A Comparative Study of Harmonic Distortion in Power System with Variety of Load before & after Compensation

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Abstract— Power quality became serious issue for the utilities and clients. Current harmonics are a standout amongst the most usually predictable Power quality issues and are typically determined by the use of shunt active filters and as per International standards concerning electrical power quality (IEEE-519, IEC 61000, EN 50160, among others) Power that electrical equipments and facilities should not introduce harmonic contents larger than specified values. In this paper the system in which shunt active power filter is adopted, this has been generally useed for elimination of harmonic. The simulation results and comparative studies shows the analysis of harmonic contents for linear and nonlinear load when operation is done with and without compensation. The design concept of the shunt active filter is verified through simulation studies and the results obtained are discussed.

Key words: Active Filter, D-Q Control Strategy, PLL, Reactive Power Compensation, MATLAB Simulation

I. INTRODUCTION

The use of Shunt Active Power Filters to improve symphonists stream and pay of reactive power for nonlinear loads has got great consideration since 1970s Fig. 1 is showing the schematic block diagram of a three stage Shunt Active PF (Power Filters), where controller and Shunt Active PF (Power Filters) facilitates the heap streams and source voltages to locate the required pay ebbs and flows for the line.

Akagi proposed the prompt reactive power (p-q) hypothesis for computing the reference remuneration streams to be infuse to the system when its connection is done with nonlinear load. From that point forward, this p-q hypothesis has utilized as a part of several reactive power pay systems utilizes active power channels, there is a section of a Shunt Active PF (Power Filters) is that, these can be master operative component without dynamic energy sources (i.e. Batteries). So these can be state that any active power fulfilled by the source does not consume by a perfect Active PF (Power Filters). It requires a feasible reference pay method for both reactive power and Harmonics current pay of the heap. Reference-outline changes theory recommended that change of source voltages and load streams from the a-b-c reference edge to the α-β (alpha-beta) reference casing to discover the ebbs and flows of APF reference.

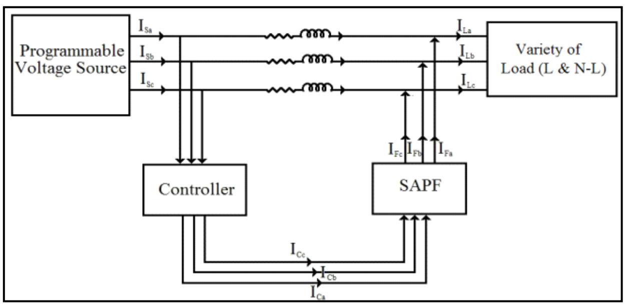

Fig. 1: Block Diagram of SAPF with variety of load

To take care of the harmonics problem due to the supplies in the system as of now introduced, Passive filters have been used as a solution, however because of little inconveniences that they channel just frequencies they were tuned already for; operation of Passive Filters can't be restricted to a specific load; resonances can turn out due to Passive Filter's connection with alternate loads, with unusual results. To overcome such an issues, late endeavors have been purposeful in the improvement of dynamic channels.

II. IMPACT OF HARMONIC

The equipments for example ovens and furnaces, which produce heat, a great part of the other electrical loads produce harmonics. The harmonics may prompt their improper procedure. Interference with the communication lines near the Power lines is because of the harmonic current travels through the transmission lines. On other way it can be said that harmonic causes interruption in sensitive loads in the power system such as medical equipments, control circuits, and PCs. A controlling system (circuit) which works on voltage or current zero crossing has superior sensitivity to the harmonics and could not appropriately, so problem is the loss in the power transmission lines. It can be given as

$$P_{Loss} = RI^2$$

Where R is AC resistance of the line and 'I' is line current's RMS value. On the off chance that the current incorporates harmonics, then

$$I_2 = I_1^2 + \sum I_H^2$$

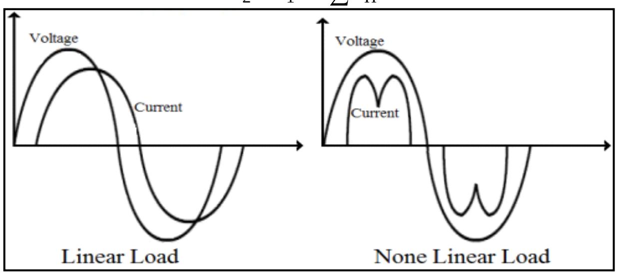

Fig. 2: Voltage and Current Behavior on Linear and none Linear Load

However active power to the loads cannot be applied by harmonic currents, they cause larger losses in the power transmission lines. Also in power transformers larger losses occurs, which is proportional to the square of the harmonic amplitude. Existence of harmonics become unnecessary losses and torque variation in electric motors, for the reason that only the fundamental component produce average torque in motors and harmonics produce core losses and torque variation. One another unavoidable problem is the existence of current harmonics in power systems that increase neutral currents. In such problems the mainly notable part of the neutral current is the third harmonic. In case of increasing neutral currents, in three phase (four-wire) systems, in addition to the increasing size of the neutral conductor, generally become a reason to overloaded feeders &

transformers, voltage distortion and also common mode noise. One more notable problem due to harmonic is the resonance in power circuits. The nonlinear loads which form Current and voltage harmonics, when go by the power system or load. This might cause a problem of resonance.

III. NEED OF HARMONIC COMPENSATION

In these modern electronic systems implementation of Active Filters has become very essential element to the power system. With technology advancement since the early eighties and significant trends of power electronic devices among consumers and industry, utilities are regularly forced in supplying a reliable and quality supply. Power electronic devices such as PCs, printers, faxes, fluorescent lights and many of other office equipment all generate harmonics. These types of equipment are usually called as ‘nonlinear loads’. Nonlinear loads introduce harmonics by drawing current in sudden short pulses quite than in a smooth sinusoidal way. The main problems linked with the supply of harmonics to nonlinear loads are strict overheating and damaging of insulation. An increased operating temperature of generators and transformers degrades the material of windings insulation.

One answer for such predictable problem is to utilize active power filters for all nonlinear loads in the power system network. Even though presently too costly, the installation of active filters proves essential for solving troubles of power quality in distribution system such as compensation of harmonic current, reactive current, voltage sag, voltage flicker and negative phase sequence current. Hence, this would confirm an arrangement with increased quality and reliability. The idea of this paper is to recognize the modeling and analysis of a Shunt Active PF. In doing so, the exactness of current compensation for current harmonics set up at a nonlinear load, for the PQ theory control strategies is supported and also verifies the reliability and effectiveness of this model for combination into a power system network.

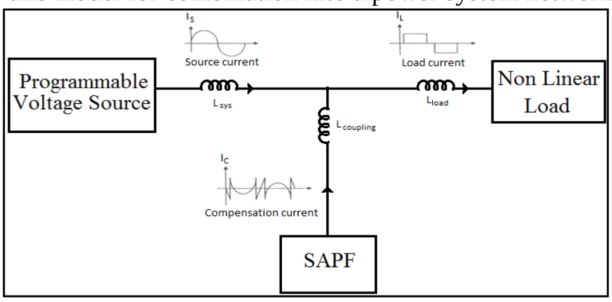

Fig. 3: single Line Diagram of SAPF Controlled Network

The model is connected across a two bus network including generation to the connection with the nonlinear load. The main aim of the system simulation is to validate the active filters effectiveness for a nonlinear load. Figure 3 shows the single line diagram of a network controlled by Shunt Active PF with a programmable voltage source in connection with linear load. The current is provided to the transmission line by SAPF is compensated current. Four waveforms of source voltage, current, load current and compensated current shown in figure 4.

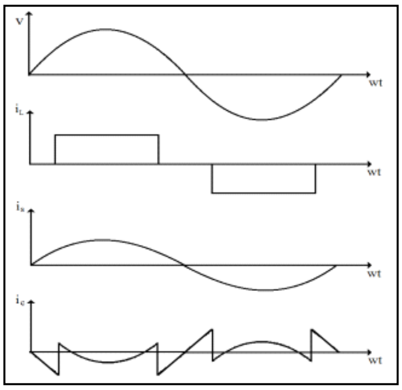

Fig. 4: Source Voltage and Current, Load and Compensation Current Waveforms

IV. SOLUTION OF POWER QUALITY PROBLEM

To reduce the power quality problems there are two approaches. First approach is known as load conditioning, which ensures that the instrument is less sensitive to power instability, permitting the process even under critical voltage distortion. Second methodology is to install conditioning systems of transmission line that compensate the power system instability or disturbances. An adaptable answer to voltage quality problems is to use APF. Presently they are support on PWM converters and join with appropriation arrangement of low and medium voltage in shunt or series. Series active power filters must work in addition with shunt passive filters keeping in mind the end goal to compensate load current harmonics. The selection of the type of active power filter to enhance power quality depends on the source of the problem as can be seen in table no. 1.

Active Filter Connection	Shunt	Series
Load on AC Supply	– Current Harmonic filtering. – Reactive current compensation. – Current unbalance. – Voltage Flicker.	– Current harmonic filtering. – Reactive current compensation. – Current unbalance. – Voltage Flicker. – Voltage unbalance
AC Supply on Load		– Voltage sag/swell. – Voltage unbalance. – Voltage distortion. – Voltage interruption. – Voltage flicker. – Voltage notching.

Table 1:

V. Types of the APF

There are generally two types of active filters: the shunt and series type. It is possible to find active filters are combination of passive filters as well as active filters of both types acting mutually.

A. *Shunt Active Power Filters*

1) It mitigates current harmonics by introducing equal but opposite harmonic compensating current.
2) It works as a current source injecting the harmonic components produced by the load but with 180deg. phase shift.

B. *Series Active Power Filters*

1) It compensates current distortion which produced by non-linear loads.
2) The high impedance imposed by the series Active PF is formed by producing a same frequency voltage that the frequency of current harmonic component that needs to be eliminated.
3) Voltage unbalance is remedied by compensating the fundamental frequency negative and zero sequence voltage components of the system.

VI. Basic Principle of the APF

In the use of a SAPF for a three-phase power system network with neutral wire, and hence it is able to compensate for current harmonics and power factor both. In addition it permits load balancing, eliminating the neutral wire current. The power stage is, basically, a VSI (voltage-source inverter) controlled in as that acts like a source of current. From the measured values of the phase voltages (V_a, V_b, V_c) and load currents (I_{la}, I_{lb}, I_{lc}), the controller estimates the reference currents (I_{ca}, I_{cb}, I_{cc}, I_{cn}) used by the SAPF to create the compensation currents (I_{fa}, I_{fb}, I_{fc}). For balanced loads (three-phase systems like motors, adjustable speed drives, controlled or non-controlled rectifiers, etc) and current in neutral wire no need to compensate. These permit to design a simpler inverter (with only three legs) and only 4 current sensors. The method of a series active filter for a three phase power system network. These are the twin of the shunt active filter, and are capable to compensate for distortion in the voltages of power line, making the sinusoidal voltages wave applied to the load (voltage harmonics compensation).

VII. The Proposed Method

The p-q theory:- In 1983, *Akagi et al.* have proposed the "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also called p-q theory. This theory is based in instantaneous values in three-phase power systems network with or without neutral wire, and is applicable for transitory or steady-state operations, as well as for waveforms of common voltage and current. This theory consists of an algebraic transformation known as Clarke transformation of the three-phase voltages and currents that transforms the *a-b-c* coordinates to the α-β-*0* coordinates. Figure 6(a) and 6(b) shows the Block Diagram and representation of p-q theory respectively. The calculation of the p-q theory instantaneous power components are:

$$p_0 = v_0 \cdot i_0 = \text{instantaneous zero - sequence power} \quad (1)$$

$$p = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta = \text{instantaneous real power} \quad (2)$$

$$q = v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha = \text{instantaneous imaginary power (definition)} \quad (3)$$

Power components *p* and *q* are related to the same α-β voltages and currents, and can be together written as:

Physical meaning of the quantities of an electrical power system represented in α-β-*0* coordinates, are:

= average numerical quantity of the instantaneous zero-sequence power (energy per unit time) transferred from the supply system to the load by the zero-sequence components of voltage and current.

= alternated numerical quantity of the instantaneous zero-sequence power (energy per unit time) exchanged between the supply system and the load by the zero-sequence components. Exist-stance of the zero-sequence power is only in three-phase systems with the neutral wire. Moreover, the systems necessary have unbalanced currents and voltages, or multiple of 3 harmonics in the current and voltage both (at least one phase).

= average numerical quantity of the instantaneous real power (energy per unit time) transferred from the supply system to the load.

= alternated numerical quantity of the instantaneous real power (energy per unit time) exchanged between the supply system to the load.

q = instantaneous imaginary power that corresponds to the power which is exchanged between the load phases. It does not show by this component that any exchange or transference of energy between the supply system and the load, but for the existence of unwanted currents it is responsible, that current circulate between the phases of the system.

The balanced system of sinusoidal voltage and a balanced load, with/without harmonics, instantaneous imaginary power (*q)* is equal to the conventional reactive power

$$\bar{q} = 3.V.I_1 .sin\varphi_1$$

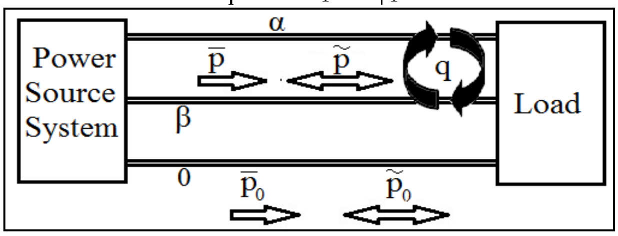

Fig. 5: Components of p-q theory in α-β-0 coordinates

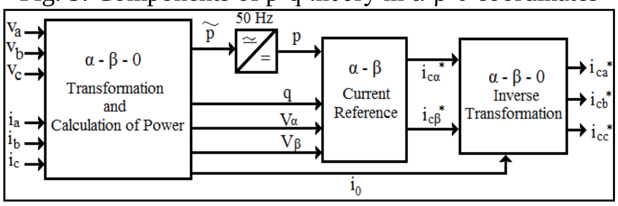

Fig. 6: p-q theory representation

A. *Application of p-q Theory on SAPF*

The all power components acquired by the p-q theory, only - and are desired, as this corresponds to the energy transferred from the supply system to the load. The other quantities can be compensated using a SAPF. Compensation done whenever required of, which is related with the load unbalancing. A way to compensate, without using any power supply in active filter, this is presented by *Watanabe et al*. They displayed that the numerical quantity of is possible to deliver from the power source system to the active filter by the coordinate's α-β, and then the active filter can provide this power to the load by the *0* coordinate. This shows that the energy transferred from the Power source to the load by the zero-sequence components of current and voltage, is now delivered from the phases of source by the active filter, in a balanced way.

The active filter capacitor is required only to compensate and, these quantities stored in this component at small time duration to be delivered to the load later. The instantaneous imaginary power (q) can be compensated with no capacitor.

The unwanted power components ( ) are compensated and the supply currents are also sinusoidal, balanced, and in phase with the voltages of a three-phase system with the balanced sinusoidal voltages. It can be understand that the power supply "sees" the load as a symmetrical load which is purely resistive.

Since compensation of all the instantaneous zero-sequence power is done, *0* coordinate has its reference compensation current i_0

$$i_{c0}^* = i_0$$

The reference compensation currents can be calculated in the α-β coordinates, the expression (3) is inverted and the powers to be compensated (px and qx) are used-

$$p_x = -\Delta^{-} \quad \Delta = q_x = q = \bar{q} + \tilde{q} \tag{4}$$

To get the reference compensation currents in the coordinates *a- b- c* the inverse of the transformation given in the expression (1) is applied-

$$i_{cn}^* = -(i_{ca}^* + i_{cb}^* + i_{cc}^*) \tag{5}$$

VIII. SIMULATION RESULTS

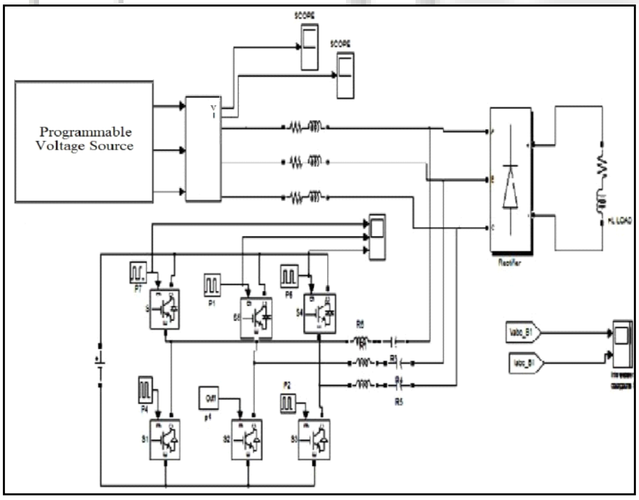

Fig. 8 (a): MATLAB based model of SAPF

Figure 8(a) shows the MATLAB based model of Shunt Active Power Filter system with the nonlinear Load.

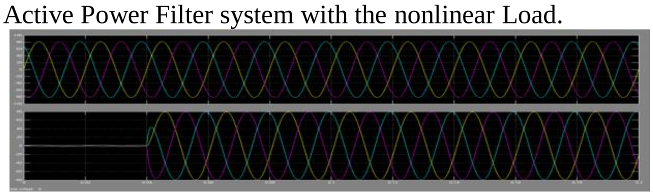

Fig. 8 (b): Source voltage (Vs) and Source current (Is) waveform, when Load is N-L

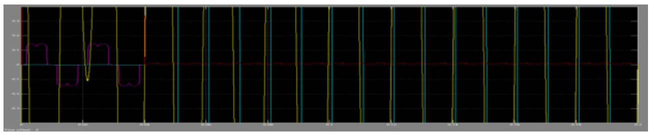

Fig. 8 (c): Load current (I_L) waveform (In-large), when Load is N-L

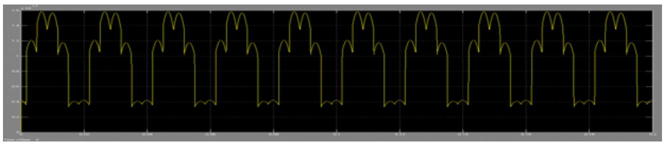

Fig. 8 (d): Load current (I_L) waveform, when Load is N-L

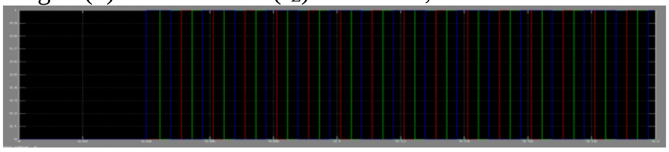

Fig. 8 (e): Gate Pulse (Ig) waveform, when Load is N-L

Figure 8(b), 8(c), 8(d), 8(e) shows Source voltage and Source current waveform, Load current waveform (In-large), Load current and Load voltage waveform and, Gate Pulse waveform respectively. Figure 9(a), 9(b), 9(c), 9(d), 9(e), 9(f) shows Compensating current harmonics spectrum, Load current harmonics spectrum, Source current harmonics spectrum, Source voltage harmonics spectrum, PID waveform and Load voltage waveform respectively.

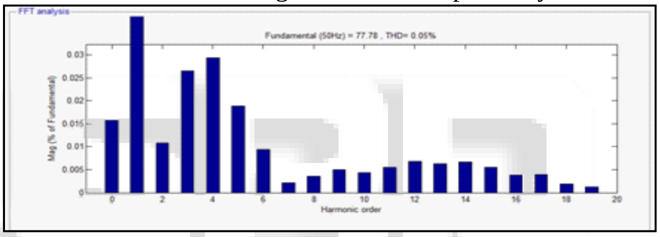

Fig. 9(a): Harmonics spectrum of Compensating current (Ic)

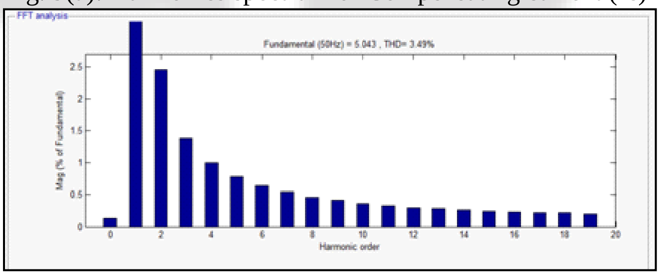

Fig. 9(b): Harmonics spectrum of Load current (I_L)

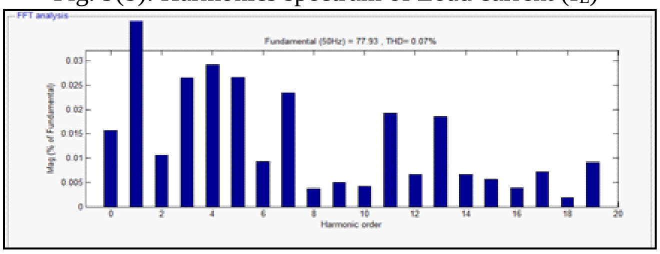

Fig. 9(c): Harmonics spectrum of Source current (Is)

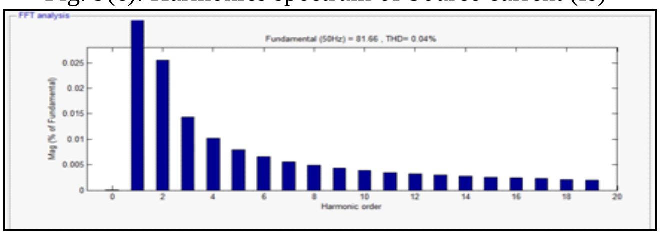

Fig. 9(d): Harmonics spectrum of Source voltage (Vs)

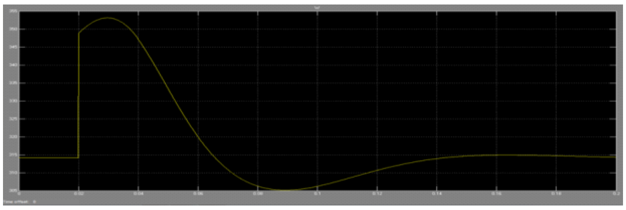

Fig. 9(e): PID waveform

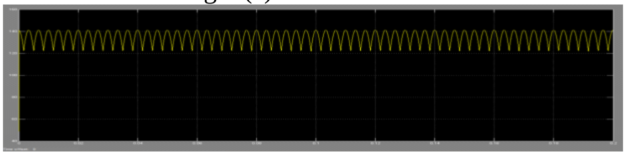

Fig. 9(f): Load voltage (V_L) waveform

The parameters required of the system are given in PARAMETER. According to uncompensated line harmonics of Source current (I_s) and load current (I_l) are given in table no. 2. According to rules of IEEE, harmonics should be less than 5%. In this paper linear load and nonlinear load THD of Source current (I_s) and load current (I_l) is also given in table no. 2.

THD %	Types of Load	
	Linear Load	Non Linear Load
Without Compensation	0.41	25.74
With Compensation	0.10	3.49

Table 2:

IX. Conclusion

This paper presents a comparative study for the compensated and uncompensated system for variable Load; shunt active power filter is a solid and viable answer for power quality problems. The active filter controller is based on the p-q strategy, which proved to be a powerful tool, Shunt active filters allow the compensation of current harmonics and unbalance, in combination with power factor correction, the comparative analysis of both the systems (uncompensated and compensation by SAPF) is shown in table no. 2. Harmonics content minimized the THD 25.74 % to 3.49 % of load current of nonlinear load.

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