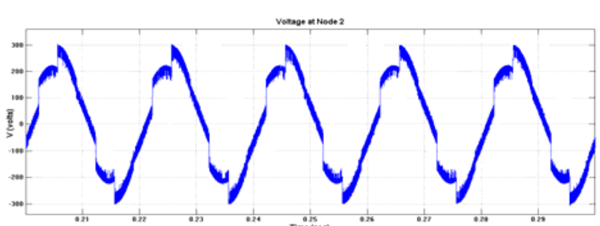

Figure-33. Voltage at node B.

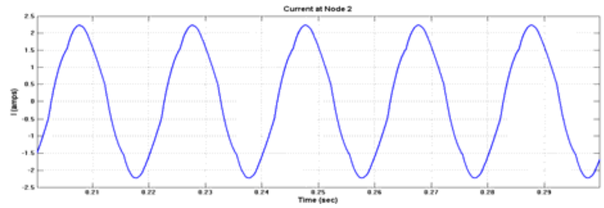

Figure-34. Current at node B.

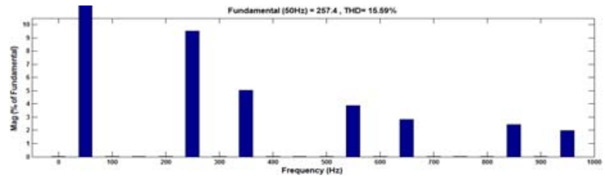

Figure-35. THD of Voltage at Node B.

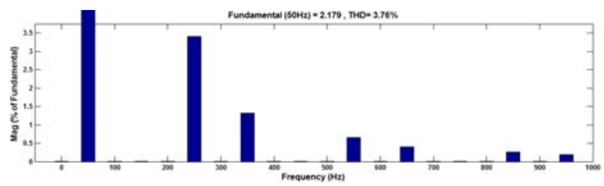

Figure-36. THD of current at node B.

Figure-33 shows the source voltage and Figure-34 shows the source current at node B. Source voltage is distorted and source current is nearer sinusoidal. Total harmonic distortion at node B is identified using THP scheme and identified to 15.5% in source voltage and 3.7% in source current as shown in Figure-35 and Figure-36.

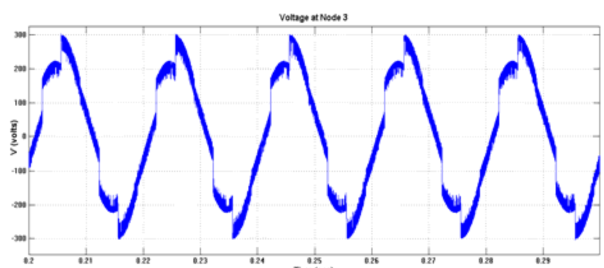

Figure-37. Voltage at node C.

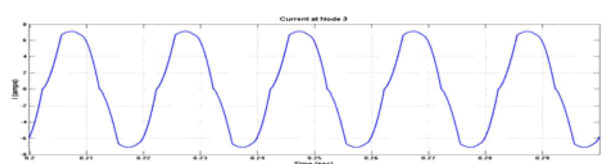

Figure-38. Current at node C.

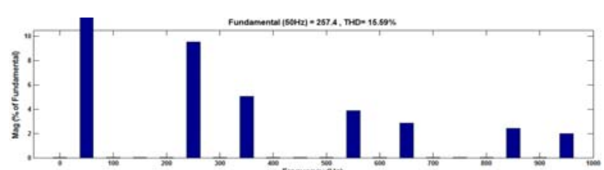

Figure-39. THD of voltage at node C.

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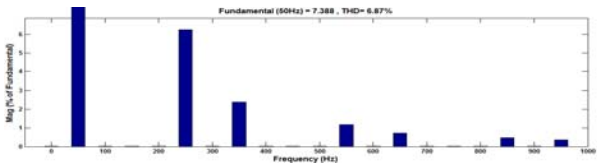

Figure-40. THD of current at node C.

Figure-37 shows the source voltage and Figure-38 shows the source current at node C. Source voltage is distorted and source current is nearer sinusoidal. Total harmonic distortion at node C is identified using THP scheme and identified to 15.8% in source voltage and 6.8% in source current as shown in Figure-39 and Figure-40.

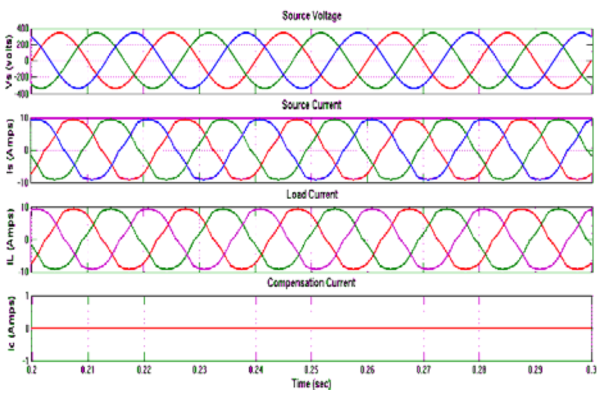

Figure-41. Source voltage, source current, load current and compensation currents without APF.

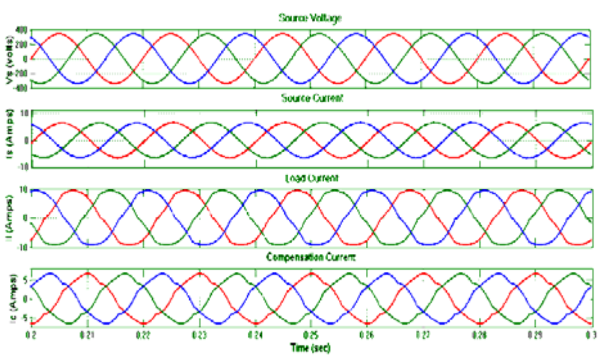

Figure-42. Source voltage, source current, load current and compensation currents with APF.

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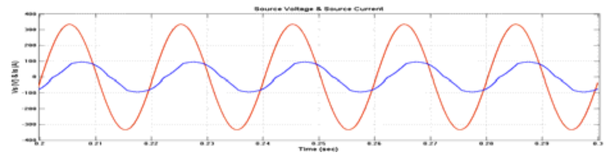

Figure-43. Power factor angle between Source voltage and source current without APF.

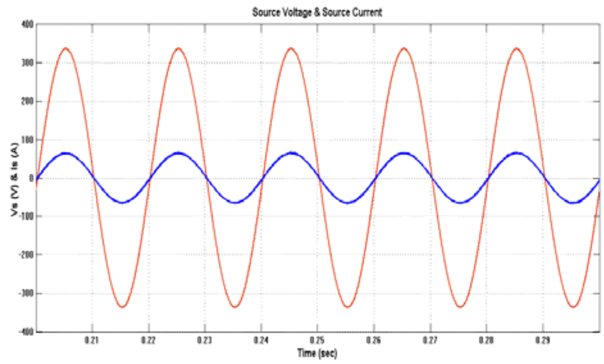

Figure-44. Power factor angle between Source voltage and source current with APF.

Figure-41 shows the source voltage, source current, load current and compensation currents without APF. Since there is no APF connected, compensation currents are zero. Source current and load current are distorted due to the presence of non-linear load. Figure-42 shows the power factor angle between source voltage and source current. Power factor angle is not maintained nearer to unity as clearly observed that phase shift between source voltage and current. Figure-43 shows the source voltage, source current, load current and compensation currents with APF. Load current are distorted due to the presence of non-linear load but source current is non-distorted as APF induces compensating signals. Figure-44 shows the power factor angle between source voltage and source current. Power factor angle is maintained nearer to unity as clearly observed that phase shift between source voltage and current is almost zero. Table-2 and Table-3 indicate THD at different nodes and with and without APF.

Table-2. THD analysis of voltages/currents at respective nodes with three phase non-linear load as RL load is placed at load/source side with $\alpha=0^0$ firing state.

	Voltage			Current		
	N1	**N2**	**N3**	**N1**	**N2**	**N3**
Source side	8.91%	33.81%	30.22%	6.60%	9.94%	8.24%
Load side	4.04%	15.88%	15.88%	3.56%	4.50%	5.89%

Table-3. THD analysis of voltages/currents at respective nodes with three phase active compensation under non-linear load as RL load is placed at load side with $\alpha=0^0$ firing state.

THD (%)	**Voltage**			**Current**		
	N1	**N2**	**N3**	**N1**	**N2**	**N3**
Without APF	4.04%	15.88%	15.88%	3.56%	4.50%	5.89%
With APF	11.73%	15.59%	15.59%	2.42%	3.76%	5.87%

CONCLUSIONS

The shunt active power filter has proved to be a useful device to eliminate harmonic currents and to compensate reactive power for linear/nonlinear loads. This paper presents harmonic identification and compensation for harmonics using shunt active filter with load consisting of linear and non-linear loads. Total Harmonic Power method/Active Compensation method is used for identification of harmonics. This paper proposes a new constant hysteresis current controlled objective for shunt active power filter which maintains a fixed switching frequency. In this control technique, the hysteresis bandwidth need not be specified in entire control objective. Results prove THD is reduced due to presence of APF and tabular comparison is shown for values of THD at different nodes and THD with and without APF.

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