MODELLING & SIMULATION OF ACTIVE SHUNT FILTER FOR COMPENSATION OF SYSTEM HARMONICS

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ABSTRACT

The present work involves the simulation study of the design, of single phase Shunt active filter. The active shunt filter for compensating harmonic currents generated by non-linear loads. The topology of the filters is based on a single-phase voltage source filter (VSI) with four Insulated gate bi-polar transistor (IGBT) semiconductor switches. Simple time-domain extraction techniques are used to determine the harmonic components present in the load current or source voltage. The pulse-width modulated (PWM) technique is then used to generate the required gate drive signals to the full-bridge VSI. A low-pass filter is also incorporated in the output of the inverse to provide a sufficient attenuation of the high switching ripples caused by the VSI.

Key-words: Shunt active filter, voltage source inverter, Sinusoidal PWM (SPWM),

I. INTRODUCTION

Harmonic contamination in power systems is a serious problem due to the increase of nonlinear loads over the last 20 years, such as static power converters, arc furnaces, and others. The widespread use of the static power converters in the recent years, the problems of power system harmonics have increased considerably. Static power Converters make use of power semiconductor devices as electronic switches to transfer and convert power from one form to another. The switching actions of the power devices result in a distorted input current, which contains a fundamental component (50Hz) and other higher harmonic components (in multiples of 50Hz). Hence, the power converter behaves as a current source, injecting harmonic current into the supply network. This constitutes the problems of power system harmonics. In addition to the operation of transformers on the sinusoidal supplies, the harmonic behaviour becomes important as the size and rating of the transformer increases. The effects of the harmonic currents are:
1. Additional copper losses due to harmonic currents
2. Increased core losses
3. Increased electromagnetic interference with communication circuits.
On the other hand the harmonic voltages of the cause:
1. Increased dielectric stress on insulation
2. Electrostatic interference with communication circuits.
3. Resonance between winding reactance and feeder capacitance.

In the present times a greater awareness is generated by the problems of harmonic voltages and currents produced by non-linear loads like the power electronic converters. These combine with non-linear nature of transformer core and produce severe distortions in voltages and currents and increase the power loss. If not properly designed or rated, electrical equipment will often malfunction when harmonics are present in an electrical system. Most people don’t realize that harmonics have been around a long time. Since the first AC generator went online more than 100 years ago, electrical systems have experienced harmonics. The harmonics at that time were minor and had no detrimental effects.

The shunt active filter is used to compensate the current harmonic distortion to power system harmonics. The design of the active filter is based on a single-phase VSI with four IGBT semiconductor switches. To verify the operating performance of the designed filters is carried out and experimental results are obtained and discussed.

II. SHUNT ACTIVE FILTER

Figure 1: Block Diagram of Shunt Active Filter.

Figure 1 shows the system block diagram for the shunt active filter that will be discussed in this section. The shunt active filter concept uses power electronic converters to produce equal-but-opposite compensating harmonic components, which cancel the harmonic components of the non-linear loads. It can limit harmonics to acceptable levels and can adapt itself in case harmonic component alternation or changes in the nonlinear load types. The design of the active filter is based on a single-phase Voltage source inverter (VSI) with four Insulated gate bi-polar transistor (IGBT) semiconductor switches. The topology of the filter is based on a single-phase voltage source inverter (VSI) with four IGBT semiconductor switches. Simple time-domain extraction techniques are used to determine the harmonic components present in the load current or source voltage. The pulse-width-modulated (PWM)
technique is then used to generate the required gate drive signals to the full-bridge VSI. A low-pass filter is also incorporated in the output of the inverter to provide a sufficient attenuation of the high switching ripples caused by the VSI.

Usually, the technique used to control the single-phase shunt active filter is to sense the non-linear load current and its harmonic components. The fundamental principle of this method of reducing harmonic current is to inject equal-but-opposite compensating harmonic current IC into the line. This IC will cancel out the harmonic current introduced by the non-linear load since they are equal but opposite. Hence, the source current Is will be sinusoidal and of good quality. Based on the above fundamental concept, the non-linear load current IL is sensed by a current transducer. The sensed IL is passed through an extraction circuit to filter out fundamental components of the IL. Thus, the output of the extraction circuit is a signal containing purely the harmonic components of IL.

A. Reference Extraction Circuit

Simple time-domain extraction techniques are used to determine the harmonic components present in the load current or source voltage [1].

![Figure 2 Block diagram of Reference extraction circuit](image)

Without active filter compensation, the line current, which is distorted by the power factor and harmonics of the characteristics of the load, results in a load current IL made up of the following four terms.

\[
i_L(t) = i_o(t) + i_p(t) + i_q(t) + i_h(t) \quad ..........(1)
\]

Where, Io-dc component, Ip-in-phase line current; Iq-reactive current, Ih-Harmonic currents. Equation (1) can be further expanded as shown in, where the first and second summation represents the even and odd harmonics, respectively. This is very general form of load current. However, in practice, the dc component is usually small or it does not exist at all. Also, when no neutral connection is used zero sequence harmonics do not exist.
The only component that the mains should supply is the active current $I_p[IP \cos(\omega t)]$. Using (1), it can be noted that if the active filter supplies the dc component, the reactive and the harmonic currents for the load, then the mains needs only to supply the active current. This can be easily accomplished by subtracting the active current component $I_p$ from the measured load current $I_L$.

$$i_F(t) = i_L(t) - i_p(t) = i_L(t) - I_p \cos(\omega t).$$  \hspace{1cm} \text{(3)}$$

In (3), $I_p$ is the magnitude of the in-phase current (which needs to be estimated) and $\cos(\omega t)$ is a sinusoid in phase with the line voltage. This operation can be accomplished by the circuit shown in above block diagram. The estimation of $I_p$ is now explained. Let us consider the product of the load current of (2) and a sinusoid in phase with the line voltage.

$$i_L(t) \cdot \cos(\omega t) = I_o \cos(\omega t) + \frac{I_p}{2}[1 + \cos(2\omega t)]$$
$$+ \frac{I_2}{2} \sin(2\omega t)$$
$$+ \sum_{j=1}^{\infty} \frac{I_{2j}}{2} \cos((2j + 1)\omega t + \phi_{2j})$$
$$+ \cos((2j - 1)\omega t + \phi_{2j})$$
$$+ \sum_{k=1}^{\infty} \frac{I_{2k+1}}{2} \cos((2k + 2)\omega t + \phi_{2k+1})$$
$$+ \cos(2k\omega t + \phi_{2k+1})]$$. \hspace{1cm} \text{(4)}$$

After the multiplication, the only dc term present in (4) is proportional $I_p$. Thus, a low-pass filter whose cut-off frequency is below $\omega$ permits one to obtain $I_p$, which is an estimation of the magnitude of $I_p(t)$. Then, this dc value is multiplied by the instantaneous active current $I^*p(t)$. Finally, this value of $I^*p(t)$ is subtracted from the measured load current $I_L(t)$ obtaining the required reference current $I_F(t)$.

**B. SPWM Current Controller**

The triangular waveform generator for the carrier signal used for the PWM. The 8038 waveform generator produces a bipolar 15 kHz triangular wave. In this SPWM, the reference signal, which is the harmonic signal output from the extraction circuit, is compared with the bipolar triangular carrier wave generated by the bipolar triangular wave generator [2].
The gating signals for the switching devices are obtained by modulating a reference sine wave with a triangular carrier of fixed frequency as shown in figure 5.3.

- If \( V_{\text{ref}} > V_{\text{tri}} \) then PULSE is generated
- If \( V_{\text{ref}} < V_{\text{tri}} \) then NOTCH is generated
- Gating signals for T1 and T4
- Gating signals for T3 and T2 is generated by modulating inverted reference sine wave.

The usual practice is that the frequency of the carrier wave is at least hundreds times that of the reference signal. That is why we generate the unipolar triangular wave at 15 kHz which is 300 times the 50Hz fundamental frequency. The input signals to the power semiconductor device, in this case IGBT, of the harmonic inverter are generated at the mutual crossing instants of the two waveforms as presented in Figure. 4. This type of operation obviously requires that the IGBT to have turn-off capability. In steady-state operation, the DC voltage output of the rectifier bridge to which the inverter is connected should be kept at a constant value with the help of output capacitor as shown in Figure. 5[3]. The inverter output becomes a train of variable-duration pulses which fluctuates between this +ve and –ve Vdc, and which digitally reproduces the reference signal when averaged.
The switching frequency of the SPWM inverter is the average rate at which the circuit develops output pulses and is determined by the frequency of the triangular carrier waveform. In this active filter application, the higher the relative switching frequency, the more fidelity to the reference signal is obtained. However, there are two factors that impose limit to the switching frequency of SPWM. They are the switching frequency capability of the IGBT, and the increase in switching losses, which is proportional to high switching frequency. The switching losses will reduce the circuit efficiency. Hence, there must be a compromise between fidelity and efficiency.

![Connection of Capacitor for constant Vdc.](image)

**Figure 5:** Connection of Capacitor for constant Vdc.

### C. Output Low-Pass Filter

Low-pass filter means attenuation of frequencies above their cut-off points. The output of the VSI is connected to a LC low-pass (LP) interfacing filter to provide a sufficient attenuation of the high switching ripples caused by the VSI. Hence, the adopted solution to this output filtering problem is the combined use of an ordinary second-order LC low-pass filter with a damping branch consisting of RC.

This LP filter is required to connect the active filter to the utility system. The need for stems from the fact that a PWM VSI is used to produce compensating harmonic current. To improve the source current waveform, the LP filter is designed with a cut-off frequency The R and C branch should be carefully designed to reduce the voltage distortion of the active filter output and to minimize the branch current at the fundamental frequency.

### III RESULTS & DISCUSSION

After designing the topology of the Shunt active filter, carried out in MATLAB/SIMULINK [5] to verify their operation. In this paper, the shunt active filter is implemented in a Single-phase system.

Figure 6 shows the source current $I_s$ before compensation and Figure 7 shows the Fast Fourier Transform (FFT) of $I_s$. The harmonics present in the source current are due to the non-linear load. Its FFT illustrates that its total harmonic distortion (THD) is 6.6%.

After the shunt active filter is connected to the system, the source current is compensated to a much better quality as shown in Figure 8 and Figure 9. Figure 8 is the waveform of the current after it is compensated by the shunt active filter and Figure 9 shows its FFT. From Figure 9, it can be seen that the THD of the source current is reduced.
from 6.6% to 0.9%. This shows that the shunt active filter is operating satisfactorily to improve the current quality.

**Figure 6** Source Current harmonics in uncompensated system.

**Figure 7** FFT of uncompensated system.
IV CONCLUSION & FUTURE WORK

A detailed Simulink model for a active shunt filter as being developed and operation has been studied using voltage source inverter Sinusoidal PWM control scheme. These type of harmonic active filter allow the harmonics present in the utility system to be filtered out without affecting the stability of the system and hence, providing a good quality of power supply to the customer side. This design is based on the SPWM VSI topology. It has shown that performance of active filter is satisfactory. Their performance can be further improved by an improvement in the design of the low pass filter and the utility system.

V REFERENCES