

DESIGN & SIMULATION OF SHUNT ACTIVE POWERFILTER USING P-Q THEORY FOR POWER QUALITY IMPROVEMENT

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Abstract— Nowadays, the active filters represent a viable alternative for controlling harmonic levels in industrial consumers' electrical installations. It must be noted the availability of many different types of filter configurations that can be used but there is no standard method for rating the active filters. This paper focuses on basic principle of SAPF and the theoretical concepts describing the shunt active power Filter structure and design. The filter controller is based on instantaneous power theory (p-q theory) and the circuit performing as an inverter with PWM hysteresis control. To validate the performance of shunt active filters a Matlab-Simulink model was developed. Simulation results are presented which verifies the power quality of the grid is enhanced.

Keywords— Shunt Active Filter, P-Q Theory, Simulink Model, PWM Hysteresis Control.

I. INTRODUCTION

In recent decades, the world has seen an expansion in the use of non-linear loads. Non-linear loads are very common in present industrial facilities, office buildings and even in our homes. These loads draw a non-sinusoidal current from the source and distribute them throughout the system so they present several Power Quality problems to the electrical grid. As a result the power quality degrades. The conventional solutions do not solve these problems in a suitable way. Therefore, it is necessary to find new solutions such as active power filters. Power quality is an issue of great concern for electrical power industry that is utility and consumer both, as the power quality determines the fitness of electrical power to consumer devices and the efficiency of consumer devices. There are many ways in which electric power can be of poor quality. The presence of harmonic content in AC power is an important factor that describes quality of electrical power. Power quality may be defined as; "The deviation of voltage from the ideal, continuous single-frequency sine wave with a rated constant frequency and amplitude. Also current deviation from the ideal, single-frequency sine wave with a constant frequency and amplitude that is in phase with the supply voltage."

Presence of different types of loads causes disturbance in the power systems. Loads can be characterized into many types according to their nature, function etc. The types of load we are interested in are linear load & nonlinear load. Linear loads do not cause any harmonic in the electrical system. Non-linear loads like switching circuits, speed control circuits, welding plants, thermal loads, variable frequency drives; motor controls, power invertors, cyclo convertors, high frequency induction furnaces, etc tends to produce harmonics distortion in power lines. These high frequency harmonic components cause greater magnetization and heating

losses in the cores of electrical machines and transmission lines.

So Harmonic injection is the main cause of poor Power quality. There are other problems due to harmonics such as, 1) Effect on Power System itself 2) Effect on consumer itself 3) Effect on communication system 4) Effect of revenue Billing

The growing concern of good power quality and awareness with the harms to power system due to harmonics along with the penalties imposed by utility companies and the standards to the limit of THD made by IEEE and other organizations are the driving factors for invention and adoption of various methods, devices and equipment for harmonic mitigation. These equipments include, 1) Line reactors 2) Isolation transformers 3) K-Factor transformers 4) Phase shifting transformer 5) Harmonic filters. The most effective and useful of the list are current harmonic filters. There are two types of harmonic filters: 1) passive harmonic filter and 2) active harmonic filters.

The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. They restrict the harmonic currents to flow into power system and divert them by providing a low resistance path. Performance of passive harmonic filter largely depends upon the system impedance and its topologies and this factor is not accurately known and is subjected to changes very frequently. Usually a separate tuned harmonic filter is required to mitigate a single harmonic. But there are some disadvantages of passive filter such as, 1) Dependency on source impedance 2) Resonance problem 3) The response is not dynamic 4) Doesn't solve the problem of load unbalancing or neutral shifting

II. PROPOSED WORK

These problems led to a power electronic solution of harmonic distortion i.e. Active Harmonic Filters

(AHF).It is the modern solution to old harmonic current problems. Active filters have been designed, improved, and commercialized in the past three decades. They are applicable to compensate current-based distortions such as current harmonics, reactive power, and neutral current. They are also used for voltage-based distortions such as voltage harmonics, voltage flickers, voltage sags and swells, and voltage imbalances and load unbalancing and neutral shifting. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. The APF overcomes the drawbacks of passive filters by using the switching mode power converter to perform the harmonic current elimination. AHF continuously monitors the load current, filter out the harmonic content and generates compensation current signals using any of the algorithms like p-q Theory, d-q transform, sliding mode control, unity power factor method, algorithm based on DSP, etc. We have selected Shunt Active Power Filter for this paper which is ideal for current harmonic compensation.

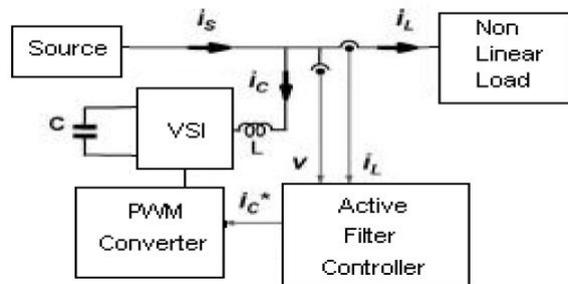


Fig. 1. Scheme of Shunt Active power Filter

The figure shows scheme of shunt active filter. This paper describes a shunt active power filter with digital control strategy which allows the harmonic correction. The model for shunt active power filter consists of two main blocks [2], 1) The active power filter controller 2) PWM converter.

A. Active Power Filter Controller:

Active Power Filter controller is based on instantaneous p-q theory [1]. In this theory only active average real power from load is used & remaining that is power from harmonics is exchanged with Shunt active filter. The p-q theory is defined as three-phase three wire systems or three phase four wire systems with neutral conductor .Three instantaneous powers are defined namely, the instantaneous zero-sequence power p₀, the instantaneous real power p, and the instantaneous imaginary power q, are defined from the instantaneous phase voltages and line currents on the αβ0 axes as,

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

If there are no zero-sequence current components in three-phase, three-wire systems, that is, $i_0 = 0$. In this case, only the instantaneous powers defined on the axes exist, because the product $v_0 i_0$ is always zero. Similarly, if there is no zero-sequence voltage components in three phase four wire systems, that is $v_0 = 0$.

This Instantaneous power Theory that is p-q theory is use for calculation of the compensating current .The p-q Theory is primarily based on a set of instantaneous calculation of powers in time domain. Voltage and current are sampled instantaneously which means there is no restriction on the shape of their waveforms, and it can be applied to three phase with or without a neutral wire. It is based in time domain rather than frequency domain. Thus, it is valid in the steady state and also in the transient state. This shows the theory is very flexible and efficient in designing controllers for active filters and power conditioners based on power electronics devices.

1) Clarke’s Transformation:

The p-q theory uses the Clarke transformation, also known as the αβ0 transformation, which consists of a real matrix that linearly maps three phase voltages and currents into the αβ0 frame, which is a stationary reference frame [1].

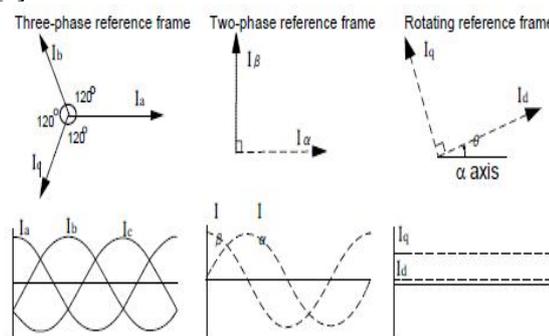


Fig. 2. Different reference Frames

The figure shows reference frames used for analysis of electrical systems.

The αβ0 transformation or the Clarke transformation maps the three-phase instantaneous voltages in the abc phases, v_a, v_b, and v_c, into the instantaneous voltages on the αβ0-axes v_α, v_β, and v₀. The Clarke Transformation and its inverse transformation of three-phase generic voltages are given by,

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

and the load current can be given by,

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

so by using values of Voltage & current we can calculate instantaneous powers,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Each one of the active & reactive instantaneous power contains a direct component & alternating component. The direct component represents the fundamentals of current & voltage. The alternating term represents the harmonics of current & voltage.

To separate the harmonics from the fundamental of the load currents, it is enough to separate the direct term of the instantaneous power from the alternating one. A low pass filter can be used for the task. Separating the direct & oscillating components,

$$p = \bar{p} + \tilde{p} \quad q = \bar{q} + \tilde{q}$$

a) Compensating current calculation

Now we have alternating active power component which is produced due to presence harmonics. Some active power is utilized in the capacitor voltage regulation. So total active power compensated is sum of alternating active power & P_i across the capacitor.

We have to compensate all reactive power present in the circuit so we have P_c & Q_c

$$P_c = \tilde{p} + P_{loss}$$

$$Q_c = q$$

By using compensating powers & voltages we can find compensating currents in $\alpha\beta 0$ domain.

$$\begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -P_c \\ -Q_c \end{bmatrix}$$

The negative sign indicates that the powers to be compensated are in perfect phase opposition so that it can cancel the Harmonics.

b) Reference current generation:

By using Inverse Clarke's inverse transformation we can calculate reference currents in phase domain.

$$\begin{bmatrix} I_{ca} \\ I_{cb} \\ I_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix}$$

In this way we can inject the compensating currents to cancel Harmonics.

B. PWM Converter:

For injecting the compensating currents in the power system a voltage source inverter is used. The gate pulses to the VSI are adjusted according to the compensating currents from the active power filter converter block.

VSI is the three arm IGBT Bridge inverter having with DC-capacitor link parallel with the bridge.

During the operation of the APF the capacitor discharges so dc voltage regulator block is added in the circuit. According to the error signal generated Gate pulse is given to the IGBT's to inject the compensating current into the line.

For Gate pulse generation PWM converter having Hysteresis current controller is used. Hysteresis current controller is used to control the voltage source inverter (VSI) through the PWM in a manner that the output current of inverter then tries to track the reference current fed to the hysteresis current controller which works in a close loop. Its advantage is that it is very easy to implement while its disadvantage is that its switching frequency is not constant.

The control circuit generates the reference current wave & is compared with the compensating phase current wave. As the current exceeds prescribed hysteresis band upper switch is turn off & lower switch is turned on.

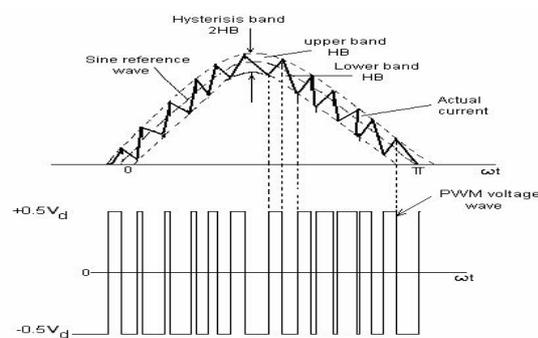


Fig. 3. Hysteresis Current Controller

The figure explains the operation of the Hysteresis Band PWM generation. As the current crosses the lower band limit, the lower switch is turned off & the upper switch is turned on. Hence the Compensating current wave is thus forced to track the sine reference wave within the hysteresis band by back- and-forth.

III. MATLAB SIMULINK MODEL FOR 3 PHASE SHUNT ACTIVE FILTER

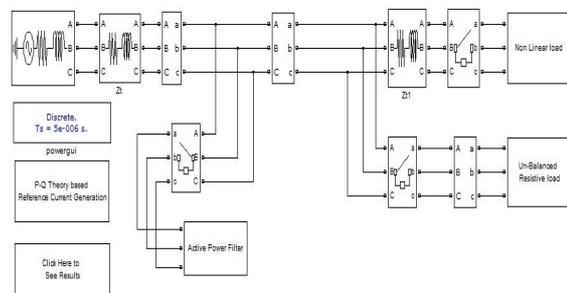


Fig. 4. Matlab Simulink Model

The fig 4 shown below gives idea about Simulink model of shunt active filter.

A. POWER SOURCE:

(Ω)=0.001, Source inductance (H)=1e-8

B. LINE Here we have considered 3-phase,

440v, 50Hz supply, source resistance IMPEDANCE (z_t):

Line impedance (z_t) is a three phase RLC branch used to represent line impedance having following parameters, $R=0.01(\Omega)$ & $L=1e-6(H)$

C. POWERGUI:

This block is needed to run any SIMPOWER System model. It Provides option for configuration of simulation and analysis of system.

D. NON-LINEAR LOAD:

The non linear load consists of two parts in parallel. One is three phase rectifier, second is unbalanced resistive load.

E. ACTIVE POWER FILTER:

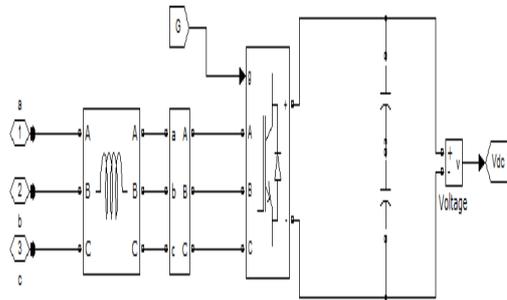


Fig. 5. Active Power Filter block

The active power filter block consists of Inverter Bridge & a dc capacitor parallel with it.

Gate pulse production is the main block of the active power filter block. The APF controller block produces 6 gate pulses to trigger IGBTs of Inverter Bridge.

The Active Power Filter Controller Block Consists of 3 main blocks, 1) Instantaneous power 2) DC Voltage regulation 3) Compensation & reference current generation

1) Instantaneous power:

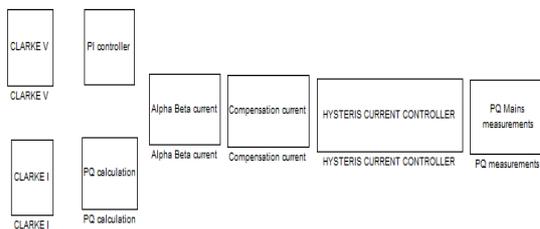


Fig. 6. Instantaneous power calculation block

Voltage & load currents are measured from measurement block. By using Clarke's transformation voltages & currents are converted from abc reference into $\alpha\beta 0$ reference frame. By using p-q instantaneous theory active & reactive power is measured. The powers can be divided into 2 parts direct & alternating part. We are compensating alternating part of active power & whole reactive power.

2) DC voltage regulation :

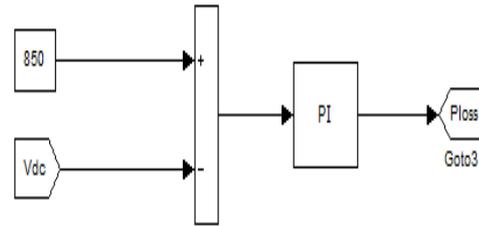


Fig. 7. Voltage Regulation block

The figure shows voltage regulation block. Inverter Bridge is having DC capacitor across parallel to it. The DC voltage V_{dc} across capacitor is regulated by using PI controller & P_{loss} is calculated. Here we want to maintain V_{dc} by comparing it with constant value that is V_{ref} . If V_{dc} is lesser than V_{ref} then it would create a +ve P_{loss} & vice versa. This loss is also compensated with compensating active power.

3) Compensation & reference current calculation:

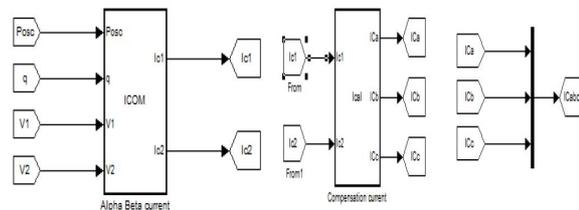


Fig. 8. Compensation & reference current block

The figure shows compensation & reference current calculation. By using Compensating active & reactive power the compensating current in $\alpha\beta 0$ reference frame is calculated & by using Inverse Clarke's transformation reference currents in the form of abc reference frame is calculated. These are reference currents used for the gate pulse generation of the IGBT's in the VSI.

F. VSI & PWM CONVERTER BLOCK:

Three arm IGBT bridge inverter with DC capacitor link parallel with it is given. VSI injects the compensating currents into the system to cancel the harmonics. The hysteresis current controller block is used for gate pulse generation. By using reference & actual current PWM is generated for each pair of IGBT & current opposite to Harmonic current is injected to cancel out the effect of Harmonics.

IV. RESULT

After having basic theoretical background, we have some simulation results that help understanding theory and behavior of SAPF. Following are cases differ by nature of load connected across the source. CASE I: Compensation of unbalanced Resistive load For unbalanced resistive load $R_a=5\Omega$, $R_b=10\Omega$, $R_c=15\Omega$ The load is switched on at 0.1 sec. The SAPF is switched on at 0.2 seconds.

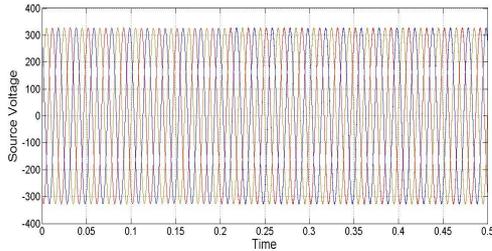


Fig. 9. Source Voltage v/s Time

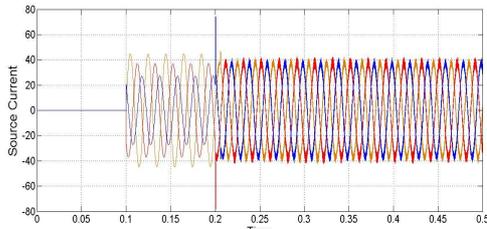


Fig. 10. Source Current v/s Time

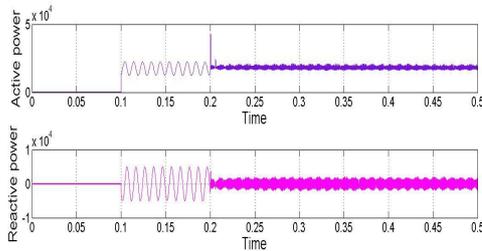


Fig. 11. Active & Reactive Power v/s Time

After compensation source current has become single frequency since having THD 2.84%, within limits as standardized by IEEE in std579.

CASE II: Compensation of Nonlinear load(Diode Bridge)

The load is switched on at 0.1 sec. The SAPF is switched on at 0.2 seconds. After compensation source current has become single frequency since having THD 6.76%, within limits as standardized by IEEE in std579.

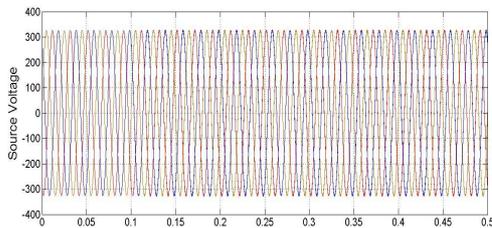


Fig. 12. Source Voltage v/s Time

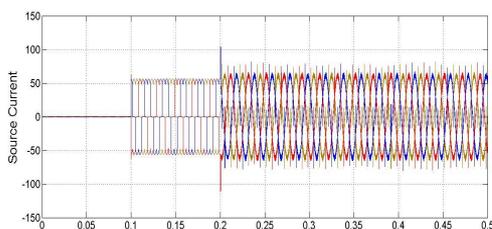


Fig. 13. Source Current v/s Time

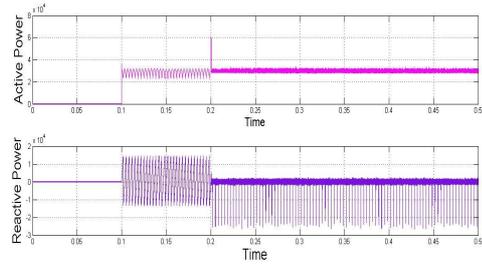


Fig. 14. Active & Reactive Power v/s Time

CASE III: Compensation Non linear load (Diode Bridge) with unbalanced Resistive load. The load is switched on at 0.1 sec.

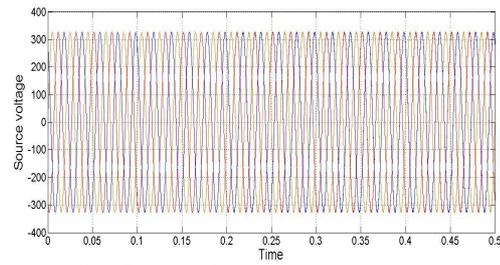


Fig. 15. Active & Reactive Power v/s Time

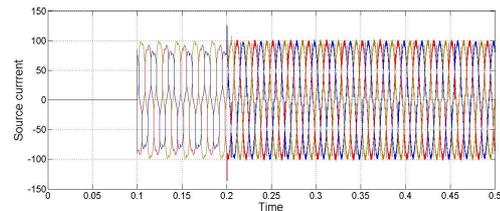


Fig. 16. Active & Reactive Power v/s Time

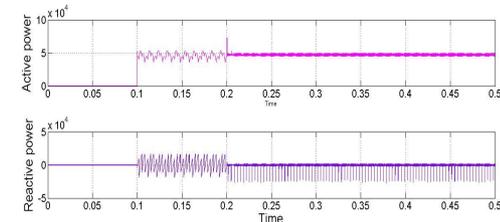


Fig. 17. Active & Reactive Power v/s Time

The SAPF is switched on at 0.2 seconds . After compensation source current has become single frequency since having THD 6.51%, within limits as standardized by IEEE in std579

The cases studied helps to understand power theory and behavior of SAPF.

CONCLUSION

On the basis of simulation results, the paper utilizes the instantaneous reactive power theory to detect the load, source& harmonic current. The compensation of the Harmonics in the load current is effectively done by reshaping the source current to that similar to sine wave. The active & reactive power graphs after & before activation of filter reveals the reactive power compensation.

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