



Harmonic Identification and Mitigation using APF in Distribution System Consisting of Single Non Linear Load

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Abstract—

This paper presents a unique approach for source side compensation of current harmonics occurred to the presence of nonlinear characteristic loads in power systems by the implementation of Active power filter (APF). This is often as a result of optimizing the ability system networks exploitation typical mathematical modeling based mostly linearized approaches is kind of tough owing to the advanced, nonlinear and non-stationary nature of systems that involve an outsized variety of difference constraints. In order avoid the complexness of conventional concepts in this paper the implementation of Total Harmonic Power (THP) to 2 complete cases with and without APF are proposed i.e. identifying the harmonics and reducing their effect with APF has been planned here to lower down the supply current Total harmonic distortion (THD) sufficiently below fifth order so as to satisfy the IEEE-519 std. even beneath distorted offer. Intensive MATLAB simulations and comparative analysis were applied for cases with and without APF management schemes using THP control techniques.

Key words: Harmonics; total harmonic power; nonlinear load; active power filter

I. INTRODUCTION

The general use of power electronic devices in our daily applications, disturbances occur on the electrical provide network. These disturbances are for extensive utilization of non-linear devices. These can introduce harmonics within the facility thereby inflicting instrumentality warming; malfunction of devices, EMI connected issues etc.

Active Power Filters (APF) is extensively can be useful to compensate this harmonics and unbalanced load problems. Power quality is one in every of the foremost necessary topics that electrical engineers are noticed in recent years. Identifying the harmonics is one in every of the issues associated with power quality.

Two schemes have been proposed for limiting the amount of harmonic pollution present in a distribution system. The first scheme involves the establishment of limits on the amount of harmonic currents and voltages generated by customers and utilities. Power systems are designed to operate within the limits. This scheme has been widely accepted in industry. The IEEE Std. 519 [1] and the IEC 1000-3 [2] are good examples. A major problem with this regulation-based scheme is that if the limits are exceeded by a customer, the only enforcement power the utility has is to disconnect the customer, which is not desirable. As a result, an incentive-based scheme has been proposed recently. This scheme, inspired by the well-known power factor management practice, is to charge harmonic generators an amount commensurate with their harmonic pollution level when the limits are exceeded. A pioneering work in this area was described in [3]. The incentive scheme is considered by many as an ideal solution to control harmonic generations from disturbing loads. Unfortunately, the scheme faces two major technical challenges. One challenge is the need to separate the harmonic contribution of a customer from that of the supply system. The other is to isolate the effect of utility impedance variation on customer's harmonic injection levels. Since the publication of [3], many

research efforts have been directed to these problems [4]–[7]. However, there are still no satisfactory solutions.

The total harmonic power (THP) method [10] is a simple method that uses the sign of the THP at a specific node to decide on whether the source of harmonic pollution is upstream or downstream from this node. Despite its simplicity, this method suffers from two main drawbacks: 1) the concept of upstream and downstream cannot be applied to nonradial networks. 2) the sign of the THP depends on the phase shifts between the voltages and currents at different harmonic orders. Hence, any error in calculating these phase shifts affects the reliability of the method. Such a problem becomes serious for higher harmonic orders when the system has an inductive nature and the phase shifts approach 90 [12]. The capability of the THP method in identifying the source of harmonic pollution correctly has been questioned by some researchers. The results were not similar for some cases and, thus, the THP method was assumed to fail in these cases. However, using an index that is entirely designed for the method proposed in [6], as a basis for the comparison, seems unreasonable. Accordingly, the THP method was assumed to be unsuitable for some cases as it cannot accommodate this concept. However, this idea is questionable, because it assumes that a load that will increase the ability loss within the system as a result of the generation of harmonic powers will still be outlined as not a problematic load that is certainly not a sensible assumption.

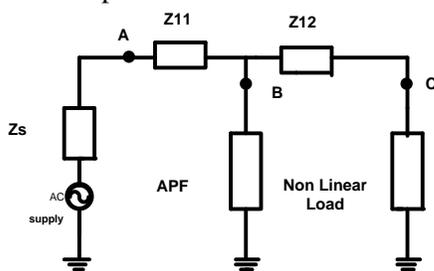


Fig. 1. Simple network with a nonlinear load connected to a sinusoidal supply with APF.

II. TOTAL HARMONIC POWER METHOD

The fundamentals of the THP technique are often illustrated by using the circuit shown in Fig. 1. a perfect sinusoidal voltage source is connected to a nonlinear load through the 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 harmonic currents and the system electrical phenomenon at harmonic frequencies. The distorted voltage and current at PCC are often expressed by Fourier series as

$$v_{pcc}(t) = V_0 + \sum_{h=1}^{\infty} \sqrt{2V_h \sin(h\omega_1 t + \theta_{hv})} \quad (1)$$

$$i_{pcc}(t) = I_0 + \sum_{h=1}^{\infty} \sqrt{2I_h \sin(h\omega_1 t + \theta_{hi})} \quad (2)$$

where $V_{pcc}(t)$ and $i_{pcc}(t)$ are the instantaneous voltage and current at point pcc, h is the harmonic order, ω_1 is the fundamental angular frequency of the supply, V_0 and I_0 are the magnitudes of dc components of the voltage and current, V_h and I_h are the rms values of the voltage and current at frequency $h\omega_1$, and θ_{hv} and θ_{hi} are the phase shifts of the h th harmonic voltage and current with respect to a common reference.

The instantaneous power at any point in the system is defined as

$$p(t) = v(t) \cdot i(t) \quad (3)$$

The average power at point pcc is

$$P_{pcc} = \frac{1}{T} \int_0^T p_b(t) dt \quad (4)$$

$$\therefore P_{pcc} = V_0 I_0 + \sum_{h=1}^{\infty} V_h I_h \cos \phi_h \quad (5)$$

The average power at point pcc can be decomposed into: 1) power due to dc components P_0 ; 2) fundamental active power P_1 ; and 3) total harmonic active power P_H

$$P_{pcc} = P_0 + P_1 + P_H \quad (6)$$

$$P_0 = V_0 I_0 \quad (7)$$

$$P_1 = V_1 I_1 \cos \phi_1 \quad (8)$$

$$P_H = \sum_{h=2}^{\infty} V_h I_h \cos \phi_h \quad (9)$$

Consider the voltage at point A as a reference, hence

$$v_A(t) = \sqrt{2} V_{A1} \sin(\omega_1 t) \quad (10)$$

Applying the procedure outlined before to point A, the average power at A can be given by

$$P_{A1} = V_{A1} I_{B1} \cos\phi_1 \quad (11)$$

Equation (11) demonstrates the well-known fact that a sinusoidal source delivers power only at the fundamental frequency. Some of this power is dissipated in the resistance of the system impedance and the rest flows to the load side. The nonlinear load is the only source of distortion in this case that generates harmonic currents at different frequencies. Thus, harmonic powers, with a total value of P_H flow from the load side to the supply side and are dissipated in the resistance of the system impedance [18]. As a conclusion, the nonlinear load converts power at the fundamental frequency to powers at the fundamental and harmonic frequencies. The THP method suggests that the THP at a certain node is an indication for the existence of a polluting load. Moreover, the sign of this power 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.

III. SYSTEM CONFIGURATION

Case 1: THP method for nonlinear loads with resistive load of 100 Ω , input 230-Vrms, 50-Hz sinusoidal supply with an internal impedance of $Z_s = 1 + j6.28 \Omega$ is connected to Node A without APF of the circuit shown in Fig. 2. The line impedance is $Z_l = 2 + j12.56 \Omega$ and the load is a phase-controlled bridge rectifier with a firing angle of $\alpha = 30^\circ$

1) The fundamental power P_1 is positive at nodes A and B and decreases from A to B. This indicates that the supply is delivering fundamental power to the load and some of this power is lost in the line resistance.

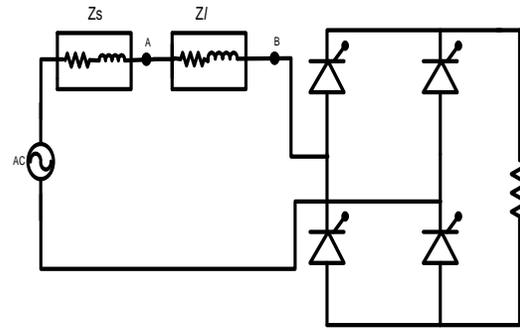


Fig .2. Nonlinear load with R load connected to an AC supply without APF

Case 2: THP method for nonlinear load of input voltage of 230-Vrms, 50-Hz sinusoidal supply with an internal impedance of $Z_s = 1 + j6.28 \Omega$ is connected to Node A the Resistive load is a phase-controlled bridge rectifier with a firing angle of $\alpha = 30^\circ$. With APF of the circuit shown in Fig. 3. 8mf of capacitive source, filter impedance of $Z_f = 0.01 + j0.05 \Omega$

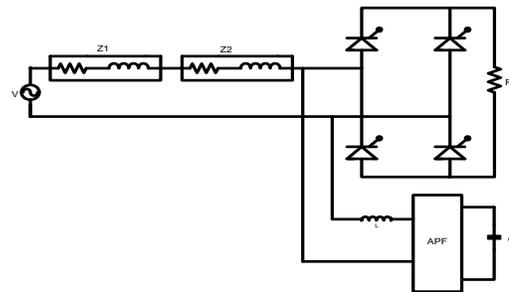


Fig .3. Nonlinear load with R load connected to an AC supply with APF

IV. CONTROLLER FOR APF

The main aim of the control technique is to generate reference source currents to control the 4 pulse APF. The block diagram of the control scheme is shown in Fig. 4. The control strategy applied to the inverter consists mainly of two cascaded loops. Usually there is a fast internal current control loop, which regulates the source current and an external voltage loop which controls the DC-link voltage. Conduction and switching losses of diodes and IGBTs in inverters increase voltage ripple in DC-link which affects the performance of the filter. The control scheme approach is based on injecting the currents into the grid using hysteresis current controller.

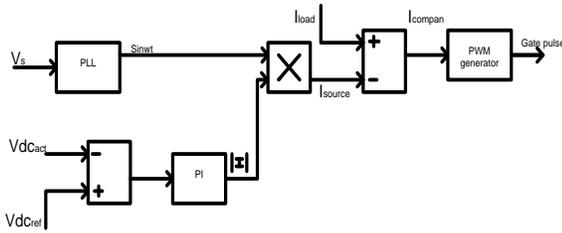


Fig.4. Block diagram representation of control scheme

A. Magnitude of the Reference current

A PI controller is used to maintain the DC link voltage at specified value. The DC link voltage is sensed and compared with reference value and the error is passed through a PI controller.

$$V_{dc_{ref}} = V_{dc}^* - V_{dc}$$

Thus the output of dc link voltage regulator results in current I_m .

B. Current Control of VSI

Sinusoidal wave form generated from Phase Locked Loop(PLL)

$$V_a = V_m \times \sin(\omega t)$$

$$U_a = \sin(\theta)$$

The multiplication of current I_m with sine wave form (U_a) generate reference current (I_a^*).

The instantaneous values of reference grid currents are computed as

$$I_a^* = I_m \cdot U_a$$

Current errors are obtained by comparing reference grid currents (I_a^*) with actual grid currents (I_a).

These current errors are given to the hysteresis current controller.

$$I_{a_{err}} = I_a^* - I_a$$

C. Switching Control of IGBTs

Switching pulses are generated using hysteresis current controller. There are various current control methods for active power filter configurations but hysteresis method is preferred among other current control methods because of quick current controllability, easy implementation and unconditioned stability. The conventional current control scheme is the hysteresis method where the actual filter currents are compared with their

reference currents with a predefined hysteresis band in their respective phases. Thus the actual currents track the reference currents generated by current control loop. The switching pattern of each IGBT is formulated as,

If $(I_a^* - I_a) = +hb$ then the upper switch S1 will be ON in the phase a leg of inverter.

If $(I_a^* - I_a) = -hb$ then the lower switch S4 will be ON in the phase a leg of inverter.

Where, hb width of hysteresis band.

V. MATLAB/SIMULINK OUTPUTS

Case I: Simulation analysis for Resistive load based Non linear load at $\alpha=30^\circ$ without APF

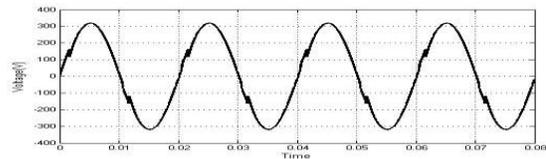


Fig. 5. Simulated Voltage wave form at Node 1 with $\alpha=30$ controlled R load

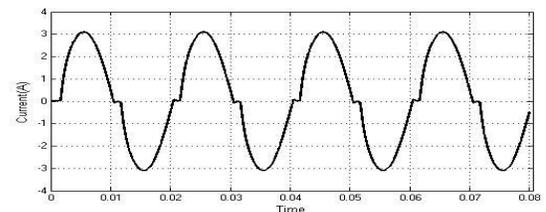


Fig. 6. Simulated Current wave form at Node 1 with $\alpha=30$ controlled R load

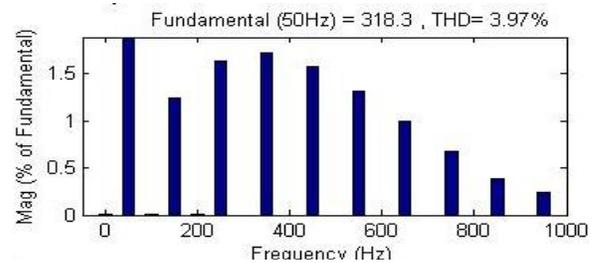


Fig. 7. Total Harmonic Distortion of Voltage at Node 1 shows 3.97% with $\alpha=30$ controlled R load

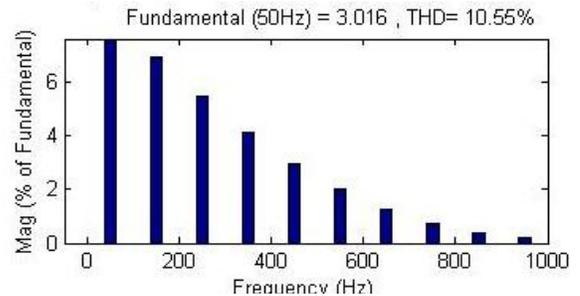


Fig. 8. Total Harmonic Distortion of Current at Node 1 shows 10.55% with $\alpha=30$ controlled R load

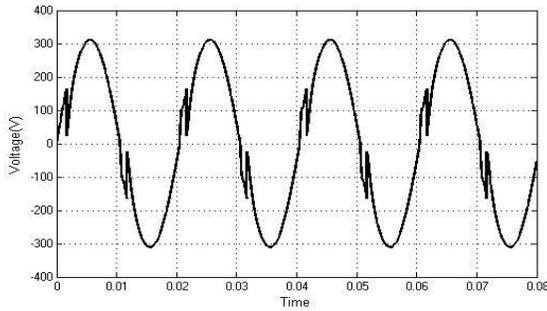


Fig .9. Simulated Voltage wave form at Node 2 with $\alpha=30$ controlled R load

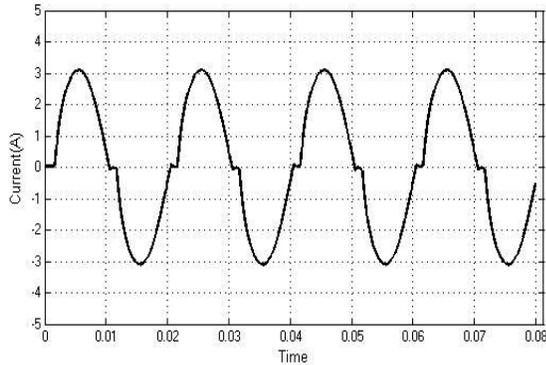


Fig .10. Simulated Current wave form at Node 2 with $\alpha=30$ controlled R load

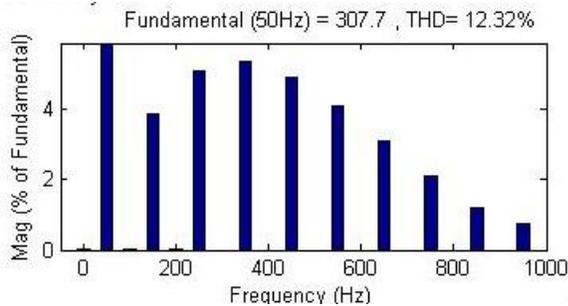


Fig .11. Total Harmonic Distortion of Voltage at Node 1 shows 12.32% with $\alpha=30$ controlled R load

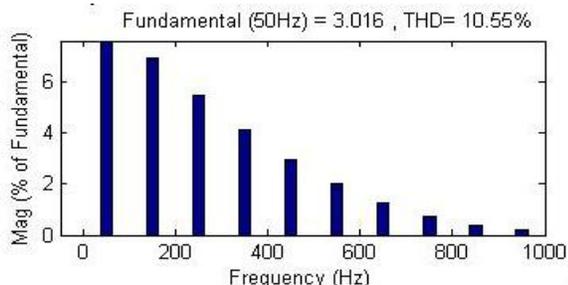


Fig .12. Total Harmonic Distortion of Current at Node 2 shows 10.55% with $\alpha=30$ controlled R load

Case II: Simulation analysis for Resistive load based Non linear load linear load at $\alpha=30^\circ$ with APF

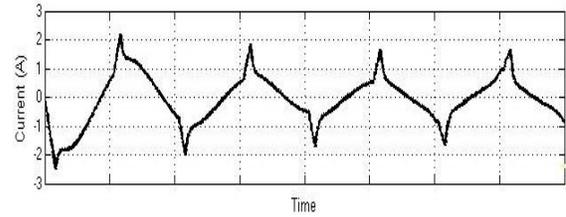


Fig .13. Simulated Current wave form injected with APF

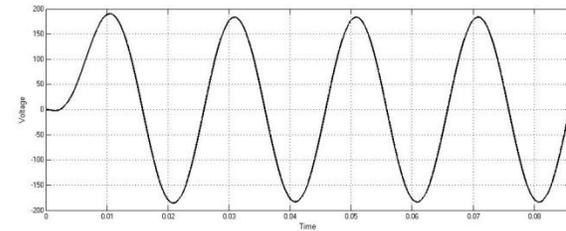


Fig .14. Simulated Voltage wave form at Node 1 with $\alpha=30$ controlled R-load with APF

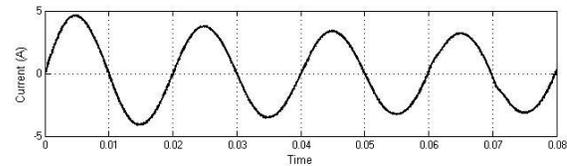


Fig .15. Simulated Current wave form at Node 1 with $\alpha=30$ controlled R-load

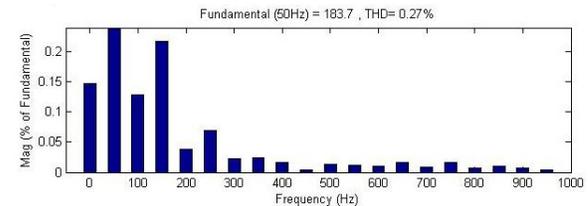


Fig .16. Total Harmonic Distortion of Voltage at Node 1 shows 0.27% with $\alpha=30$ controlled R-load with APF

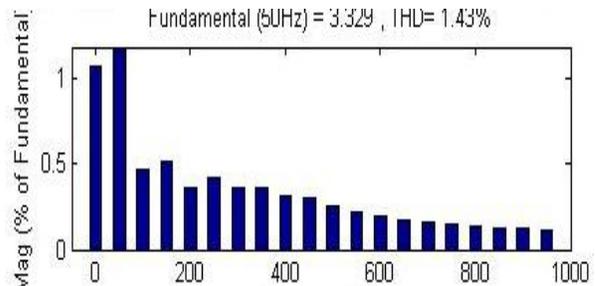


Fig .17. Total Harmonic Distortion of Current at Node 1 shows 1.43% with $\alpha=30$ controlled R-load with APF

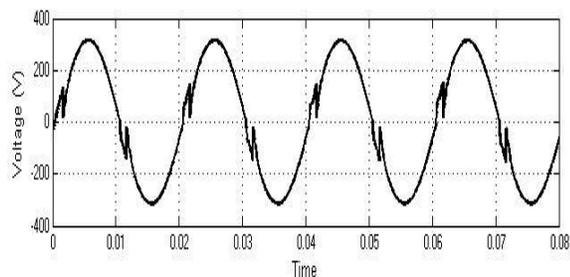


Fig. 18. Simulated Voltage wave form at Node 2 with $\alpha=30$ controlled R-load with APF

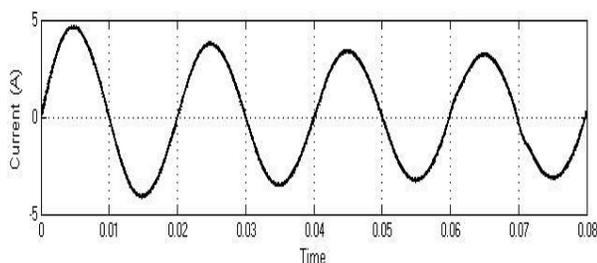


Fig. 19. Simulated Current wave form at Node 2 with $\alpha=30$ controlled R-load with APF

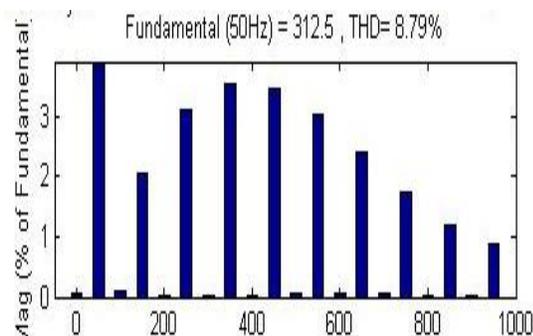


Fig. 20. Total Harmonic Distortion of Voltage at Node 2 shows 8.79% with $\alpha=30$ controlled R-load with APF

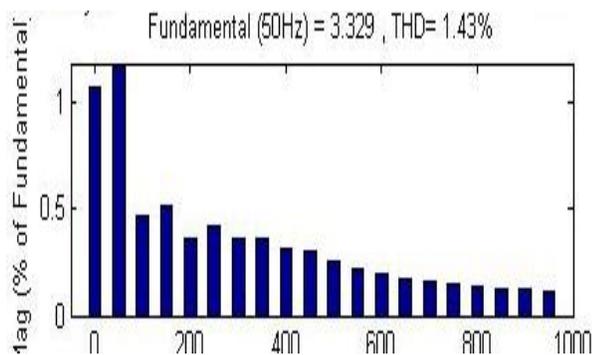


Fig. 21. Total Harmonic Distortion of Current at Node 2 shows 1.43% with $\alpha=30$ controlled R-load with APF

TABLE I

Harmonics in Voltages and Currents with Rectifier Controlled R-Load with and without APF

Harmonics in	Without APF		With APF	
	Node 1	Node 2	Node 1	Node 2
V	3.97%	12.32%	0.27%	8.97%
I	10.55%	10.55%	1.43%	1.43%

VI. CONCLUSION

In this paper it has been studied the recognition of harmonic pollution caused due to resistive based non-linear loads. The harmonic analysis has done with non linear load controlled with $\alpha=30^\circ$. The harmonic caused due these non radial loads has been efficiently recognized and calculated with Total Harmonic Power method. And finally compensated by using Active power filter. From the simulation analysis it is proved that for a certain node in the system, the sign of the fundamental power can be used as a reference, while the signs of the harmonic powers are compared to this reference sign to specify the responsibility of the load connected to this node to the harmonic pollution. The new modification was applied to several case studies and proved to be successful. Moreover, to eliminate the possible errors associated with measuring the harmonic powers due to calculating the phase shifts between harmonics.

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