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Harmonics Reduction of Power System using Shunt Active Filter

[1]Sourav K. Sahu, [1]L.N. Tripathy, [2]Basanta K. Panigrahi and [1]P. Pahadsingh
[1]Department of Electrical Engineering, Indira Gandhi Institute of Technology (IGIT),
Sarang, Dhenkanal, Odisha, India
[2]Department of Electrical Engineering, Institute of Technical Education (ITER), Bhubaneswar, India

Abstract: The active power filtering technique is becoming a reliable technology to compensate for the harmonics in the power system network that may be for the three phases or for three phases with neutral network which feed the loads that are non-linear. In this research a detail analysis is done on the various aspect of controlling strategies, working of individual components, explicit application of the components and the technicality involved in these systems. This research describes mainly an application of shunt active power filter to the system for elimination of current harmonics and fixed reactive power compensation. The above explained system consists of a low rated voltage source active power filter and a series connected LC passive filter in each phase. Excluding this no additional switching filter is needed for the current ripple elimination. This reality of this system can be checked by implementing this system in a MATLAB Model. Presently the modern shunt active filter is widely used for medium and high voltage application. In this research the Shunt APF is controlled by instantaneous real and reactive power theory (p-q) theory to compensate the power. By this strategy the Total Harmonic Distortion (THD) in supply current is reduced to a acceptable range. A MATLAB Simulink Model is taken for the investigation and the desired output is obtained for the above said idea.

Key words: Shunt active filter, THD, hysteresis controller, strategy, acceptable, range

INTRODUCTION

The active filter is an analog device constitutes mainly active devices such as amplifier. The amplifier used in the filter design mainly used to improve the efficiency and predict the certainty of the filter which does not require inductors, so, the system remains sound. Due to use of these amplifiers the load impedance unable to affect the characteristic of the filter (Chaer *et al*., 2012). The required poles and zeros for the system that is complex poles or zeros can be achieve without bulky inductors (Saidi *et al*., 2016a, b). If required the shape of the response and frequency can be obtained by simply using some very cheap variable resistors. One of the most important characteristics of these circuits is that some time we can change one parameter without affecting the others. These active devices have some limitation that is presently available devices have limited band width, so these can't be use at higher frequencies. Normally, the amplifiers guzzle power and add noise into the system (Singh *et al*., 1999). Due the vast research in power electronics, electrical devices and the power system network is polluted with all disturbances. The main cause of these pollution is nonlinear loads and power electronics devices (Rahmani *et al*., 2014). The pollution issues in the network are due the fast switching of the power electronic devices. This nonlinearity may cause low system efficiency and may also cause in deregulated power factor (Chakravarthy *et al*., 2011). The effect of nonlinearity in the system may cause disturbance in the nearby system and in the communication network. As the power system is expanding exponentially these nonlinearities are also increasing in the network and it will be huge in coming years (Abbassi *et al*., 2015). So, it becomes at most important for the network to overcome these problems due to nonlinearity. Naturally in shunt passive filter tuned LC filter or various passive filters are used for the attrition of harmonic and huge power capacitors are introduced to revamp power factor of the system (Bina and Pashajavid, 2009). In passive filter configuration generally, we have a limitation of fixed compensation, this system also can cause resonance and are very big in size. So, active power filters are found to be the best alternative for this conventional power filter for the purpose of reduction of harmonics and compensate the reactive power required by the nonlinear load (Singh *et al*., 1999). Modern active filters are used as the substitute for the traditional passive filter because of the ability to reimburse harmonics along with the reactive power needed by the non-liner loads (Oku *et al*., 1994).

Corresponding Author: Basanta K. Panigrahi, Department of Electrical Engineering, Institute of Technical Education (ITER), Bhubaneswar, India

The main mechanism involved in these active power filters are reduced size of necessary passive components. By adopting the active power filter scheme, we are optimising the peripheral passive component values to a minimum value possible.

MATERIALS AND METHODS

Shunt active filter: Power processing and signal processing units are two broadly classified blocks of shunt active filter. The converter containing PWM module generates a compensating current which is taken away from power system network. The signal required by the PWM converter that is instantaneous current which acts as reference, produced at the active filter controller. The diagram explaining the fundamental construction of the shunt APF to counter the harmonic current for a specific loading. Shunt APF comprises of a converter which has pulse width modulation current controller, it also has a filter controller both of which have instant control mechanism. The shunt active filter works in closed loop system (Saidi *et al.*, 2016). It continuously senses the load current and calculate the instantaneous value of reference current for the PWM control scheme (Singh *et al.*, 2007). For shunt APF pulse with modulation converter is regarded as power amplifier which has liner characteristic because the compensating current is very accurate in this case and it is possible for ideal conditions only.

For the estimation of the precise compensating current the pulse with modulation converter must have very high switching frequency where f_{PWM} is the switching frequency of the PWM scheme. Generally, the switching frequency of the PWM converter is greater than ten times of f_{MAX} where f_{MAX} refers to the highest frequency of the current wave which we need to compensate. Voltage-source converters or current-source converters can be used in shunt active filters (Hayashi *et al.*, 1991; Choe and Heumann, 1991; Akagi, 1994). Voltage-source converters are widely used as shunt active filter now a day (Akagi, 1994). Voltage-Source Converter (VSC) is the synonymous to voltage-fed converter. This converter is normally taken as voltage source converter. Irrespective of converters, the PWM has a feedback loop which helps the converter to act as controlled non sinusoidal current source.

Shunt active compansation: Compensation of undesirable harmonic current is one of the major implementation of active-reactive power theory. In this Fig. 1, the source is feeding load which is non liner in nature, the harmonics produced by it is mitigated by the shunt APF (Malinowski *et al.*, 2001). From, it is simplified as a controlled current source that can compensate for the load harmonic where i^*_{ca}, i^*_{cb}, i^*_{cc} the reference currents. The real power measured at the load segregated into two sections those are oscillating power $(\tilde{p})$ and average power $(\bar{p})$. Likewise, the imaginary power (q) of the load is also divided into two types those are average and oscillating component. Which are to be compensated are then selected for compensation. The compensating power by the active filter are $-p^*_c$ and $-q^*_c$. The negative sign signifies that the compensator will draw that amount of current which will cause the drawing of same amount of power as drawn by the nonlinear load In this harmonic mitigation method the load and the compensating current that is the shunt active filter current are the two components of the source current. The α, β reference frame then converted to a-c reference frame for the estimation of the instantaneous compensating currents those are $i^*_{ca}, i^*_{cb}, i^*_{cc}$ for the phases a-c, respectively. Each of these quantity reflects the current is to be compensated. Figure 1 shows all the quantity like the current that should be eliminated from the load current, source side active and reactive power, the compensating current. The compensating current that produce the inverse of the power which eliminate the harmonic $(-p^*_c, -q^*_c)$, resulting same current as above. Now the compensating current generated by the shunt APF contributes to the load current. The terms p_s and q_s are the active and reactive power taken from the source after the compensation is done. In this p-q technique the current component that cause the power loss in the network are excluded.

Reference source current calculation: The instantaneous current can be estimated from the Fig. 1 as:

$$i_s(t) = i_L(t) - i_c(t) \tag{1}$$

The source voltage can be written as:

$$v_s(t) = v_m \sin\omega t \tag{2}$$

If there is a non liner load in the system which is drawing current from the power system, this current will have two components that are fundamental and harmonic. This current can be estimated as:

$$\begin{aligned} i_L(t) &= \sum\nolimits_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) = \\ &I_1 \sin(n\omega t + \phi_1) + \sum\nolimits_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \end{aligned} \tag{3}$$

$$\begin{aligned} P_L(t) &= v_s(t) \times i1(t) = V_m I_1 \sin^2 \omega t^* \cos\phi_1 + \\ &v_m I_1 \sin\omega t^* \cos\omega t^* \sin\phi_1 + V_m \sin\omega t^* \sum_{n=2}^{\infty} \sin(n\omega t + \phi_n) \end{aligned} \tag{4}$$

$$= P_f(t) + P_r(t) + P_h(t) \tag{5}$$

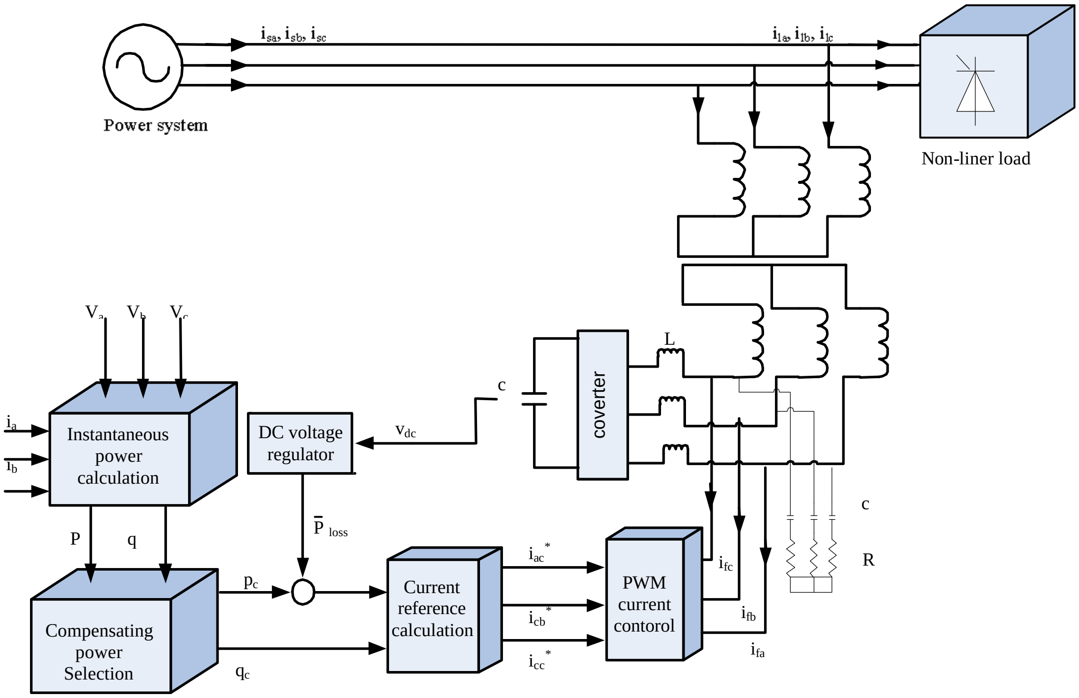

Fig. 1: Shunt active filter scheme (Saidi *et al*., 2016a, b)

The real fundamental power which is consumed by the load is given as:

$$P_f(t)=V_m I_1 \mathrm{Sin}(2\omega t)\mathrm{Cos}\varphi_1 = V_s(t)^* i_s(t) \quad (6)$$

The source current supplied by the source, after compensation is:

$$i_s(t)=P_f(t)/V_s(t)=I_1\cos\phi_1\sin(\omega t)=I_m\sin\omega t$$

Where, $I_{sm} = I_1 \cos\phi_1$ as losses are unavoidable in the system to matchup the load demand the utility must supply the losses that are PWM switching along with capacitor leakage losses. So, the total current that needs to be supplied by the source is:

$$I_{sp} = I_{sm} + I_{s1} \quad (7)$$

When the active filter supplies all the reactive power and the harmonic powers, at this condition the source voltage is in phase with the source current and the current wave form is pure sinusoidal. At this stage the active filter generates the following current:

$$i_c(t) = i_l(t) - i_s(t) \quad (8)$$

For the perfect compensation of the reactive power and harmonic power it is very much important to estimate the load current and its fundamental value. This fundamental current is taken as reference current. For the calculation of the reference current the dc capacitor voltage must be controlled accordingly. After ideal compensation the source current becomes sinusoidal and in phase with the source voltage and this characteristic is independent of the nature of load. The expected current at the source end after the application of shunt APF are given as:

$$I_{sa}^* = I_{sp}\sin(\omega t)$$
$$I_{sb}^* = I_{sp}\sin(\omega t\text{-}120°)$$
$$I_{sc}^* = I_{sp}\sin(\omega t\text{+}120°)$$

In the ideal compensation the source current and voltage are sinusoidal irrespective of the load. The phase angle can be determined from the source voltage. From the above discussion the wave form and phase is known, the only unknown is the magnitude of the source current. The maximum value can be determined from the regulating DC capacitor voltage of the PWM converter. This capacitor voltage is compared against the reference voltage and error is feed to the controller (PI) to process.

RESULTS AND DISCUSSION

Hysteresis band control strategy is used here to generate switching pulses in a more particular and rapid manner (Maswood and Liu, 2007). This current controller

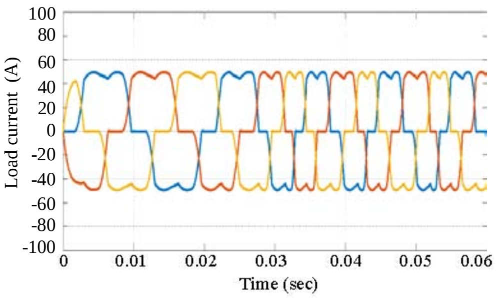

Fig. 2: Source current containing THD

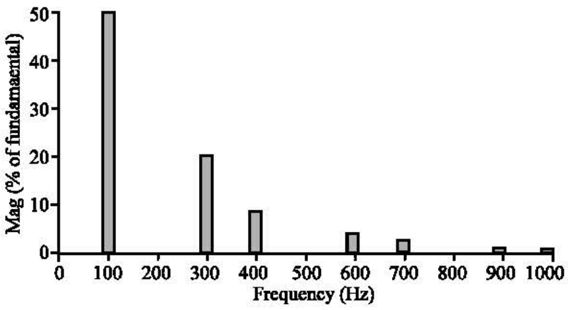

Fig. 3: THD bar plot for source current (Fundamental (50 Hz) = 52.13, THD = 22.43%)

is the most appropriate for voltage source inverters which is controlled by current in the application of active power filters. The independent stability characteristics of hysteresis band controller with very fast response and accuracy make it more practical to use in the power system. Active filter switching paten is decided by the hysteresis band controller in Fig. 2 and 3. For switching of the phases B and C same principle is adopted.

The switching logic is formulated as follows: If $i_{ca}< (I^*_{ca}\text{-HB})$ upper switch is OFF and lower switch is ON for leg "a": (SA = 1). If $i_{ca}< I^*_{ca}\text{+HB})$ upper switch is ON and lower switch is OFF for leg "a" (SA = O).

In this research, we have taken a number of conditions to verify the proposed method. We have implemented PI controller to generate the accurate reference currents. Here, the constants of the PI controller are fine tuned to give most practical results. The parameter values are $V_s = 230$ V, Rs. = 0.01 Ω, $L_s = 1$ μH, $R_L = 6$ Ω, $L_L = 3$ mH, $C_{apf} = 35$ μF. We get the THD of the load current is 22.43%. In the Fig. 2, harmonic distortion can be clearly seen.

After switching 'ON' the shunt active filter at 0.02 sec, we are getting a almost smooth current wave. The effect of the shunt active filter can be noticed from the Fig. 4 and 5. As there is a significant change in the shape of current wave in this Fig. 4. At the instant of switching at 0.02 sec, we are getting a slightly high current which is die out after the transient period is over.

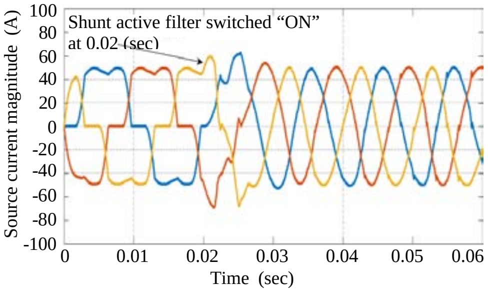
Shunt active filter switched "ON" at 0.02 (sec)

Fig. 4: Source current wave form after shunt active filter application at 0.02 sec

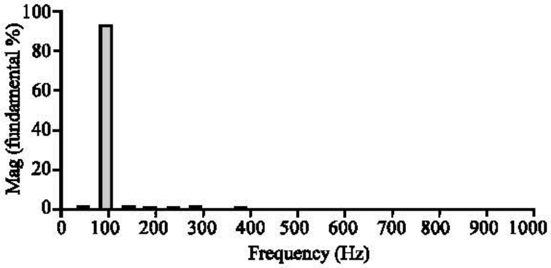

Fig. 5: THD bar plot for source current after shunt active filter implimentation

The harmonic distortion of the source current wave can be clearly differentiate after implementation and before implementation of the shunt active filter from the Fig. 4.

CONCLUSION

Here, the results are obtained by compensating the current harmonic for the nonlinear load. The transformation used here played a vital role for efficiently generation of the reference current. Here we have derived the results for unbalanced loads. The variation in the total harmonic distortion by varying the parameters of the system that is load parameter and active filter parameter are observed. The effect of parameter variation is also observed with less variation in the Total Harmonic Distortion (THD).

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