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Reduction of Harmonics for Traction System Using Shunt Active Filter

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Abstract

The presence of the non linear load in the system results in the generation of the current and voltage harmonics. Due to the presence of the harmonics it leads to low system efficiency, poor power factor, increased losses and reactive power components of current from AC mains. This paper mainly deals with the elimination of the harmonics which is caused due to the presence of the non linear load. Here, the topology of the shunt active filter will be analyzed. The evaluation performance of the shunt active filter will be done by comparing the values of THD by employing the system with the different control strategies. The non linear load of the traction system is considered for the generation of the harmonics. The different control theories such as Synchronous Detection Method and the Perfect Harmonic Cancellation method will be employed for the injection of the compensating current for the elimination of the harmonics which is caused due to the DC motor drive. The effective control concept will be demonstrated with the extensive MATLAB/ Simulink simulation studies.

Keywords-Harmonics, Shunt active filter, Synchronous Detection method, Perfect Harmonic Cancellation method, Total Harmonic Distortion

I. Introduction

Now a days there has been a significant increase in the occurrence of non-linear loads in power systems. This is due to the increase in the growth in power electronic technology and the associated use of power semiconductor switching devices such as thyristors and transistors of various types. Loads such as computer loads and TV sets with switched – mode supplies at the inputs lead to the great amount of the injection of harmonics in the distribution systems. Due to the usage of the large rectifying loads such as motor drives, arc welding and arc furnaces leads to larger generation of the harmonics in the medium voltage network [1].

Harmonics are the by-products of modern electronics. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies (UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC [2].

The term linear and non linear load is explained by the Figure 1. A non-linear load has a discontinuous current relationship that does not correspond to the applied voltage waveform whereas the linear load has continuous current relationship that corresponds to applied voltage waveform. All variable frequency drives cause harmonics because of the nature of the frontend rectifier.

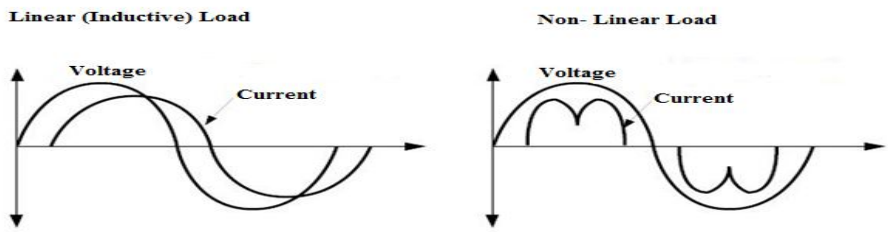

Fig 1: Difference between Linear and Non- Linear loads

The presence of harmonics leads in the transformer saturation, mains-voltage flickering, audible noise in power system components, electromagnetic interference, shorter life of organic insulation, the malfunction of protective relaying systems and incorrect operation of voltage sensitive devices. These effects leads to the harmonic pollution in the power system.[1]Hence these effects leads in the idea to eliminate or at least reduction of the harmonics[1]. The effect and the characteristics of the harmonics will be explained under Section II. Filters are mainly employed for elimination or the reduction of the harmonics. Active power filters have been used widely to improve the power quality. The shunt active power filter is mostly employed for the elimination of the load current harmonics. [2]. Hence the shunt active filter will be discussed in the Section II. Many control strategies are employed for the generation of the reference current. The control strategies of the shunt active power filter such as Synchronous detection method and Perfect Harmonic Cancellation method under Section III and IV respectively. The Simulation results and the comparison of the results are explained under the Section V.

II. Shunt Active Filter

Classically, shunt passive filters, consist of tuned LC filters and/or high passive filters are used to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and resonance conditions. Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components [2].

Shunt active power filter is mainly composed of harmonic current detecting circuit and compensation current generation circuit and is parallel connected with the non-linear load. Its working procedure is illustrated by the following figure 2.Firstly the current of the load iL(t) is detected, and its harmonic component is then calculated by the harmonic current detecting circuit. The inverter is controlled to output the compensation current whose polarities are inversed with the harmonic currents. According to the formula for power line current calculation is(t) = iL(t)+ic(t) = iL(t)-iLh(t)If the reactive power compensation is demanded additionally, the only procedure to add is to compute the reactive power component together with the calculation of harmonic component. Consequently, the unity power factor can be realized [3].

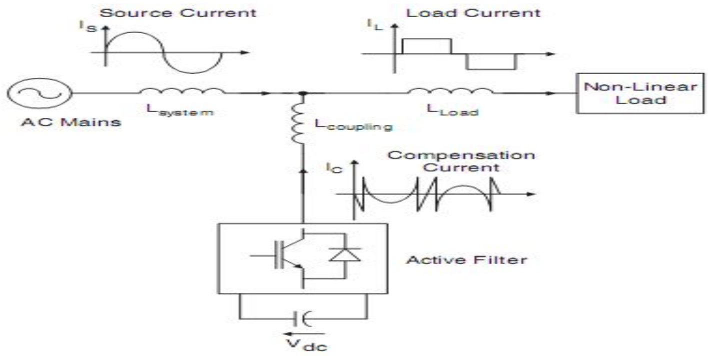

Fig 2: Shunt Active filter

III. Synchronous Detection Theory

The Synchronous Detection Method is introduced in order to calculate instantaneously the reference currents [4]. Synchronous detection (SD) theory can work effectively under balanced as well as unbalanced source and load conditions because the compensating currents are calculated taking into account the magnitudes of per phase voltages. In this paper, the simulation implementation of synchronous detection algorithm using equal current distribution method is presented.

The following assumptions are made in calculating the three phase compensating currents using equal current distribution method of synchronous detection algorithm: (i) Voltage is not distorted; (ii) loss in the neutral line is negligible. The equal current synchronous detection method shows a better profile of source side line current after compensation [5].

Assume the peak values of source currents are balanced after compensation;

$$\mathrm{Iam} = \mathrm{Ibm} = \mathrm{Icm} \quad (1)$$

Peak values of active current

$$\mathrm{Iam} = \frac{2\mathrm{Pa}}{\mathrm{Vam}} \quad (2)$$

$$\mathrm{Ibm} = \frac{2\mathrm{Pb}}{\mathrm{Vbm}} \quad (3)$$

$$\mathrm{Icm} = \frac{2\mathrm{Pc}}{\mathrm{Vcm}} \quad (4)$$

From above equations

$$\frac{2Pa}{Vam} = \frac{2Pb}{Vbm} = \frac{2Pc}{Vcm} \quad 5$$

$$Pb = \frac{Vbm}{Vam} \cdot Pa \quad 6$$

$$Pc = \frac{Vcm}{Vam} \cdot Pa \quad 7$$

Total average power;

$$Pav = Pa + Pb + Pc \quad 8$$

By rearranging;

$$Pa = \frac{Vam}{Vt} \cdot Pav \quad 9$$

$$Pb = \frac{Vbm}{Vt} \cdot Pav \quad 10$$

$$Pc = \frac{Vcm}{Vt} \cdot Pav \quad 11$$

where

$$Vt = Vam + Vbm + Vcm \quad 12$$

Reference active source current are calculated as;

$$iacc(t) = \frac{2pav}{Vam*Vt} van(t) \quad 13$$

$$ibcc(t) = \frac{2pav}{Vbm*Vt} vbn(t) \quad 14$$

$$iccc(t) = \frac{2pav}{Vcm*Vt} vcn(t) \quad 15$$

Compensating current is obtained as

$$ican(t) = ian(t) - iacc(t) \quad 16$$

$$icbn(t) = ibn(t) - ibcc(t) \quad 17$$

$$iccn(t) = icn(t) - iccc(t) \quad 18$$

IV. Perfect Harmonic Cancellation Method

The objective of Perfect Harmonic Cancellation is to compensate all the harmonic currents and the fundamental reactive power demanded by the load in addition to eliminating the imbalance. The perfect harmonic cancellation (PHC) method is the control strategy that is capable of corrective action under all conditions. The source current will therefore be in phase with the fundamental positive-sequence component of the voltage at the PCC [6]. In turn, is achieved through a two-stage procedure. 1. The reference filter currents are obtained 2. In the second stage, a PWM hysteresis band current control is used to generate the required gate signals which are then fed to the inverter switches. The PHC control method is adopted here to generate the required compensation currents for the shunt active power filter. Any set of voltages (v_a,v_b,v_c) and currents (i_a,i_b,i_c) can be transformed into the(α-β -0) system where T is the transformation matrix using the power invariant as

$$\begin{bmatrix} v0 \\ v\alpha \\ v\beta \end{bmatrix} = T \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \quad (19)$$

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = T \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (20)$$

The function of the APF, controlled with the PHC method, is to compensate for all of the harmonic currents, provide the fundamental reactive power demanded by the load, and eliminate imbalance if it exists. To achieve these objectives altogether, the source current must be in phase with the fundamental positive- sequence component of the voltage at PCC. Therefore, the reference source current can be given in the form

$$isr = K.v_1^+ \quad 21)$$

where v_1^+ is the PCC voltage positive-sequence component.

The power delivered by the source p_s will be

$$p_s = v.i_{sr} = v.K.\ v_1^+ \quad (22)$$

The constant K can be determined by using the condition that the source power is equal to the average power (active power) $\underset{PL}{\rightarrow}$ demanded by the load, thus

$$K = P_L/(V_{\alpha 1}^{+2} + V_{\beta 1}^{+2}) \quad (23)$$

The reference current will be given by

$$\begin{bmatrix} is0r \\ is\alpha r \\ is\beta r \end{bmatrix} = K \begin{bmatrix} 0 \\ v\alpha 1 \\ v\beta 1 \end{bmatrix} = P_L/\ (V_{\alpha 1}^{+2} + V\beta 1^{+2}) \begin{bmatrix} 0 \\ v\alpha 1 \\ v\beta 1 \end{bmatrix} \quad (24)$$

After converting the α -β-0 components to the a-b-c phase quantities, the APF reference currents are generated as

$$[i_{fnr}] = [i_{Ln}] - [i_{snr}] \quad (25)$$

A hysteresis band PWM current control scheme is applied in this method to control the inverter so that its output current follows the reference current waveform. In this method, the switches in an inverter are asynchronously controlled and the actual current is ramped up and down to follow the reference current [7]. When the actual current exceeds the upper limit or drops below the lower hysteresis limit, the associated switching pattern of the switch will force the current to get back within the hysteresis band limit. Hence, the current ramp can be altered by the width of the hysteresis band. Decreasing the hysteresis band results in the filter current by following exactly the filter reference current; however, it increases switching losses.

V. Simulation Results

The simulation of the shunt active filter is carried in MATLAB/SimPowerSystems environment. The simulation model is shown in Fig.3. As can be seen from the figure, the non-linear load is a DC motor drive.

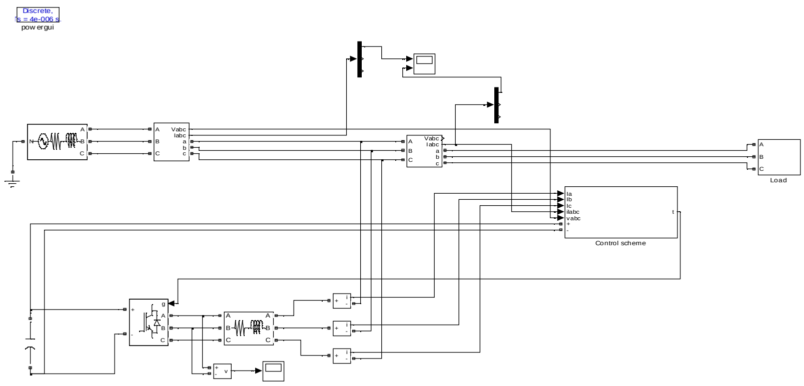

Fig 3: Overall Implementation

The simulation is done for various sources and the load condition of DC motor drive for providing harmonic compensation. The simulation result of the load current appears to be distorted due to the presence of the non linear load due to the absence of filter and is shown in Fig.4 and its THD is shown in Fig.5

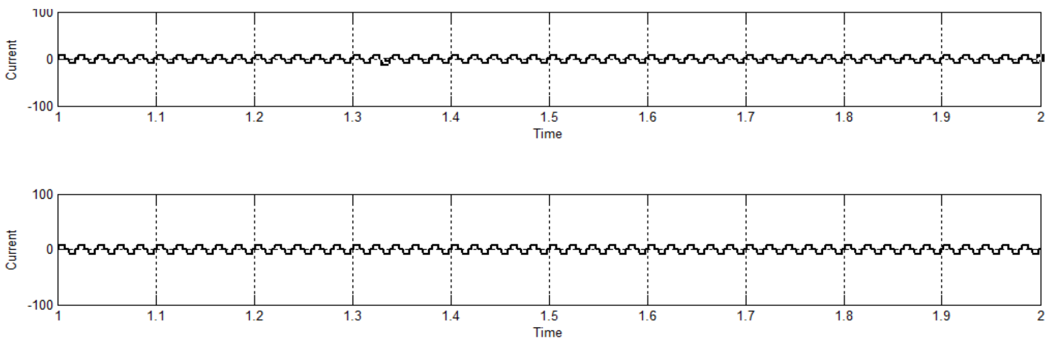

Fig 4: Distorted Source and Load current due to non linear load in the absence of filter

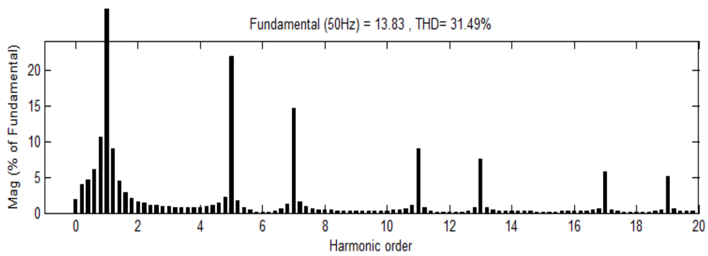

Fig 5: % THD in the absence of filter

- **Synchronous Detection Method**

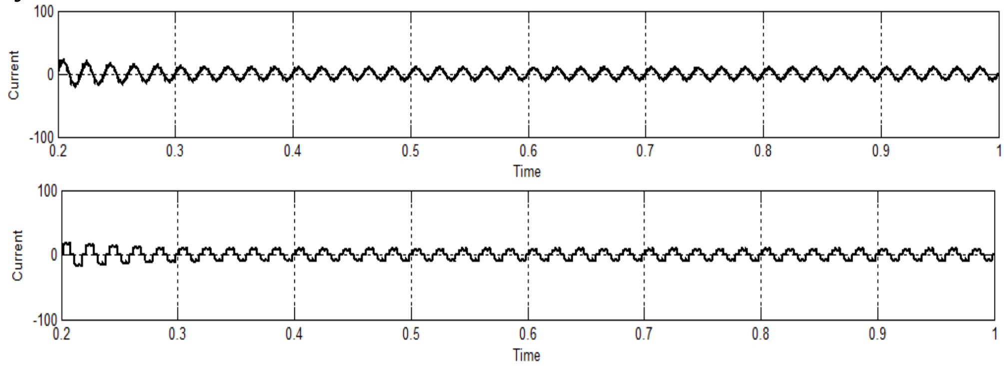

Fig 6: Output source current and load current waveform

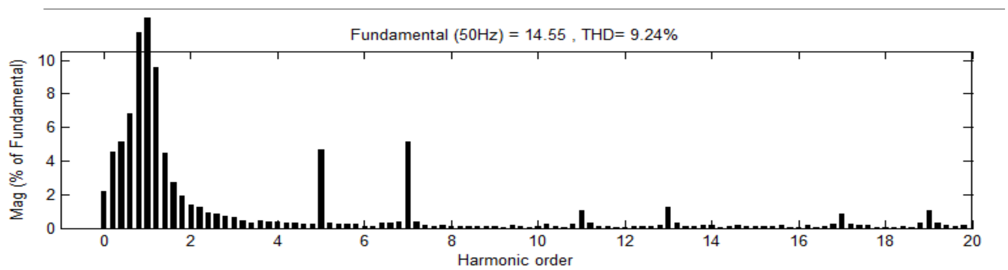

Fig 7: % THD of the source current

- **Perfect Harmonic Cancellation Method**

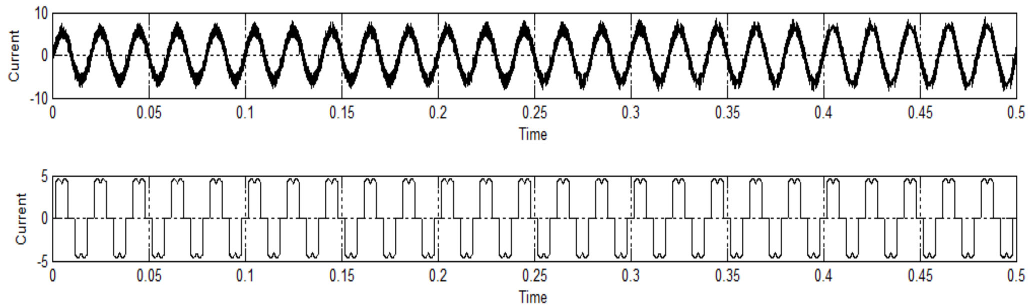

Fig8: Output source current and load current waveform

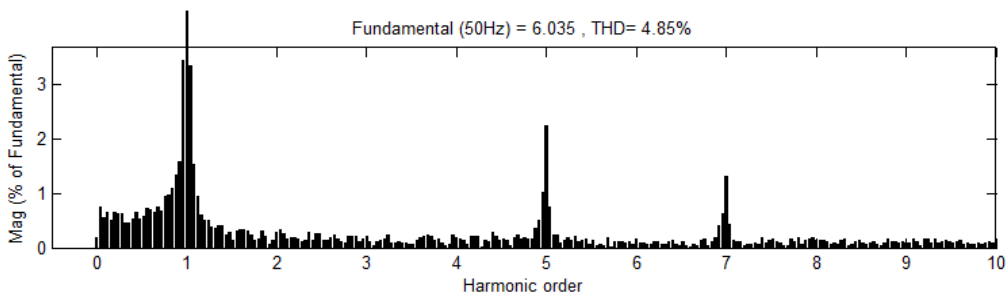

Fig 9: % THD of the source current

Table 1: Comparison of THD with different control strategies

S.no	Method	% of THD
1.	Absence of Filter	31.49
2.	Synchronous Detection	9.24
3.	Perfect Harmonic Cancellation	4.85

Conclusion

The comparison of two control techniques implemented for the generation of the reference current for shunt active power filters was presented. Figs.4-9 shows the simulated results of the control strategies. The compensation performance of the above techniques is almost similar under ideal balanced conditions. Under unbalanced conditions, it was shown that the synchronous detection method is more sensitive to distortion and imbalance in the voltages at the PCC. The simulation results and the comparison table shows that PHC strategy is efficient among both methods and capable of compensating action under any conditions of use.

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