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REDUCTION OF CURRENT HARMONICS USING ACTIVE POWER FILTERS BY INSTANTANEOUS REACTIVE POWER THEORY

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Abstract: Most of the pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger because sensitive equipment will be more sensitive for market competition reasons, equipment will continue polluting the system more and more due to cost increase caused by the built-in compensation and sometimes for the lack of enforced regulations. Instantaneous reactive power theory (IRP theory) is proposed for calculating the reference compensating currents required to inject into the network at PCC. Switching scheme of compensator is provided by comparing the reference compensating currents obtained from IRP theory and compensator currents. Thus, IRP theory is used to identify the amount of compensating current injected into the network to compensate the reactive power required by non-linear loads and to bring the source current waveform as sinusoidal. Simulations for a three-phase three-wire system with a shunt active power filter have been carried out for current harmonic reduction. Thus, power quality has been improved. The systems are modelled by using MATLAB/SIMULINK and performance is observed. The simulation results reveal that the proposed method of IRPT is a good solution for improving power quality and for the compensation of reactive power.

Keywords: Active Power Filter (APF), instantaneous p-q theory, adaptive hysteresis band current controller.

I. INTRODUCTION

In 1983 Akagi et al. [1, 2] proposed a new theory for the control of active filters in three-phase power systems called “Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as “Theory of Instantaneous Real Power and Imaginary Power”, or “Theory of Instantaneous Active Power and Reactive Power”, or “Theory of Instantaneous Power”, or simply as “p-q Theory”.

The theory was initially developed for three-phase three-wire systems, with a brief mention to systems with neutral wire. Later, Watanabe et al. [3] and Aredes et al. [4] extended it to three-phase four-wire systems (systems with phases a, b, c and neutral wire). Since the p-q theory is based on the time domain, it is valid both for steady-state and transient operation, as well as for generic voltage and current waveforms, allowing the control of the active filters in real- time. Another advantage of this theory is the simplicity of its calculations, since only algebraic operations are required[5,6]. The only exception is in the separation of some power components in their mean and alternating values. However**,**as it will be shown in this paper, it I possible to exploit the reactive power and zero-sequence compensation do not introduce any delay.

Furthermore, it is possible to associate physical meaning to the p-q theory power components[7,8], which eases the understanding of the operation of any three-phase power system[9,10], balanced or unbalanced, with or without harmonics.

II. THREE-WIRE SAPFS

Solid-state power converters have been widely used in three-phase three-wire nonlinear loads such as ASDs and lately many other electrical loads have incorporated active power filters in their front design. A large number of publications have appeared on three-wire APFs with different configurations. SAPFs are also designed with three single phase APFs with isolation transformers for proper voltage matching, independent phase control, and reliable compensation with unbalanced systems.

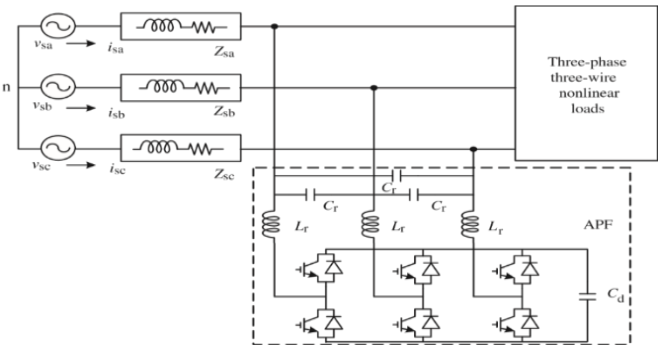


Fig.1 A three-wire SAPF with a voltage source converter

III. PRINCIPLE OF OPERATION OF SHUNT ACTIVE POWER FILTERS

The main objective of shunt active power filters is to mitigate multiple power quality problems in a distribution system. SAPF mitigates most of the current quality problems, such as reactive power, unbalanced currents, neutral current, harmonics, and fluctuations, present in the consumer loads or otherwise in the system and provides sinusoidal balanced currents in the supply along with its DC bus voltage control.

In general, a SAPF has a VSC connected to a DC bus and its AC side is connected in shunt normally across the consumer loads or across the PCC, as shown in Figure 9.9.

The VSC uses PWM current control; therefore, it requires small ripple filters to mitigate switching ripples. It requires Hall effect voltage and current sensors for feedback signals and normallya digital signal processor (DSP) is used to implement the required control algorithm to generate gating signals for the solid-state devices of the VSC of the SAPF. The VSC used as SAPF is normally controlled in PWM current control mode to inject appropriate currents into the system. The SAPF also needs many passive elements such as a DC bus capacitor, AC interacting inductors, and small passive filters.

IV. CONTROL OF SHUNT ACTIVE POWER FILTERS

Reference current signals for the control of SAPF have to be derived accordingly and these signals may be estimated using a number of control algorithms. There are many control algorithms reported in the literature for the control of SAPFs, which are classified as time-domain and frequency-domain control algorithms. There are more than a dozen of time-domain control algorithms that are used for the control of SAPFs.

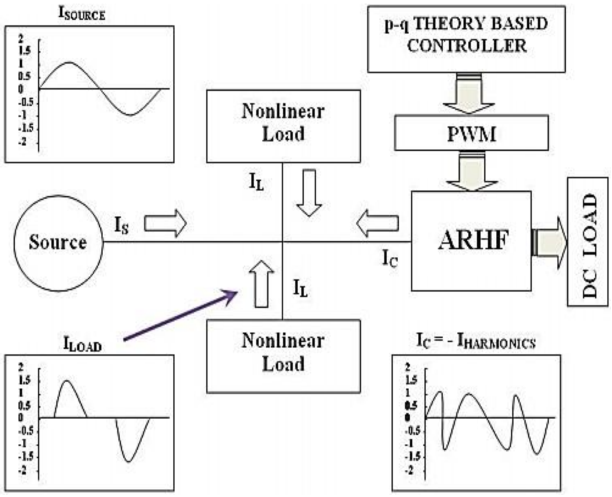
Most of these frequency-domain control algorithms are used for power quality monitoring for a number of purposes in the power analyzers, PQ instruments, and so on. Some of them have been used for the control of SAPFs. However, these algorithms are sluggish and slow, requiring heavy computation burden; therefore, these control methods are not much preferred for real-time control of SAPFs compared with time-domain control algorithms.

All these control algorithms may be used in the control of SAPFs. However, because of space limitation and to give just a basic understanding, only SRF theory also known as d–q theory, unit template technique or PI controller-based theory, and IRPT also known as PQ theory or α–β theory are explained

V. IRPT-BASED CONTROL ALGORITHM OF APFS

It is also known as pq theory or $\alpha\beta$ theory. The control algorithm of the APF using IRPT is shown in Figure.6.11 Three-phase load currents and the PCC voltages are sensed and used to calculate the active and reactive powers due to harmoniccomponents.

Three-phaseload (PCC) voltages are sensed and processed through BPFbefore their transformation to eliminate the ripple contents and are denoted as (vsa;vsb;vsc). A first-order Butterworth filter is used as a BPF.



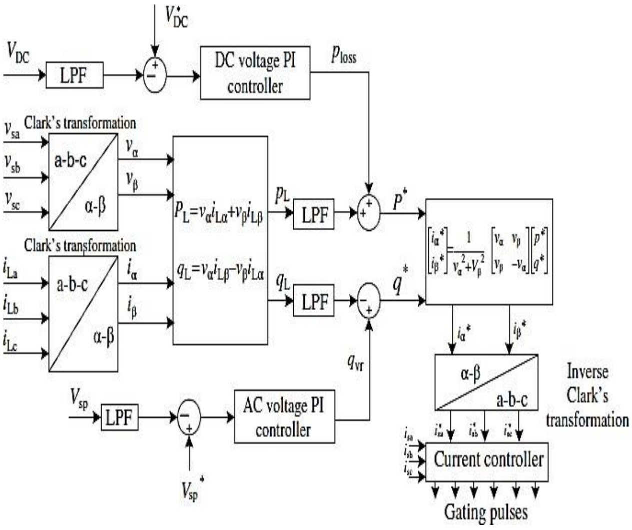


Fig.2 Control algorithm of APF using instantaneous reactive power theory

These three-phase filtered load voltages are transformed into two-phase α–β orthogonal coordinates (v_α, v_β) as

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}}\begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix}$$

Similarly, the three-phase load currents (i_{La};i_{Lb};i_{Lc}) are transformed into two-phase α–β orthogonal coordinates ($i_{L\alpha}$, $i_{L\beta}$) as

$$\begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix} = \sqrt{\frac{2}{3}}\begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{pmatrix}$$

From these two expressions, the instantaneous active power p_L and the instantaneous reactive power q_L flowing into the load side are computed as

$$\begin{pmatrix} p_L \\ q_L \end{pmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{pmatrix}\begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix}$$

Let $p_L$and $\tilde{P}_L$ are the DC component and the harmonic component of p_L, respectively, and $q_L$and $\tilde{q}_L$ are the DC component and the harmonic component of q_L, respectively, Therefore, these may be expressed as

$P_L=\overline{P}L+\tilde{P}L,$
$q_L=\overline{q}L+\tilde{q}L.$

In these expressions, the fundamental component of the load power is transformed to DC components pL and qL, and the harmonics are transformed to AC components $\tilde{p}$L and $\tilde{q}$L. Now, the AC components of active and reactive powers are extracted by using two low-pass filters and the reference three-phase supply currents i* sa; i* sb; i* scare obtained as

$$\begin{pmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1} \begin{pmatrix} p^* \\ q^* \end{pmatrix}$$

where ploss and qvrare, respectively, the instantaneous active power necessary to adjust the voltage of the DC capacitor to its reference value and the instantaneous reactive power necessary to adjust the voltage of the AC bus to its reference value (it may be achieved using a PI controller similar to above algorithms), and $\tilde{p}$Land $\tilde{q}$L are the extracted load fundamental active and reactive power components.

Hysteresis Current Controller:

Hysteresis current control method is used to provide the accurate gating pulse and sequence to the IGBT inverter by comparing the current error signal with the given hysteresis band.

As seen in figure the error signal is fed to the hysteresis band comparator where it is compared with hysteresis band, the output signal of the comparator is then passed through the active power filter to generate the desired compensating current that follow the reference current waveform.

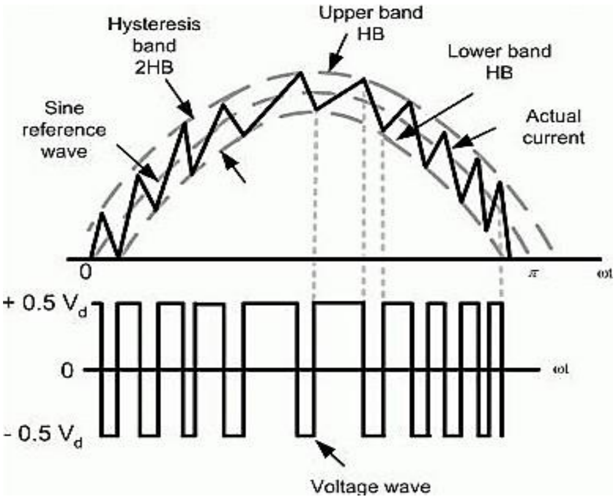


Fig.3 Principle of the hysteresis modulation

- There are two limits on the hysteresis band i.e. upper and lower band and current waveform is trapped between those two bands as seen from figure.3
- When the current tends to exceed the upper band the upper switch of the inverter is turned off and lower switch is turned so that the current again tracks back to the hysteresis band.
- Similar mechanism is taking place when current tends to cross the lower band.
- Thus current lie within the hysteresis band and compensating current follow the reference current. By the above mechanism, the reference waveform and the distorted waveforms produce the gate trigger pulse.

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VI. SIMULINK DIAGRAM WITH SHUNT ACTIVE FILTER BY IRPT METHOD OF DETECTING HARMONICS

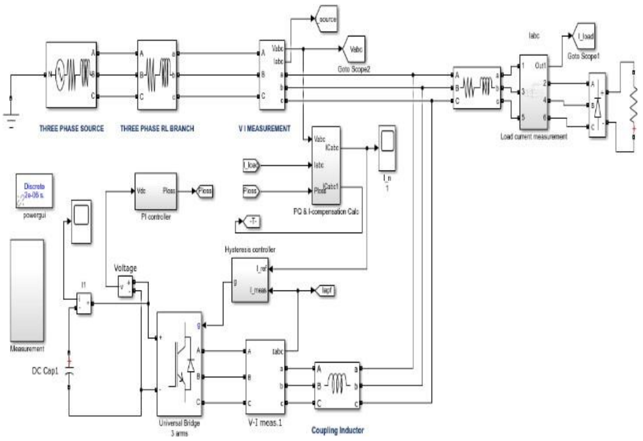

Fig.4 Simulink model circuit for Shunt Active Power Filter using IRPT method of detection of harmonics in the system

Table.1 Parameters of the three phase three wire non linear load with filter

Source Voltage	440 V_{rms}
Frequency	50Hz
Source resistance	$1*10^{-6}$ Ω
Source inductance	$1*10^{-8}$H
Load resistance	10 Ω
Coupling inductance	0.2 MH

With filter –Result Waveforms in Scope

On X – axis, Time in seconds. On Y – axis,

a. SourceVoltage.

b. SourceCurrent.

c. Load Current.

d. Compensatingcurrent.

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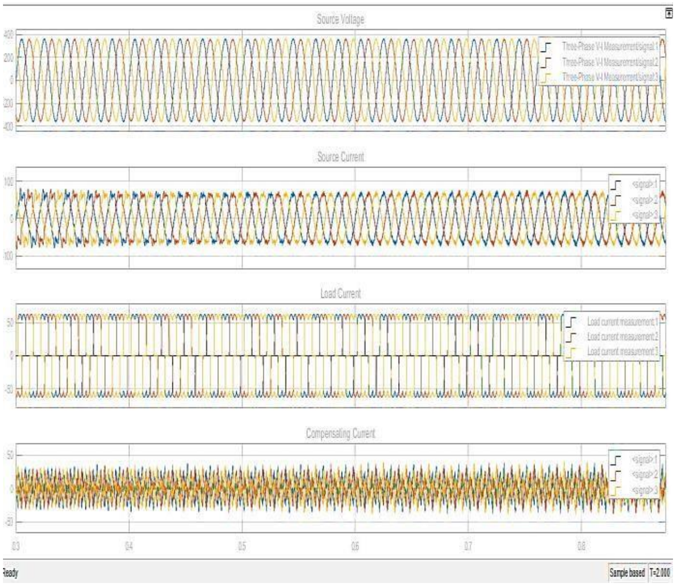
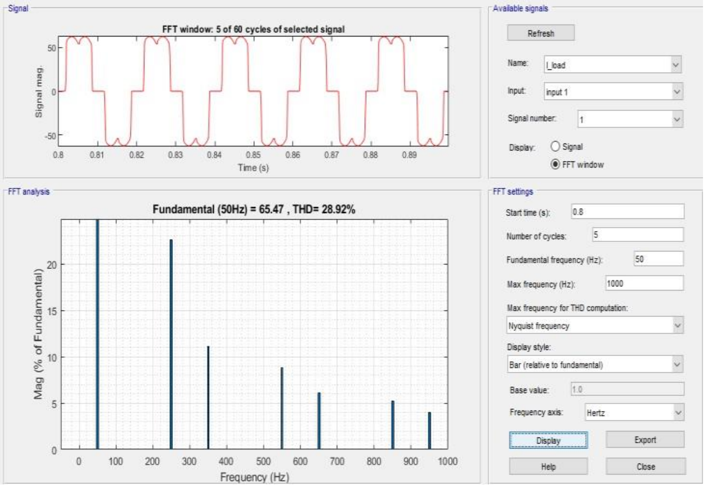


With shunt active filter by IRPT method of detection – load current:

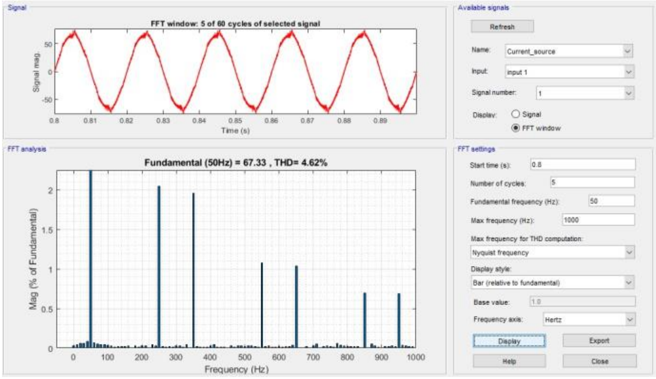


Name: I_load
Input: input 1
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.8
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig.5 FFT analysis of load current with filter

The nonlinear load current with harmonics THD =28.92%

With shunt active filter by IRPT method of detection – Source Current:



Name: Current_source
Input: input 1
Signal number: 1
Display: ○ Signal ● FFT window
Start time (s): 0.8
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig.6 FFT analysis of source current with filter

The non-linear system with shunt active filter–source current THD =4.62%

VII. CONCLUSION

Proposed IRP theory is used to identify the amount of compensating current injected into the network to compensate the reactive power required by non-linear loads and to bring the source current waveform as sinusoidal. A shunt active power filter has been investigated for power quality improvement. The MATLAB simulation results shown that the harmonic currents drawn by non-linear load are compensated and source currents are appeared as sinusoidal.Also power factor is improved by reactive power compensation, so that source voltage and source current are in phase. The THD of line currents has been reduced by implementing shunt active power filter.

VIII. FUTURE SCOPE

Experimental investigations can be done on shunt APF by developing a prototype model in the laboratory to verify the simulation results for both conventional and digital controllers.By taking the algorithm of digital HCC development of control algorithm for AHCC.

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