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Comparison of synchronous detection and I.cosϕ Shunt active filtering algorithms

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ABSTRACT

The intensive use of power electronic controlled applications and non linear loads in industry by consumers cause an increasing deterioration of the power system voltage and current waveforms. As a result, harmonics are generated from power converters or nonlinear loads that cause the power system to operate with the low power factor, low efficiency, increased losses in transmission and distribution lines, failure of electrical equipments and interference problem with communication system. So, there is a great need to mitigate these harmonic and reactive current components. Active Power Filters are a viable solution to these problems. The basic principle of Active Power filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling thereby forcing the source current to be pure sinusoidal. The active power filter control has two main blocks, first one is to generate control reference compensating currents from nonlinear load current and second one is the control method to inject these compensation currents into the line. In this paper, the two control schemes for shunt active power filter namely synchronous detection algorithm and I.cosϕ control algorithm are compared. Both control schemes are simulated for balanced source-balanced load, balanced source-unbalanced load and unbalanced source-balanced load conditions.

Keywords : Active Filter, Control algorithm, PWM techniques for VSC,

Introduction

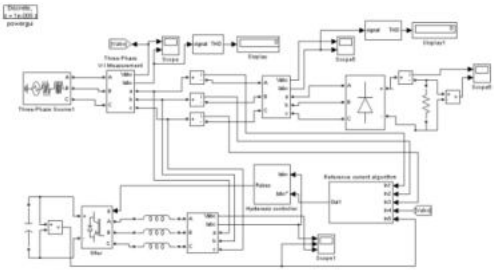
The main objective of electric utilities is to supply its consumer's continuous sinusoidal voltage of constant magnitude. However this is becoming increasingly difficult, because of the rapid growth of non-linear and poor power factor loads. The use of the modern electronic equipments has changed our lives and has introduced wide variety of loads in the power systems. This has changed the load characteristics of the electric supply networks, all the electronic loads are "non-linear" and this is because of the way they draw the power from the supply. These types of loads are used for the conversion, variation and regulation of the electrical power in commercial, industrial and residential installations. The continuous usage of non- linear loads injects current and voltage harmonic components into the power system and increases reactive power demands and power system voltage fluctuations. Harmonic current components create several problems like Increase in power system losses. Oscillatory torques in rotating machinery. Significant interference with communication circuits that share common right-of-ways with AC power circuits. Reactive power burden, low system efficiency, poor power factor, system unbalance and causes excessive neutral currents. Malfunctioning of the protective relays and untimely tripping, Failure of capacitor banks Most commonly used non-linear loads are switch mode power supply system's found in personal computers. Microwave ovens, laser printers, medical to instrumentation systems, stereos, televisions and electronic lighting are also examples of equipments using switch mode power supplies. Other types of nonlinear loads include rectifiers, both controlled and uncontrolled, and phase angle controlled power supplies. Power system contamination with harmonics deteriorates power quality and it has become a major concern for the power system engineers due to its adverse effects on sensitive loads connected to the power distribution system. There are two approaches to mitigate the power quality problems. The first approach is called load conditioning, which ensure that the equipment is made less sensitive to the power disturbances, allowing the operation of equipments even under significant voltage distortion. The other solution is to install line conditioning

systems that suppress or counteract the power system disturbances. Power electronic equipment can be designed to provide harmonic-free performance. But in most applications, the economic incentives have not been sufficient to bring about design improvements. The sinusoidal nature of the power system voltage should be preserved, while protecting components from added harmonic loadings. In order to maintain good power quality, various international agencies recommended limits of harmonic current injection into the utility. According to IEEE-519 standards the limits on the magnitudes of harmonic currents and harmonic voltage distortion at various harmonics frequencies are specified .The amount of distortion in the voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD). The THD in current is defined as

$$\mathrm{THD}=\sqrt{\sum_{h=2}^{\infty}\left(\frac{Ish}{I_1}\right)^2}*100\%$$

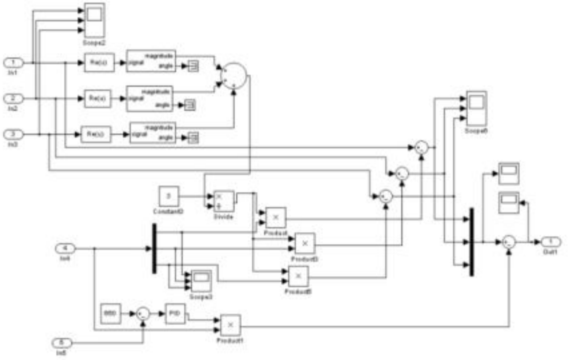
2. Active Power Filters (APF)

Fig.2.1 Shunt APF with balanced source-balanced load.



Active filters have been recognized as a valid solution to harmonic and reactive power compensation of non-linear loads. The principle of operation of active filters is based on the injection of the harmonics required by the load. Thus the basic principle of Active Power filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling thereby forcing the source current to be pure sinusoidal. Active power filter consists of two blocks, first one reference harmonic component calculation block, which calculates harmonic content on the load side and the second one is inverter block .Calculated harmonic currents are given to inverter block. Active power filter requires inverter to inject the harmonics in opposite polarity at point of coupling .The characteristics of the harmonic compensation are strongly dependent on the filtering algorithm employed for the calculation of load current harmonics. Many filtering algorithms are developed to extract the harmonic components. Control method also plays an important role in active power filter control. Reduced Switching losses, compensation of higher harmonics, less current ripple etc need a control method to meet the all these requirements.

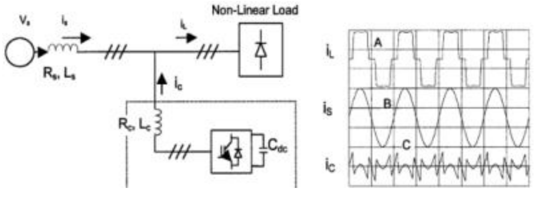
Fig.2.2. I.cosϕ control algorithm.



Control algorithms for reference current generation.

The basic compensation principle of a shunt APF is shown in Figure 3.1 It is controlled to draw/supply a compensating current Ic from/to the system, so that it cancels current harmonics on AC side, and makes the source current in phase with the source voltage. The different waveforms are shown in Fig 3.1. Curve A is the non-linear load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all harmonics, to make mains current sinusoidal.

Fig.3.1. Basic compensation principle of shunt active power filter



The performance of these active filters is based on two design criteria.

- The control strategy used to generate the reference current.
- PWM control method.

Reference Current Generation for I.cosϕ

The performance of the active power filter mainly depends on the control strategy used to generate the reference current. Most of the control strategies are based on sensing harmonics and reactive volt ampere requirements of non-linear load, and require complex control system. The present control scheme is based on direct generation of reference value for the source current on the basis of the dc voltage level. In this control scheme, the load currents I La, I Lb and I Lc are sensed and the amplitudes of the fundamental components of these three-phase currents are deduced as La I Lb I and Lc I , respectively. Unit amplitude sine waves in phase with the mains voltages are generated. The desired mains currents isa(re)f) isb(ref)i and isc(ref) are computed as the products of the amplitude L I and the unit sine wave for each phase. The difference between the actual load currents and the desired mains currents is computed using comparator blocks to generate reference compensation signals. The reference mains currents are deduced as the fundamental component of the load currents or the real part of the fundamental load currents depending on whether the requirement is to compensate for the harmonic contents only (non-reactive load) or for reactive load current also. In the latter case, the fundamental component of the active part of the mains current, that is, I.cos ϕ (where cos ϕ is the displacement power factor DPF) is deduced by passing the uncompensated mains current in each phase through fundamental detector blocks.

The shunt AF is expected to provide compensation for the harmonic and reactive portion of the three-phase load current, and for any imbalance in the three-phase load currents. This ensures that the balanced current will be drawn from the mains which will be purely sinusoidal and in phase with the mains voltage. So the main is required to supply only the active portion of the load current. In the I.cosϕ algorithm, the desired mains current is hence assumed to be the product of the magnitude I.cos ϕ and a unit amplitude sine wave in phase with the mains voltage.

Basic equations of I.cos ϕ control algorithm

Assuming a balanced source, the three-phase instantaneous voltages can be specified as

$$v_a = V_m \sin \omega t \qquad 1$$

$$v_b = V_m \sin(\omega t - 120^\circ) \qquad 2$$

$$v_c = V_m \sin(\omega t + 120^\circ) \qquad 3$$

Let this balanced three-phase source supply a nonlinear reactive load with some imbalance. For instance, let one of the phases of the load draw a lower current than the other two. The unbalanced, three-phase, reactive, harmonic-rich load currents can be expressed as

$$i_{La} = I_{La1}.\sin(\omega t - \phi_a) + \sum_{n=2}^{\infty} I_{Lan}.\sin(n\omega t - \phi_{an}) \qquad 4$$

$$= \mathrm{Re}(i_{La1}) + \mathrm{Im}(i_{La1}) + harmoniccomponent \qquad 5$$

$$i_{Lb} = I_{Lb1}.\sin(\omega t - 120^0 - \phi_b) + \sum_{n=2}^{\infty} I_{Lbn}.\sin(n(\omega t - 120^0) - \phi_{bn}) \qquad 6$$

$$= \mathrm{Re}(i_{Lb1}) + \mathrm{Im}(i_{Lb1}) + harmoniccomponent \qquad 7$$

$$i_{Lc} = I_{Lc1}.\sin(\omega t + 120^0 - \phi_c) + \sum_{n=2}^{\infty} I_{Lcn}.\sin(n(\omega t + 120^0) - \phi_{cn}) \qquad 8$$

$$= \mathrm{Re}(i_{Lc1}) + \mathrm{Im}(i_{Lc1}) + harmoniccomponent \qquad 9$$

where

$\varphi_a, \varphi_b, \varphi_c$	Phase angles of fundamental currents in a,b, and c phases:
$\varphi_{an}, \varphi_{bn}, \varphi_{cn}$	Phase angles of the nth harmonic currents in a,b,and c phases;
$I_{La1}, I_{Lb1}, I_{Lc1}$	Three-phase fundamental current amplitude,
$I_{Lan}, I_{Lbn}, I_{Lcn}$	Three-phase nth harmonic current amplitude;

The magnitude of the real component of the fundamental load current in each phase is given

$$|R_e(I_{La1})| = |I_{La}|.\cos\phi_a \qquad 10$$

$$|R_e(I_{Lb1})| = |I_{Lb}|.\cos\phi_b \qquad 11$$

$$|R_e(I_{Lc1})| = |I_{Lc}|.\cos\phi_c \qquad 12$$

To ensure balanced, sinusoidal currents at a unity power factor to be drawn from the source, the magnitude of the desired source current can be expressed as the average of the magnitudes of the real components of the fundamental load currents in the three phases

$$|I_{s(ref)}| = \frac{|\mathrm{Re}(I_{La1})| + |\mathrm{Re}(I_{Lb1})| + |\mathrm{Re}(I_{Lc1})|}{3} \qquad 13$$

$$= \frac{|I_{La}|.\cos\phi_a + |I_{Lb}|.\cos\phi_b + |i_{Lc}|.\cos\phi_c}{3} \qquad 14$$

Let U a , U b and U c be the unit amplitude templates of the phase-to-ground source voltages in the three phases, respectively

$$U_a = 1.\sin\omega t \qquad 15$$

$$U_b = 1.\sin(\omega t - 120^\circ) \qquad 16$$

$$U_c = 1.\sin(\omega t + 120^\circ) \qquad 17$$

The desired (reference) source currents in the three phases are therefore given as

$$i_{sa(ref)} = |I_{s(ref)}| * U_a = |I_{s(ref)}|.\sin\omega t \qquad 18$$

$$i_{sb(ref)} = |I_{s(ref)}| * U_b = |I_{s(ref)}|.\sin(\omega t - 120^0) \qquad 19$$

$$i_{sc(ref)} = |I_{s(ref)}| * U_c = |I_{s(ref)}|.\sin(\omega t + 120^0) \qquad 20$$

The reference compensation currents for the shunt AF are thereby deduced as the difference between the actual load current and the desired source current in each phase

$$i_{a(comp)} = i_{La} - i_{sa(ref)} \qquad 21$$

$$i_{b(comp)} = i_{Lb} - i_{sb(ref)} \qquad 22$$

$$i_{b(comp)} = i_{Lb} - i_{sb(ref)}; \quad i_{c(comp)} = i_{Lc} - i_{sc(ref)} \qquad 23$$

Equation (7) can be expressed as

$$i_{a(comp)} = [\mathrm{Re}(i_{La}) + \mathrm{Im}(i_{La}) + harmoniccomponent\} - [|I_{s(ref)}|.\sin\omega t]] \qquad 24$$

$$i_{b(comp)} = [\mathrm{Re}(i_{Lb})] + \mathrm{Im}(i_{Lb}) + harmoniccomponent\} - [|I_{s(ref)}|.\sin(\omega t - 120^0)] \qquad 25$$

$$i_{c(comp)} = [\mathrm{Re}(i_{Lc})] + \mathrm{Im}(i_{Lc}) + harmoniccomponent\} - [|I_{s(ref)}|.\sin(\omega t + 120^0)] \qquad 26$$

PWM Techniques for Voltage Source Converters:

In many applications it is desirable to have a nearly sinusoidal output. In order to achieve sine wave output from square wave output waveform, large filters are required to filter out the low order harmonic contents from the square wave output. With PWM control it is possible to achieve sinusoidal outputs. In voltage source converters (VSC), variables to be controlled are the amplitude and frequency of the converter output voltage. PWM techniques enable the modulation of the controllable switches of the converter. By proper modulation of the controllable switches, a high frequency converter output voltage can be generated, whose low frequency or localized average during each switching cycle is same as that of the desired output voltage of the converter at that cycle. Following are the desired characteristics of the PWM techniques. Good utilization of the converter DC bus voltage. Wide linear modulation range. Low amplitudes of lower order harmonics in output voltage to minimize harmonics in output current. Low switching losses in the converter switches.

Various PWM techniques are there for getting sinusoidal output, they are

1. Sine triangle PWM
2. Selective harmonic elimination method of PWM
3. Stair case PWM
4. Hysteresis current controller.

Simulation Results:

Simulation results for Shunt APF with Balanced Source-Balanced Load condition.

Fig.4.1.Three phase source voltages

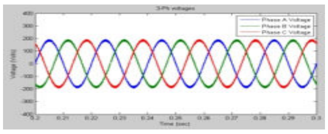


Fig.4.2.Three phase load currents

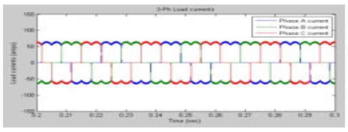


Fig.4.3.Three phase Source currents

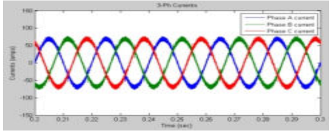
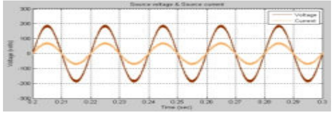


Fig.4.4.Source voltage and Source current



The load current harmonic spectrum with out the use of shunt active filter is shown in Fig 4.10. The load current Total Harmonic Distortion is 25.25%. Source current Total Harmonic Distortion is improved to 3.77% with the use of shunt active filter. Harmonic spectrum for source current after compensation is shown in Fig 4.11. Fig 4.10 Harmonic spectrum for load current

Fig.4.5. Harmonic spectrum for load current

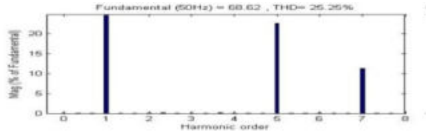
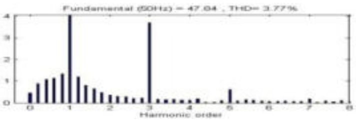


Fig.4.6. Harmonic spectrum for source current.



The THD with the use of I.cosϕ algorithm for shunt active filter for balanced load balanced source has been reduced from 25.25% to 3.77%.

Simulation results for Shunt APF with Unbalanced Source-Balanced Load Condition.

Fig.4.7.Three phase Source voltages

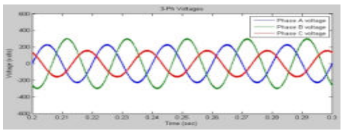


Fig.4.8.Three phase Load currents

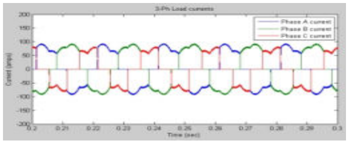


Fig.4.9.Source voltage and source current

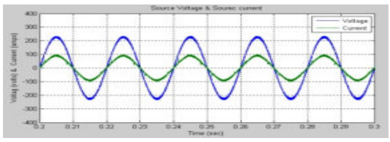


Fig.4.10.Harmonic spectrum for load current

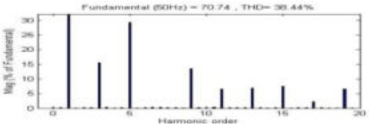
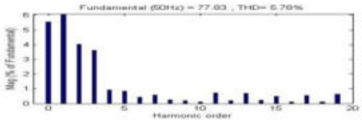


Fig.4.11.Source current Harmonic Spectrum (magnitude % of fundamental Vs Harmonic order) Total Harmonic Distortion = 5.78 %.



The THD with the use of I.cosϕ algorithm for shunt active filter for unbalanced source-Balance Load has been reduced from 38.44% to 5.78%.

4.3. Simulation Results for Shunt APF with Balanced Source- Unbalanced Load Condition.

Fig.4.12.Three phase voltages

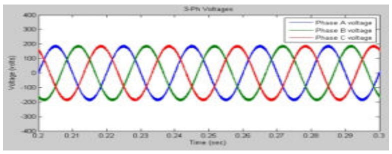


Fig 4.13 Three phase load currents

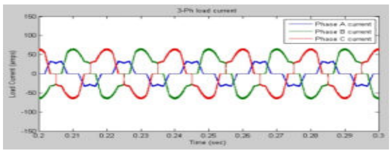


Fig.4.14. Three phase source currents

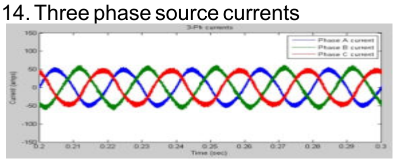


Fig.4.15. Harmonic spectrum for load current

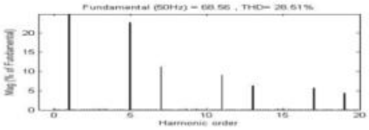
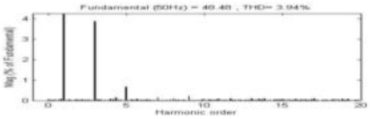


Fig .4.16. Source current Harmonic Spectrum (magnitude % of fundamental Vs Harmonic order) Total Harmonic Distortion = 3.94 %.



Simulation Diagrams for Synchronous Detection Algorithm APF with Balanced Source-Balanced Load Condition:

Fig 5.1 Simulink model of shunt active power filter with Balanced Source- Balanced Load.

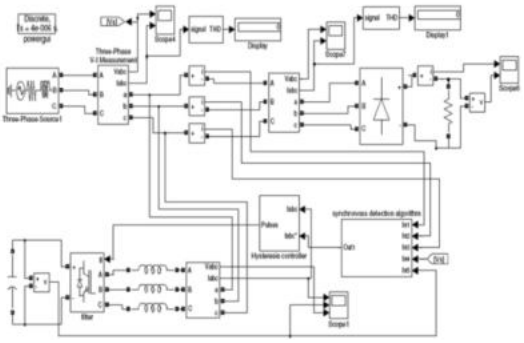


Fig.5.2 Harmonic spectrum for load current

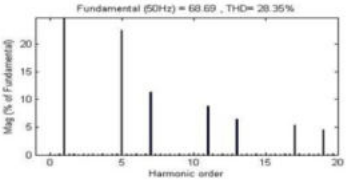
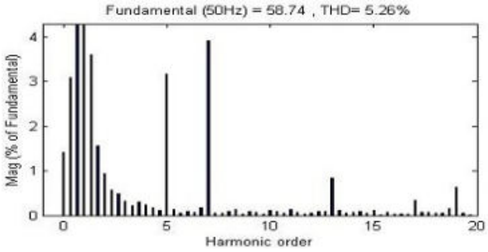


Fig 5.3 Source current Harmonic Spectrum (magnitude % of fundamental Vs Harmonic order) Total Harmonic Distortion = 5.26 %



The THD with the use of Synchronous Detection Algorithm for shunt active filter for balanced source Balanced load has been reduced from 28.35% to 5.26%.

Simulation results for APF with Balanced Source-Unbalanced Load Condition:

Fig.5.4 Harmonic spectrum for load current.

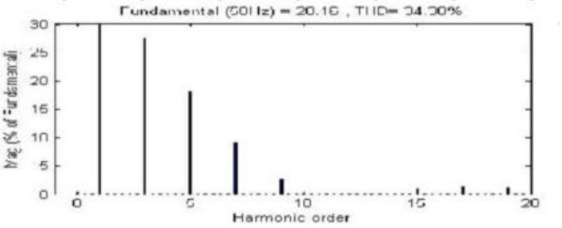
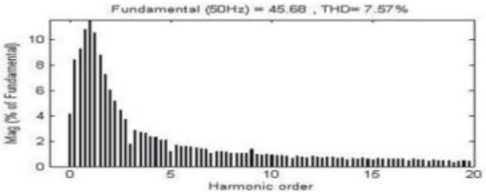


Fig .5.5. Source current Harmonic Spectrum (magnitude % of fundamental Vs Harmonic order) Total Harmonic Distortion = 7.57 %.



The THD with the use of synchronous detection algorithm for shunt active filter for balanced source Unbalanced load has been reduced from 34.30% to 7.57%.

5.6. Simulation results for APF with Unbalanced Source-Balanced Load Condition

Fig.5.6. Harmonic spectrum for load current.

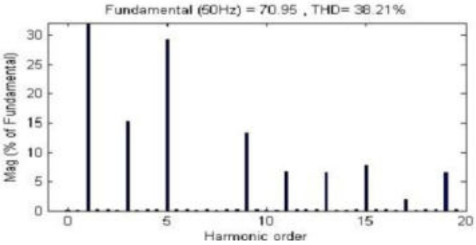
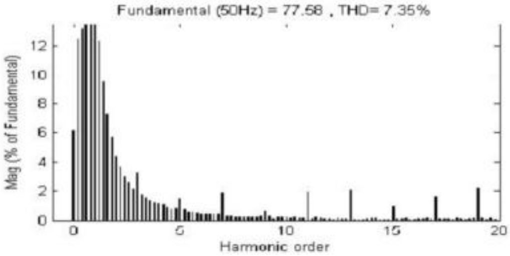


Fig 5.7. Source current Harmonic Spectrum (magnitude % of fundamental Vs Harmonic order) Total Harmonic Distortion = 7.35 %.

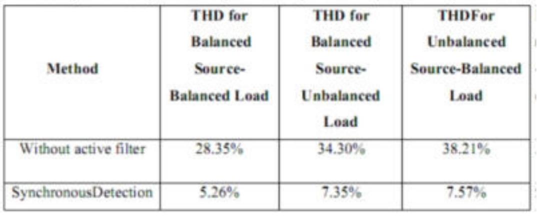


The THD with the use of synchronous detection algorithm for shunt active filter for unbalanced source Balanced load has been reduced from 38.21% to 7.35%.

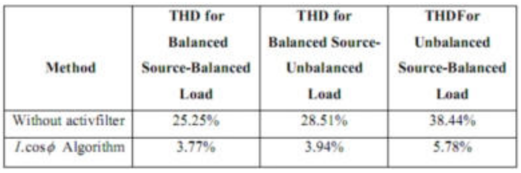
Three phases shunt active power filter with Balanced source-Balanced load, Balanced source-Unbalanced load and Unbalanced source-Balanced load conditions are compared for both control algorithms of I.cosϕ and synchronous detection algorithm. The THD is the source current for comparison under the two control schemes are shown in Table 5.1.

Comparison of the table two methods:

Table 5.1.Comparison of THD in source current



Method	THD for Balanced Source-Balanced Load	THD for Balanced Source-Unbalanced Load	THDFor Unbalanced Source-Balanced Load
Without active filter	28.35%	34.30%	38.21%
SynchronousDetection	5.26%	7.35%	7.57%



Method	THD for Balanced Source-Balanced Load	THD for Balanced Source-Unbalanced Load	THDFor Unbalanced Source-Balanced Load
Without activfilter	25.25%	28.51%	38.44%
$I.\cos\phi$ Algorithm	3.77%	3.94%	5.78%

Scope for future work

Neural network or fuzzy logic based controllers can be incorporated for better response of the active filtering system.

Conclusion

Two control schemes namely I.cosϕ algorithm and Synchronous Detection Algorithm used for shunt active power filter is being compared in this work. The two different schemes are analysed for non-linear load under different balanced / unbalanced source load conditions. Both of the schemes need the reactive power demand of the load. The simulation results shows that the performance of I.cosϕ algorithm is reducing the Total Harmonic Distortion is better over the Synchronous Detection Algorithm.

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