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Power Quality Improvement of Non-Linear Load by Using Instantaneous P-Q Theory

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Abstract: **The "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", proposed by Akagi and also known as the p-q theory, is an interesting tool to apply to the control of active power filters to analyze three-phase power systems in order to detect problems related to harmonics, reactive power and unbalance of the load. Due to the intensive use of power converters and other non-linear loads in industry and by consumers in general, it can be observed an increasing deterioration of the power systems voltage and current waveforms. To overcome all these problems and to improve power quality, Akagi was introduced p-q theory in 1983.In which, the unwanted reactive power is generated which causes bad effects in power systems are reduced by using shunt active power filter compensation technique. In this technique by using compensator, we are injecting the reactive power which opposes the unwanted reactive power. The quantity of reactive power is determined by using p-q theory.**

Keywords: **Power quality, Harmonics, PI controller, Active Filter, Non-Linear Load, IGBT, Diode, Instantaneous power Theory.**

I. INTRODUCTION

Harmonic current pollution of three-phase electrical power systems is becoming a serious problem due to the wide use of nonlinear loads, such as diode or thyristor rectifiers and a vast variety of power electronics based appliances. Traditionally, passive LC filters have been used to eliminate the current harmonics and to improve the power factor. However, passive LC filters are bulky, load dependent and inflexible. They can also cause resonance problems to the system. In order to solve these problems, APFs have been reported and considered as a possible solution for reducing current harmonics and improving the power factor. shows the basic compensation principle of the three phase shunt APF. It is designed to be connected in parallel with the nonlinear load to detect its harmonic and reactive current and to inject into the system a compensating current. In the conventional p-q theory based control approach for the shunt APF, the compensation current references are generated based on the measurement of load currents. However, the current feedback from the SAPF output is also required and therefore, minimum six CSs are desired in a unbalanced system. In addition, the reference current calculation algorithm are simplified and easily implemented in the experimental prototype. In the reduced current measurement control algorithm, sensing only three-phase voltages, three source currents and a DC-link voltage is adequate to compute reference currents of the three phase SAPF. In this way, the overall system design becomes easier to accomplish and the total implementation cost is reduced switching **devices**: Gate Turn-Off Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT). Each type has its.

II. ACTIVE FILTERS

There are basically two types of active filters: the shunt type and the series type. It is possible to find active filters combined with passive filters as well as active filters of both types acting together. The electrical scheme of a shunt active filter for a three-phase power system with neutral wire, which is able to compensate for both current harmonics and power factor. Furthermore, it allows load balancing, eliminating the current in the neutral wire. The power stage is, basically, a voltage-source inverter with only a single capacitor in the DC side (the active filter does not require any internal power supply), controlled in a way that it acts like a current-source. From the measured values of the phase voltages (*va*, *vb*, *vc*) and load currents (*ia*, *ib*, *ic*), the controller calculates the reference currents (*ica**, *icb**, *icc**, *icn**) used by the inverter to produce the compensation currents (*ica*, *icb*, *icc*, *icn*). This solution requires 6 current sensors and 4 voltage sensors, and the inverter has 4 legs (8 power semiconductor switches). For balanced loads without 3rd order current harmonics (three-phase motors, threephase adjustable speed drives, three-phase controlled or non-controlled rectifiers, etc) there is no need to compensate for the current in neutral wire. These allow the use of a simpler inverter (with only three legs) and only 4 current sensors. It also eases the controller calculations. It is the dual of the shunt active filter, and is able to compensate for distortion in the power line voltages, making the voltages applied to the load sinusoidal (compensating for voltage harmonics). The filter consists of a voltage-source inverter (behaving as a controlled voltage source) and requires 3 single-phase transformers to interface with the power system. The series active filter does not compensate for load current harmonics but it acts as high-impedance to the current harmonics coming from the power source side. Therefore, it guarantees that passive filters eventually placed at the load input will not drain harmonic currents from the rest of the power system. Another solution to solve the load current harmonics is to use a shunt active filter together with the series active filter (Fig. 3), so that both load voltages and the supplied currents are guaranteed to have sinusoidal waveforms. Shunt active filters are already commercially available, while the series and series-shunt types are yet at prototype level.

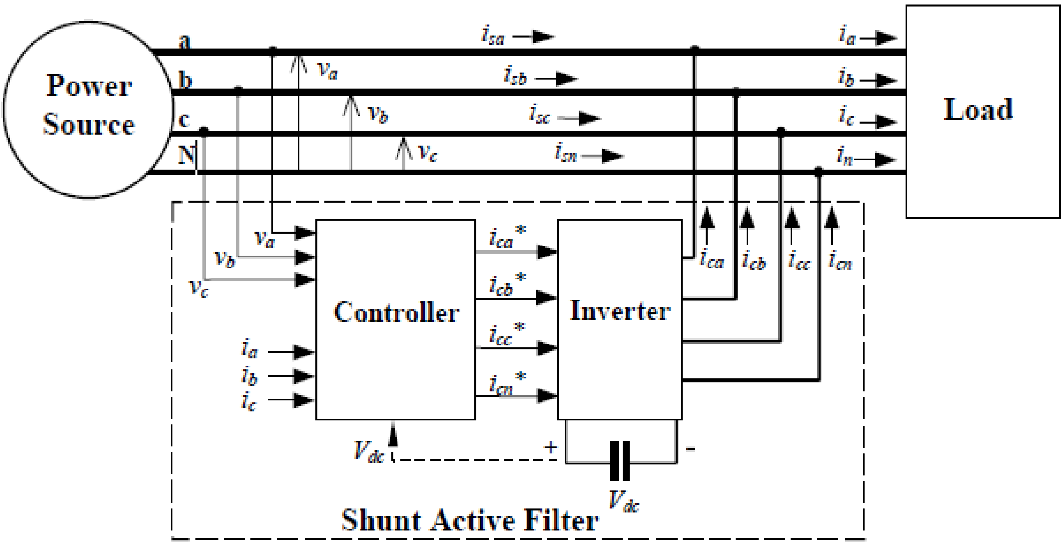


Fig. 1 - Shunt active filter in a three-phase power system.

III. SHUNT ACTIVE FILTER WITH CONTROLLER BASED ON INSTANTANEOUS P-Q THEORY

The concept of Shunt Active Filtering was first introduced by Gyugyi and Strycula in 1976 [6]. Nowadays, a Shunt Active Filter is not a dream but a reality, and many SAFs are in commercial operation all over the world. The controllers of the Active Filters determine in real time the compensating current reference, and force the power converter to synthesize it accurately. In this way, the Active Filtering can be selective and adaptive. In other words, a Shunt Active Filter can compensate only for the harmonic current of a selected nonlinear load, and can continuously track changes in its harmonic content. The Instantaneous active and reactive power theory or simply the *p-q* theory is based on a set of instantaneous values of active and reactive powers defined in the time domain. There are no restrictions on the voltage or current waveforms, and it can be applied to three-phase systems with or without a neutral wire for three-phase generic voltage and current waveforms. Thus, it is valid not only in the steady state, but also in the transient state [16]. This theory is very efficient and flexible in designing controllers for power conditioners based on power electronics devices. Other traditional concepts of power are characterized by treating a three-phase system as three single-phase circuits. The *p-q* Theory first uses Clarke transformation to transforms voltages and currents from the *abc to αβ0* coordinates, and then defines instantaneous power on these coordinates. Hence, this theory always considers the three-phase system as a unit, not a superposition or sum of three single-phase circuits.

A. THE CLARKE TRANSFORMATION

The *αβ0* transformation or the Clarke transformation converts the three-phase instantaneous voltages in the *abc* phases, va, *vb and vc* into the instantaneous voltages on the αβ0 axes *v0, vα, and vβ.* The Clarke Transformation of three-phase generic voltages is given by:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{3.1}$$

and its inverse transformation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} \tag{3.2}$$

Similarly, three-phase generic instantaneous line currents, *ia*, *ib*, and *ic*, can be transformed on the αβ0 axes by:

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3.3}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3.4}$$

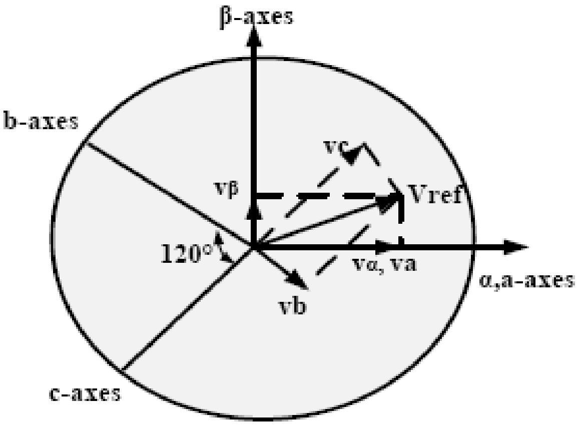
and its inverse transformation:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{3.5}$$

The advantage of using the *αβ0* transformation is to separate zero-sequence components from the *abc*-phase component since *α and β* axes make no contribution to zero-sequence components.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{3.6}$$

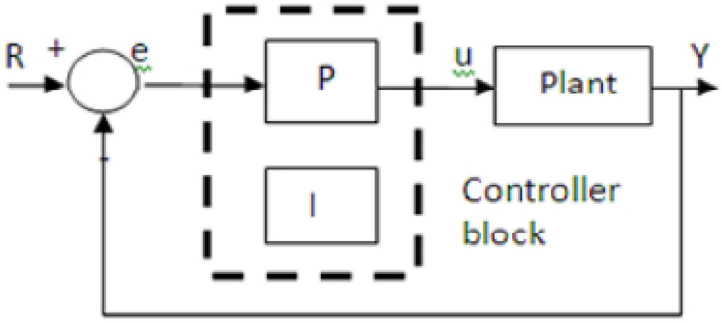
Similar equations hold for the line currents. The transformation of equation (3.5) & (3.6) can also be shown in Figure 3.4.The instantaneous values of phase voltages and line currents referred to the *abc* stationary axes are transformed into the αβ0 stationary axes, or vice-versa. They are stationary axes and should not be confused with the concepts of voltage or current phasors. The, *b*, and *c* axes are spatially shifted by 120° from each other while the α and β axes are orthogonal, and the α axis is parallel to the *a* axis. The direction of the β axis is chosen in such a way that if voltage or current spatial vectors on the *abc* coordinates rotate in the *abc* sequence, they would rotate in the *αβ* sequence on the *αβ* coordinates.



Graphical Representation of Clarke Transformation

Proportional- Integral (PI) Control:

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. The PID controller block is reduced to P and I blocks only as shown in figure.



Proportional Integral (PI) Controller block diagram

The proportional and integral terms is given by:

$$u(t) = K_p e(t) + K_i \int e(t)dt$$

K_p and K_I are the tuning knobs, are adjusted to obtain the desired output. The following speed control example [3] is used to demonstrate the effect of increase/decrease the gain , K_P and K_I . A DC motor dynamics equations are represented with second order transfer function,

$$G(s) = \frac{\dot{\theta}}{V} = \frac{K_t}{(Js+b)(Ls+R)-K_e K_t}$$

Where,

$K_p = Ki$= electromotive force constant = 0.01Nm/Amp

b = damping ratio of the mechanical system = 0.1Nms

J = moment of inertia of the rotor = 0.02kgm2s2

R = electric resistance =1ohm

L = electric inductance = 0.5H

After we include the PI controller, the closed-loop transfer function become:

$$Gp(s) = \frac{Y}{R} = \frac{K_t K_p}{(Js+b)(Ls+R) - K_e K_t - K_t K_p}$$

Figure shows the effects of closed-loop response as we vary the integral gain Ki. The response yields that as k_i increasing, the response reaches the steady state faster with steady state error approaching to zero. Figure 3 shows the comparison of proportional controller and PI controller.

The result obviously shows with PI controller, we are able to eliminate the steady state error. In summary with small value of Ki (Ki = 0.01) , we have smaller percentage of overshoot (about 13.5%) and larger steady state error (about 0.1). As we increase the gain of Ki, we have larger percentage of overshoot (about 38%) and manage to obtain zero steady error and faster response. With the response depicted in figure 2 and 3, P-I-D controller can be introduced in order to reduce the overshoot and to ensure the response converge to the specified design objectives.

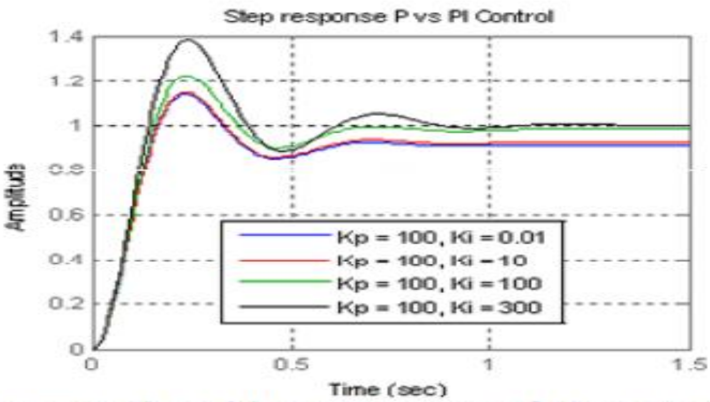


Figure 2: Closed-loop response of PI controller

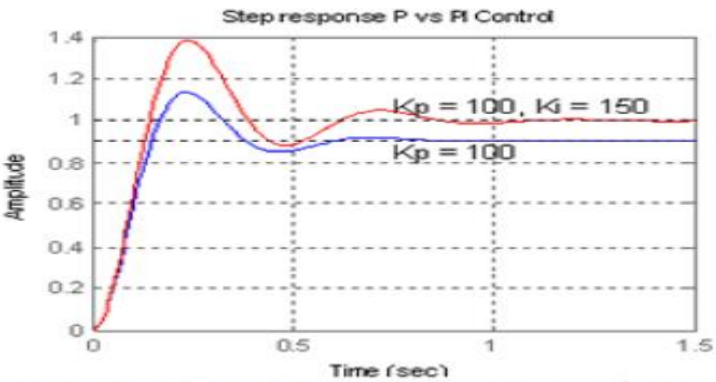


Figure 3: Closed-loop response of P vs PI controller

SYSTEM PARAMETERS AND VALUES:

S.no	Parameters	Values used
1.	Main supply voltage per phase	230v
2	Supply Frequency	50Hz
3	Source impedance	Ls=0.005 mH Rs=0.001 Ω
4	Injection transformer turns ratio	1:1
5	PI controller	K_p =0.1, K_i=1,sample time=50 µs
6	Fault Resistance	0.001 Ω
7	Main Drive Load	500W,15VAR
8	Sensitive Load	1KW,10VAR
9	Inverter	IGBT based 3 arms , 6 pulse,Carrier Frequency=20000 Hz, Sample time= 5 µs
10	Filter circuit	l_f=21mh, c_f=45µf

MATLAB MODELING CIRCUIT:

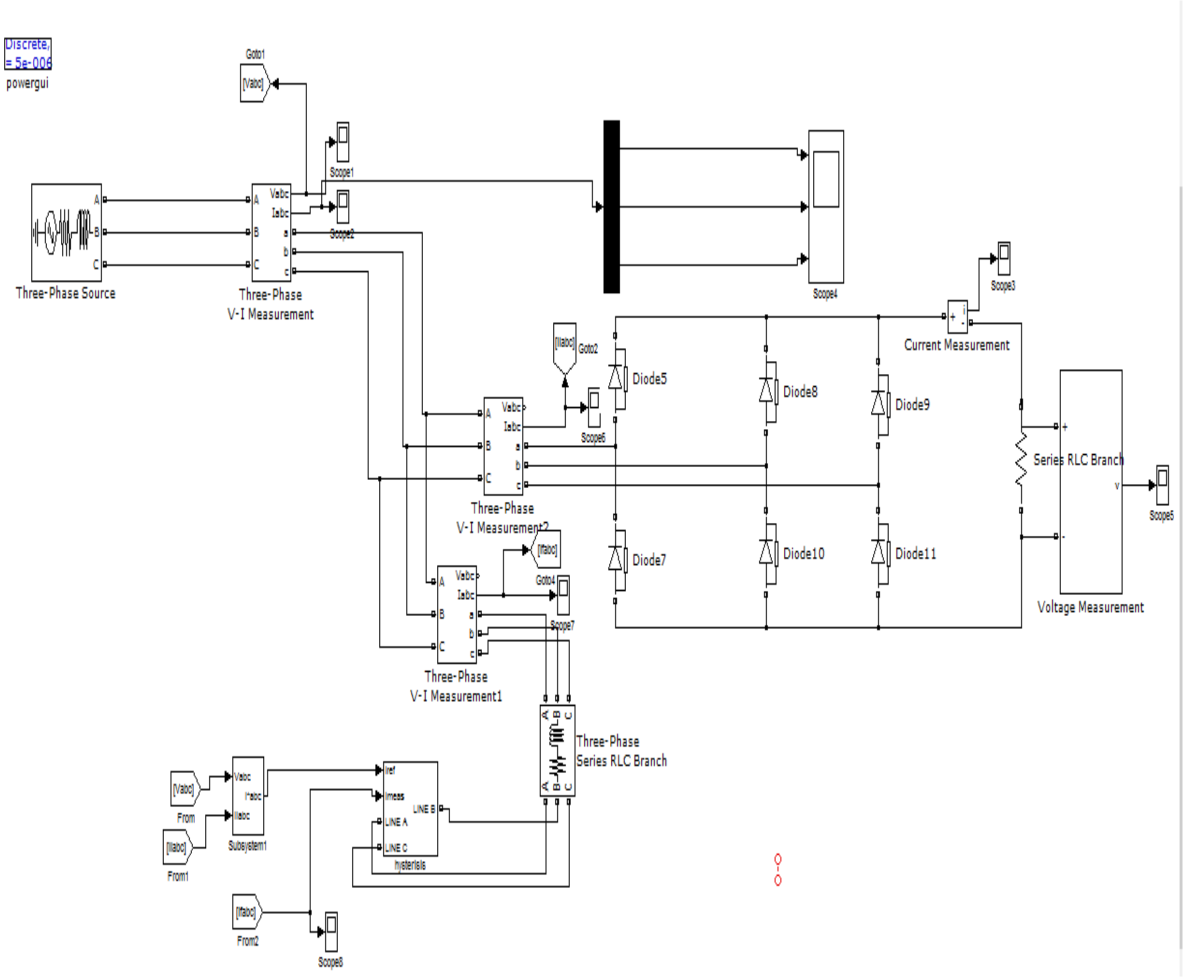


Figure 4: MATLAB SIMULINK Modeling of the PQ Theory

The *p-q* theory model is modelled and is shown in the Figure. The inputs to the *p-q* controller are the currents form the non-linear load. The outputs are the three phase reference currents that are send to the hysteresis current controller where these currents are compared with the actual currents of the active filter to get the driving pulses of the inverter.

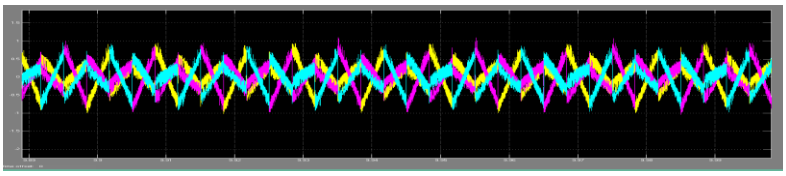


Fig.5: Source Current without SAF

Shows source current without shunt active filter. Due to the presence of the non linear load, so the current waveform is in distorted manner. The current is taken along the Y-axis and time is taken along the X-axis.

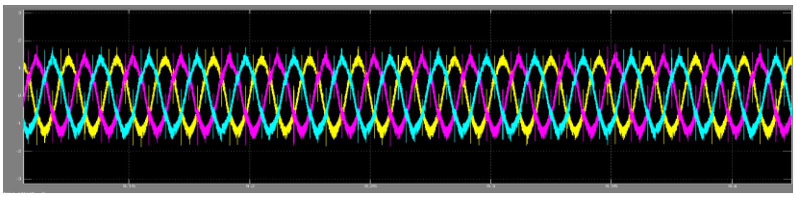
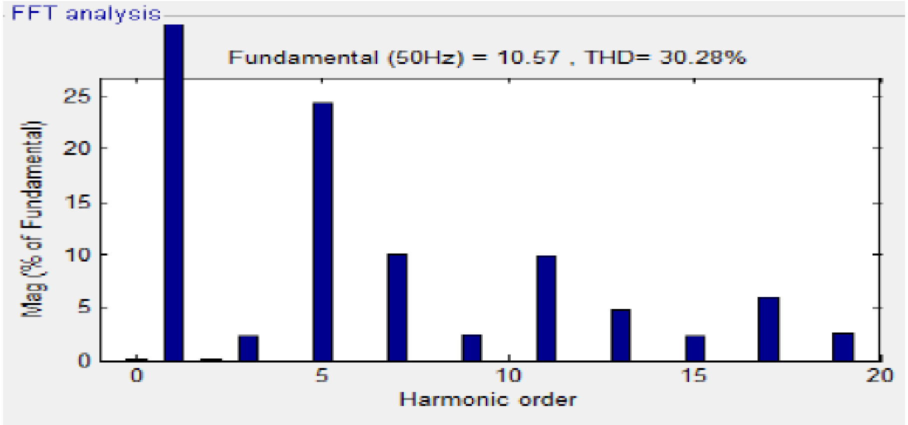


Fig.6: Source current with SAF

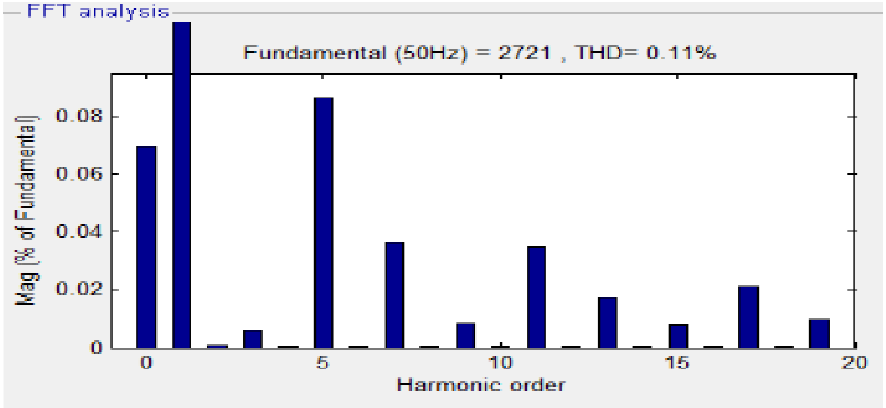
The sinusoidal waveform of the source current due to the implementation of the shunt active filter. The harmonic which gets induced due to the presence of the non linear load gets reduced and forming the nearby sinusoidal current.

Total Harmonic Distortion (THD) Analysis:



THD in source current before SAF

The THD analysis of source current without SAF.THD is found to be 30.28% respectively due to nonlinear load which creates harmonics in the three phase system the IEEE standard THD value should be less than 2%. In order to reduce the THD the proposed system is implemented



THD in source current after SAF

The THD analysis of source current with SAF.THD is found to be 0.11% respectively.

COMPARISON OF THD IN SOURCE CURRENT:

THD IN SOURCE CURRENT BEFORE SHUNT ACTIVE FILTER	THD IN SOURCE CURRENT AFTER SHUNT ACTIVE FILTER
30.28%	0.11%

IV. CONCLUSION

This paper has presented the power quality problems such as distortions and harmonics. The design and applications of Shunt Active Power Filter for harmonics and comprehensive results were presented. A PI control scheme was implemented in this proposed Shunt Active power Filter. The performance of the proposed topologies and an improvement of suggested controller can be observed through simulation and experimental results. The THD and the amount of unbalances in load voltage are decreased with this application of PQ Theory. The proposed system performs better than the traditional methods in mitigating harmonics and Distortions.

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