Implementation of Single Phase Shunt Active Filter for Low Voltage Distribution System

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Abstract—The use of power electronic circuits in a wide range of applications has resulted in distorted current in the power system. Custom power device such as shunt active filter is used to improve the quality of power in distribution system by injecting reactive and harmonic currents. Hysteresis current control is one of the simplest techniques used to control the magnitude and phase angle of the current injected by shunt active filter. In this paper, simulation and hardware implementation of single phase Shunt Active Filter (SAF) is carried out. The simulation results presented in this paper illustrate the performance of shunt active filter in mitigating the source current harmonics and improving the input power factor. The simulation is carried out using MATLAB/SIMULINK and laboratory implementation is done using DSP Controller TMS320LF2407. In the present work, there is no separate measurement for the phase angle of supply voltage, which makes the controller implementation simple in real time. Hardware results confirm the simulation results under practical conditions.

Keywords – Power Quality, Current distortion, Nonlinear Loads, Harmonics, Power factor, Shunt Active Filter (SAF).

NOMENCLATURE

\[ V_s = \text{Source voltage, V} \]
\[ R_s = \text{Line resistance, } \Omega \]
\[ L_s = \text{Line inductance, mH} \]
\[ L_f = \text{Filter inductance, mH} \]
\[ R_d = \text{Load resistance, } \Omega \]
\[ L_d = \text{Load inductance, mH} \]
\[ i_s = \text{Source current, A} \]
\[ i_l = \text{Load current, A} \]
\[ i_f = \text{Filter current, A} \]

I. INTRODUCTION

Power Quality (PQ) is an important measure of an electrical power system. The term PQ means to maintain purely sinusoidal current in phase with a purely sinusoidal voltage. The power generated at the generating station is purely sinusoidal in nature. The quality of electric power is deteriorating mainly due to current and voltage harmonics, zero and negative sequence components, voltage sag, voltage swell, flicker, voltage interruption, etc. [1].

An unavoidable increase of nonlinear loads in industrial, commercial and residential applications requires local supply of reactive and harmonic powers in order to reduce the power loss and maintain the quality of power in the system. Traditional compensation methods such as passive filters, synchronous condensers, phase advance, etc. were employed to improve the power quality. The shunt passive LC filters are used to improve power factor and to suppress current harmonics. One of the major disadvantages of passive filters is the non changeable compensation characteristics.

Other traditional controllers also possess several disadvantages like bulkiness, electromagnetic interference, resonance, etc. These disadvantages urged to further research in developing adjustable and dynamic solutions using custom power devices. Custom power devices are power conditioning equipment using static power electronic converters to improve the power quality. Shunt active filter (SAF) is one among the various types of custom power devices proposed to improve the power quality [2].

Various current control methods were proposed for shunt active filter. Hysteresis current control method is the most popular one in terms of quick current controllability, versatility and easy implementation [1]. For implementing hysteresis current control, Digital Signal Processor has good dynamic and fast response among many digital controllers [3]. DSP 2407 is employed in the present work for the prototype implementation of single phase shunt active filter.

II. SHUNT ACTIVE FILTER

A. Principle of Operation

The shunt active filter shown in Fig. 1 is a current controlled voltage source inverter (VSI), which is connected in parallel with the load. It is controlled in such a way to generate the required reactive and harmonic currents of the load. Hence, the utility needs to supply only the active part of the fundamental component of the load current and thus the power pollution problem along the power line could be avoided.

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B. Compensation Technique

The control algorithm computes the reference for the compensation current to be injected by the shunt active filter. The choice of the control algorithm therefore decides the accuracy and response time of the filter. The calculation steps involved in the control technique have to be minimal to make the control circuit compact. The control strategy has an objective to guarantee balanced and sinusoidal source current at unity power factor. This objective can be easily realized if the active part of the fundamental component of the load current is accurately and instantaneously determined.

C. Hysteresis Current Control

The hysteresis current control scheme used for the control of shunt active filter is shown in Fig.2. The reference for compensation current to be injected by the active filter is referred to as $i_{ref}$ and the actual current of the active filter is referred to as $i_{inj}$. The control scheme decides the switching pattern of active filter in such a way to maintain the actual injected current of the filter to remain within a desired hysteresis band (HB) as indicated in Fig. 2.

The switching logic is formulated as follows:

If $i_{inj} < (i_{ref} - HB)$  $S_1, S_2$ ON & $S_3, S_4$ OFF
If $i_{inj} > (i_{ref} + HB)$  $S_1, S_2$ OFF & $S_3, S_4$ ON

III. SIMULATION OF SHUNT ACTIVE FILTER

The simulation study on a single-phase, 50-Hz, 75 V (peak) distribution system feeding a single phase diode rectifier with RL load has been carried out in MATLAB 7.4. The Simulink model of the distribution network with shunt active filter is shown in Fig. 3.

The system parameters are furnished in Table I. In the present simulation, harmonic compensation and input power factor improvement are considered.

<table>
<thead>
<tr>
<th>Details</th>
<th>Parameters</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Input source voltage (V_s)</td>
<td>75 V (Peak)</td>
</tr>
<tr>
<td></td>
<td>DC Voltage (V_d)</td>
<td>120 V</td>
</tr>
<tr>
<td></td>
<td>Filter Resistor($R_f$)</td>
<td>2.5 Ω</td>
</tr>
<tr>
<td></td>
<td>Filter inductor ($L_f$)</td>
<td>10 mH</td>
</tr>
<tr>
<td>Load (0.1 kW)</td>
<td>Resistance of the load ($R_l$)</td>
<td>10 Ω</td>
</tr>
<tr>
<td></td>
<td>Inductance of the load ($L_l$)</td>
<td>30 mH</td>
</tr>
<tr>
<td>Voltage Source</td>
<td>Per unit reactance</td>
<td>0.02</td>
</tr>
<tr>
<td>Inverter</td>
<td>Transformation ratio</td>
<td>1:1</td>
</tr>
<tr>
<td>Shunt Transformer (1.5 kVA)</td>
<td>Transformation ratio</td>
<td>1:1</td>
</tr>
</tbody>
</table>
A. Reference Current Generation

The discrete Fourier Transform (DFT) has been used to extract the magnitude and phase angle of the fundamental component of the load current. This fundamental component has both real and reactive parts. The magnitude of the real part of the fundamental component is multiplied with unit sine having same phase angle of the supply voltage. The difference between the real part of the fundamental component and the actual load current constitute the reference for the current to be injected.

B. Firing Pulse Generation

The MATLAB implementation of firing pulse generation using hysteresis current control is shown in Fig. 4. The generated pulses are used to trigger the respective IGBTs of the inverter.

IV. HARDWARE IMPLEMENTATION

The hardware implementation of the considered distribution network along with SAF is shown in Fig. 5. A DPST is used to connect the shunt active filter, which includes a shunt transformer, VSI, associated filters and the DSP controller, with the system.

The simulation results along with the hardware results are discussed in section V.

The flow chart for the control algorithm of shunt active filter implemented using DSP TMS320LF2407 is shown in Fig. 6. The load current is sensed at PCC using a current sensor. The real part of the fundamental component of the load current will be in phase with the source voltage. Hence, with a suitable voltage sensor circuit design, the equivalent voltage of the real part of the fundamental load current can be derived from the source voltage itself. This technique avoids the determination of the phase angle of the supply voltage in practice. These sensed signals are given as input to the Analog to Digital Converter (ADC) of DSP controller. Sampling frequency used in ADC is 20 kHz.

Determination of reference current ($i_{ref}$) is made by eliminating the real part of the fundamental component of load current from the actual load current as given below.

\[
\begin{align*}
    i_{load} & = i_{real} + i_{react} + i_{har} \\
    i_{load} - i_{real} & = i_{react} + i_{har} \\
    i_{ref} & = i_{react} + i_{har}
\end{align*}
\]
This reference current when injected cancels out the harmonic and reactive component of load current so that the source current becomes sinusoidal and harmonic free at unity power factor. A hysteresis band is fixed along this determined reference current. The actual inverter current is also sensed and given as an input to the ADC of DSP controller. The control signals are obtained from the Digital to Analog Converter (DAC) of DSP, based on the developed control algorithm given in Fig. 6, such that the inverter current should follow the reference current within the hysteresis band.

V. SIMULATION AND EXPERIMENTAL RESULTS

As discussed in Section III and IV, the distribution network is supplied with a voltage of 75 V (peak). The simulated and experimental waveforms of the source voltage are shown in Figs. 7(a) and 7(b). The single phase rectifier fed RL load draws a non sinusoidal current from the source as shown in Figs. 8(a) and 8(b). When the SAF is connected with the circuit, the load current changes as shown in Figs. 9(a) and 9(b). This change in load current is observed due to the compensation effected by the shunt active filter. The injected current through the shunt transformer with the hysteresis band and the corresponding pulse pattern is shown in Figs. 10 (a) and 10(b). This compensation current when injected makes the source current sinusoidal and harmonic free as shown in Figs.11(a) and 11(b).

The load current, the current injected by SAF and the compensated source current are shown in Figs. 12(a) and 12(b). The source voltage (C1) load current (C2) and the compensated source current (C3) are shown in Figs. 13(a) and 13(b). These results clearly depict the improvement in input power factor.

The harmonic spectrum of the source current before and after compensation obtained from simulation and experiment are shown in Figs. 14(a), 14(b) and Figs. 15(a), 15(b) respectively. The THD of the source current improves from 11% to 4% which is within the limit of IEEE 519 harmonic standard. The experimental measurement of input power factor before and after compensation is shown in Figs. 16(a) and 16(b). It can be clearly observed that the input power factor is improved from 0.91 to unity.

VI. CONCLUSION

The simulation and prototype implementation of single phase shunt active filter have been carried out. Hysteresis current control is implemented in the present study for harmonic elimination of source current. DSP controller is employed in the laboratory to implement prototype model of SAF. In the present work, there is no separate measurement for the phase angle of supply voltage, which makes the controller implementation simple in real time. The simulation results show that the performance of SAF is satisfactory in elimination of source current harmonics and improving the input power factor. The experimental results confirm the satisfactory operation of SAF in distribution system with non linear loads. The SAF is found to be effective in both simulation and practice to meet IEEE 519 standard recommendation on harmonic levels in source current.

REFERENCES

Simulation Results

Fig. 7 (a) Source voltage

Fig. 8 (a) Load / Source current without SAF

Fig. 9 (a) Load current with SAF

Fig. 10 (a) Reference current and Pulse generation using Hysteresis control

Fig. 11(a) Source current after compensation

Experimental Results

Fig. 7 (b) Source Voltage

Fig. 8 (b) Load /Source Current without SAF

Fig. 9 (b) Load Current with SAF

Fig. 10 (b) Reference current and Pulse generation using Hysteresis Control

Fig. 11(b) Source current after compensation
Fig. 12 (a) Load current, Filter current and Source current

Fig. 13 (a) Source voltage (C1), Load current (C2) and Source current (C3)

Fig. 14 (a) Harmonic spectrum of source current before compensation

Fig. 15 (a) Harmonic spectrum after compensation

Fig. 16(a) Input power factor before compensation

Fig. 12 (b) Load current, Filter current and Source current

Fig. 13 (b) Source voltage (C1), Load current (C2) and Source current (C3)

Fig. 14 (b) Harmonic spectrum of source current before compensation

Fig. 15 (b) Harmonic spectrum after compensation

Fig. 16(b) Input power factor after compensation