

Control of Shunt Active Power Filter with PHC and SRF Methods for Compensation of Source Current Harmonics along with Hardware Implementation of SRF Method

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Abstract- In this paper, control schemes for shunt active power filter using perfect harmonic cancellation (PHC) and synchronous reference frame (SRF) methods as reference current generation techniques are proposed. SAPFs are used to eliminate source current harmonics and to improve the power factor in system feeding non-linear loads. In PHC method reference signals are calculated using positive sequence component of voltages taken from PCC and in SRF method reference signals are transformed from three-phase stationary frame (a-b-c) into three phase rotating frame (0-d-q). Using these techniques Total Harmonic Distortion (THD) can be reduced to acceptable level. These algorithms have been simulated in MATLAB/Simulink.

This SRF theory is experimentally implemented with dSPACE module CP1104 which has been used for real time interfacing.

Keywords- Shunt Active Power Filter (SAPF), Perfect Harmonic Cancellation (PHC) method, Synchronous reference Frame (SRF) method, Power Quality, THD, dSPACE module CP1104.

I. INTRODUCTION

In recent decades, the growing number of power electronics based equipment in both industrial and domestic applications loads causes harmonics in the system and impacts on the power quality of electric supply. At the same time, most of the equipment causing the disturbances is quite sensitive to deviations from the ideal sinusoidal line voltage. Due to the non-ideal characteristics of the voltage source, harmonic currents create voltage distortion. Non-linear loads such as rectifiers, cycloconverters, variable speed drives and arc furnaces, large decaying DC components, asymmetrical loads and other electrical equipment can cause high disturbances in the power supply system. The harmonics generated by the most common non-linear loads affects on amplitude and nature of source current hence the performance of the system.

This harmonic distortion problem has traditionally solved with the use of passive filters. However, it has some limitations so passive filters are dropped. And power engineers developed a dynamic and adjustable solution to power quality problems.

Such equipment as shown in fig. 1 is called an active filter and is able to compensate current and voltage harmonics [1].

The basic principle of a shunt 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 common coupling, thereby forcing the source current to be pure sinusoidal. Harmonic and reactive currents are thus cancelled at the source end and the result is undistorted sinusoidal balanced currents.

The Active filters are overcome the problem occurring in the passive filter. The characteristics and efficiency of harmonic compensation and its effectiveness depend on the control algorithm applied to calculate the load current harmonics.

Recently we are using the following devices to reduce the harmonics and to improve the performance of the electrical network [2]: SVC- Static Var compensator, FACTS device Unified power quality conditioners (UPQC).

But the most effective way to eliminate the harmonics in the electrical network is done by using the active power filter (APF).

With the use of active power filter we can achieve Harmonic Compensation, Harmonic Damping, Harmonic Isolation, Reactive power compensation, Voltage regulation.

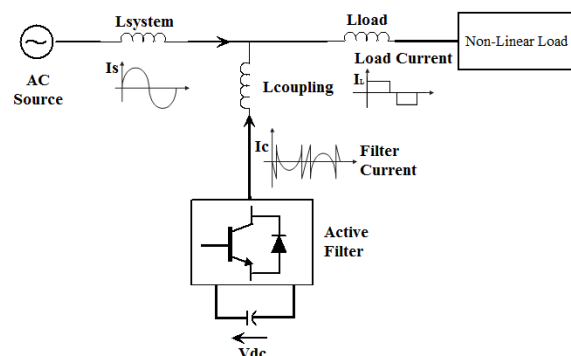


Fig. 1. Basic Structure of SAPF

The reference current generation is very important for APF. In this paper reference current generation using SRF theory is presented. The experimental setup is done using DS1104 card of DSPACE system. Finally simulation and experimental results are presented.

II. CONTROL STRATEGY

A. PHC- Perfect Harmonic Cancellation

The PHC control method is adopted here to generate the required compensation currents for the shunt active power filter. The objective is to compensate all the harmonic currents and the fundamental reactive power demanded by the load in addition to eliminating the imbalance. The source current will be in phase with the fundamental positive sequence component of the voltage at the PCC[8]. The required equations of the PHC control method are explored in [5], [11]. Assume the voltages at the point of common coupling PCC are Va, Vb, Vc, and loading currents are ILa, ILb, ILc, the instantaneous power of the load is given by [12].

$$P_L = V_a I_{L_a} + V_b I_{L_b} + V_c I_{L_c}$$

This power has mean and oscillating values

$$p_L = \tilde{P}_L + \bar{P}_L$$

The capacitor voltage Vdc is kept constant through controlling the switch power loss in the inverter using PI controller which regulates DC capacitor voltage.

The total active power fed by the source is the sum of the inverter switching loss Psw and the active power needed by the load pL.

The reference source current is given by:

$$i_{sref} = K v_+^1$$

Where v+1 is the PCC voltage space vector with a single fundamental positive sequence component obtained from the phase-locked loop (PLL) circuit.

The power delivered by the source will be:

$$p_s = v i_{sref} = v \cdot K \cdot v_+^1 = K (v_\alpha \cdot v_{\alpha+}^1 + v_\beta \cdot v_{\beta+}^1)$$

The average (mean) power is calculated by using low pass filter (LPF).

The value of K parameter in the above equation is calculated by taking division of average load power and summation of the squared of the positive sequence component of the PCC voltages.

$$K = \frac{\bar{p}_L}{v_{\alpha+}^2 + v_{\beta+}^2}$$

Once the parameter K is obtained, the source reference currents are calculated by multiplying it by the positive sequence component of the voltage.

$$\begin{bmatrix} i_{s0ref} \\ i_{saref} \\ i_{s\beta ref} \end{bmatrix} = K \cdot \begin{bmatrix} 0 \\ v_{\alpha+}^1 \\ v_{\beta+}^1 \end{bmatrix} = \frac{\bar{p}_L}{v_{\alpha+}^2 + v_{\beta+}^2} \cdot \begin{bmatrix} 0 \\ v_{\alpha+}^1 \\ v_{\beta+}^1 \end{bmatrix}$$

The actual reference currents are calculated by taking inverse transformation of the above equation.

The basic diagram of reference current generation with PHC method is as shown in figure 2.

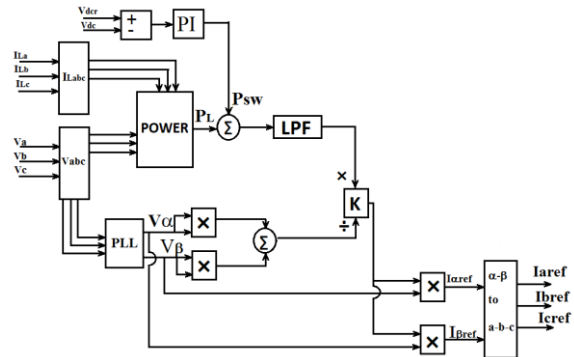


Fig. 2. Block diagram of reference current generation using perfect harmonic cancellation method

III. SIMULATION RESULT FOR PHC METHOD-

The first result in the following fig. shows that the source current before compensation and second result shows that current after compensation.

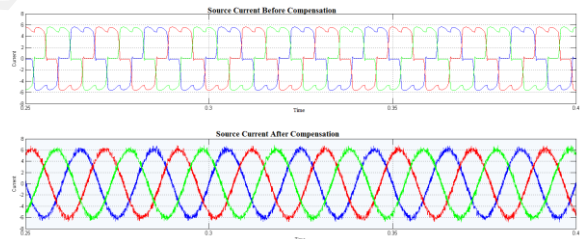


Fig. 3. Source current before compensation and after compensation

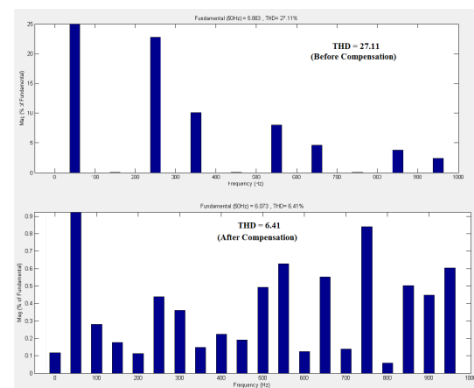


Fig. 4. THD before compensation and after compensation

From the above figure it is seen that THD reduces to 6.41 from 27.11.

A. SRF- Synchronous Reference Frame method-

Reference Frame transformation is the transformation of coordinates from a three-phase a-b-c stationery co-ordinate

system to the 0-d-q rotating coordinate system [3] as shown in Figure 2.

This transformation is important because it is in 0-d-q reference frame the signal can effectively be controlled to get the desired reference signal. Transformation is made in two steps: In 1st transformation from the three-phase stationary coordinate system to the two-phase so-called α - β -0 stationary coordinate system is done. Load currents and voltages at Point of Common Coupling (PCC) are transformed to $0\alpha\beta$ coordinates.

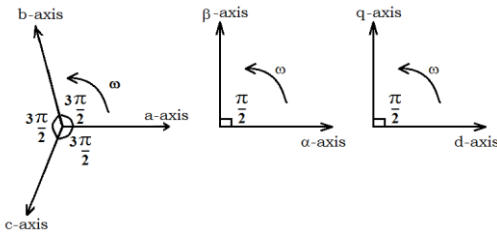


Fig. 5. Reference Frame Transformation

The axes a, b, and c are fixed on the same plane and are separated from each other by 120 degree,

α - β -0 are orthogonal axes with the α -axis being synchronized with the a-axis of a-b-c plane and β -axis being orthogonal to the α -axis. $0\alpha\beta$ in fig.2 is still rotating with the frequency of ω radians/second. To eliminate this frequency, a 2nd step is taken, in this transformation from the 0- α - β stationary coordinate system to the 0-d-q rotating coordinate system.

The transformation from 3 phase a-b-c stationary frame to 2 phase α - β -0 stationary frame is given by,

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

The transformation from 2 phase α - β -0 stationary frame to 2 phase 0-d-q rotating frame is given by,

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin \theta & -\cos \theta \\ \cos \theta & \sin \theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

The DC quantities and all other harmonics are transformed to non-DC quantities using a low pass filter:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \tilde{i}_d + \tilde{\tilde{i}}_d \\ \tilde{i}_q + \tilde{\tilde{i}}_q \end{bmatrix}$$

The algorithm is further carried a step forward, where the current reference signal in 0-d-q rotating frame is converted back into a-b-c stationary frame, the reference signal for the from 0-d-q rotating frame to a-b-c stationary frame is achieved with two steps 0-d-q to 0- α - β and again 0- α - β to a-b-c [4]. Pulse Width Modulation (PWM). The inverse transformation The transformation from 2 phase 0-d-q rotating frame to 2 phase α - β -0 stationary frame is given by,

$$\begin{bmatrix} i_{\alpha_ref} \\ i_{\beta_ref} \end{bmatrix} = \begin{bmatrix} \sin \theta & -\cos \theta \\ \cos \theta & \sin \theta \end{bmatrix}^{-1} \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

The transformation from 2 phase α - β -0 stationary frame to 3 phase a-b-c stationary frame is given by,

$$\begin{bmatrix} i_{a_ref} \\ i_{b_ref} \\ i_{c_ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{\alpha_ref} \\ i_{\beta_ref} \end{bmatrix}$$

These reference currents are used for the generation of the PWM pulses by using the HCC i.e. hysteresis current controller.

In the HCC we compare reference current with the load current and filter current to get the pulses for the inverter [5].

By using,

$$i_{ca}^* = i_{sa}^* - i_{La}^*$$

$$i_{cb}^* = i_{sb}^* - i_{Lb}^*$$

$$i_{cc}^* = i_{sc}^* - i_{Lc}^*$$

These pulses will be used for triggering of the IGBT's used in the inverter circuit. The o/p of the inverter is fed to the system to compensate the harmonics in the system. These current is nothing but Filter current or compensation current for the system.

The basic diagram of the reference current generation technique is as shown below, in this load currents are used to generate the reference signal with the help of source voltage of system.

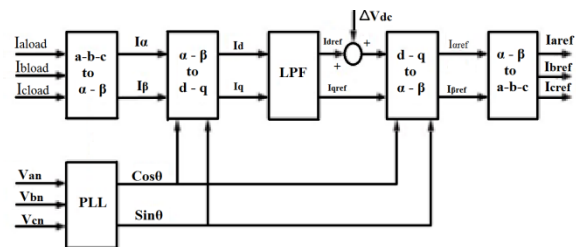


Fig. 6. Block diagram of current reference generation using synchronous reference frame method

IV. SIMULATION RESULT

The first result in the following fig. shows that the source current before compensation and second result shows that current after compensation.

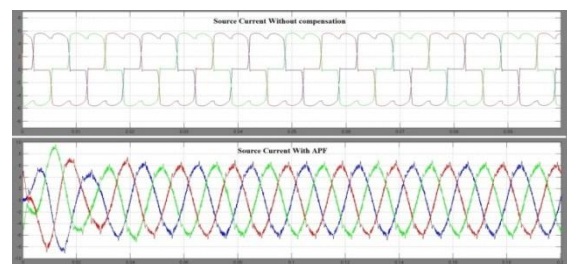


Fig. 7. Source current before and after compensation

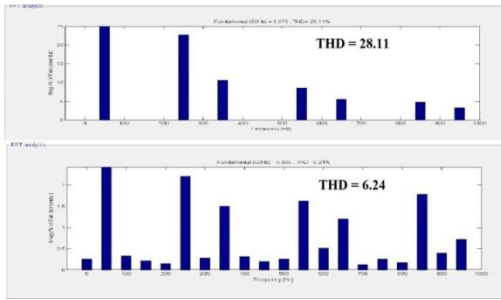


Fig. 8. THD before compensation 28.11 and THD after compensation 6.24

In the above figure THD of the system after compensation is reduced to 6.24 from 28.11.

V. HARDWARE DETAILS

The details of the hardware used for project work is as follows,

Components used in this project are,

A. Interfacing system :



System is loaded with MATLAB 2010a, along with the interfacing kit fixed in CPU of the system.

B. Three phase supply :



It is three phase source, supplies 3-ph, 440V AC, 50 Hz.

C. Hall Effect Current and Voltage Sensors:



The sensor block consists of 3 numbers of each current and voltage sensors.

1) Current Sensor:

Primary Nominal r.m.s. current, $I_{PN} = 12\text{ A}$

Primary Output voltage, $V_{out} (I_p=0) = 2.5\text{ V}$

2) Voltage Sensors:

Primary Nominal r.m.s. current, $I_{PN} = 10\text{ mA}$

Primary Nominal r.m.s. Voltage, $V_{PN} = 10\text{ to }500\text{ V}$

Secondary Nominal r.m.s. current $I_{SN} = 25\text{ mA}$

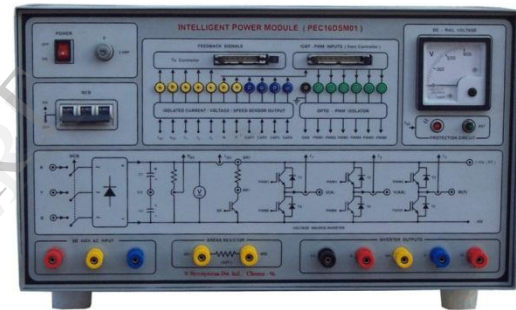
D. dSPACE module:



It is dSPACE module CP1104 which is being used in project for Real Time interfacing. It consists of 8 input channels (ADC) and 8 output channels (DAC), with indicating LEDs for each pin. Also consist of digital I/O pins; these I/O pins are used for gating signal for IGBT of the INVERTER module shown below.

ADC ports are used as input ports and DAC ports are used as output ports.

E. Intelligent Power Module (PEC16DSM01):



It consists of IGBTs internally connected to each other. IGBTs are used for inverter.

It operates on 3-ph, 440 V, 50 Hz,

Switching frequency of IGBT = 20 KHz.

DC link voltage = 750 V. Maximum current $I_{max} = 8\text{ A}$.

VI. HARDWARE WORK:-

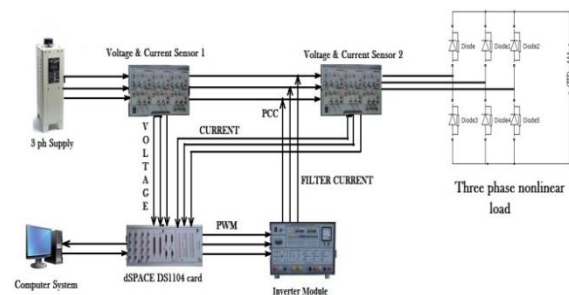


Fig. 9. Hardware implementation

The 3phase, line to line voltage used in above system is 400V. These voltages are given to load through two voltage and current sensors. Outputs of the sensors are in the form of voltages which ranges from 0-10V i.e. into electronic level voltage. These voltages are further given to the dSPACE

DS1104 kit. These voltages are then taken into MATLAB Simulation window with the help of ADC ports of the dSPACE. First sensor is used to sense source voltages and second sensor is used to sense load currents. These currents and voltages are used to find out the reference currents which are used as gating pulse for IGBT's of the inverter. These pulses are generated by using Hysteresis current controller (HCC). The outputs of HCC are given to inverter through I/O ports of the dSPACE kit.

Output of the Inverter is filter current which is also known as compensating current. This compensating current is feed at PCC which will help to reduce the harmonics in source current. So that we can get sinusoidal source current.

VII. HARDWARE RESULTS

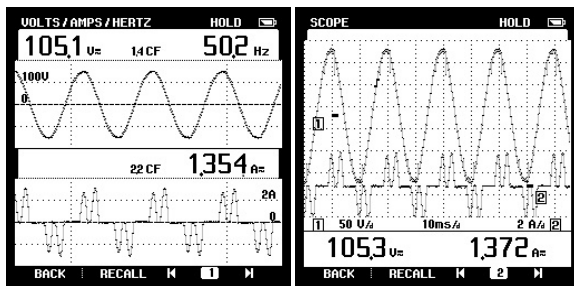


Fig. 10. Source voltage and Source current before compensation measured by a. fluke meter b.fluke scope meter

From the above results we get distorted current waveform, which is observed in both meters. Waveforms of source current and load current before compensation are same in nature and in magnitude.

These currents and voltages are taken in the system with the help of Hall Effect sensor and ADCports of dSPACE kit. The process for calculation of reference currents are done in MATLAB. These reference currents are taken from the I/O ports of the dSPACE 1104 kit. These reference currents are as shown in figure 9 below.

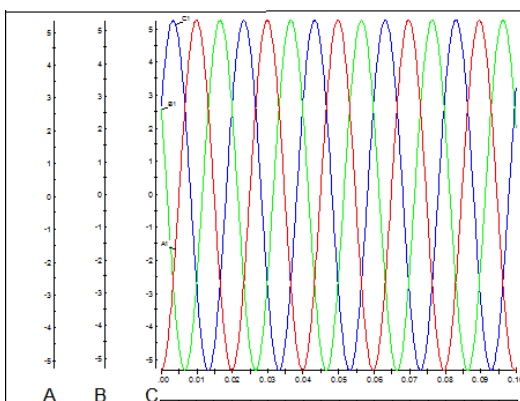


Fig. 11. Reference currents measured in control desk

These reference currents are sinusoidal which are same as o/p of MATLAB module results.

VIII. CONCLUSION

This paper presents the real time current reference generation technique simulated using software MATLAB. The performance of three-phase distribution system with and without Shunt Active Power Filter for Non-linear load was

discussed in the above section and following observation is obtained.

In PHC method THD of the system without SAPF is 27.11% this is reduced to 6.41% with help of SAPF.

In SRF method THD of the system without SAPF is 28.11% this is reduced to 6.24% with help of SAPF.

SRF strategy is the most sensitive to distortion and imbalance in the voltages at the PCC. In hardware, load balancing and harmonic elimination is also achieved and the response of SAPF to compensate the load is found effective and fast.

IX. REFERENCES

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