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Satyendra Gupta

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Harmonics Elimination Using Shunt Active Filter

Satyendra Gupta
Assistant Professor, Department of Electrical Engineering,
Shri Ramswaroop Memorial College of Engineering and Management, Lucknow, India.
Email: 2006.satyendra@gmail.com

Abstract - This paper presents the description and modelling of a shunt active filter for harmonics mitigation in power system. The controlling of the active shunt filter is based on the p-q theory. The simulation model of the implemented solution is presented along with the FFT analysis of the voltage and current waveforms of the source and the load using MATLAB/Simulink software.

Keywords – Harmonics, Total Harmonics Distortion (THD), Shunt Active Filters, Fast Fourier Transform (FFT).

1. INTRODUCTION

Electricity is generated at constant frequencies of 50 Hz or 60 Hz and the e.m.f of the generator can be considered as purely sinusoidal. However, when a non-linear device or load is connected across the source, the current drawn by the load is not sinusoidal. This current while passing through the system impedance causes a voltage drop which is also non-sinusoidal. This leads to a distortion in load voltage, which is termed as harmonics.

A. Definition of Harmonics

The frequency (50 Hz or 60 Hz) at which power is generated is known as fundamental frequency. Any higher order frequency current or voltage waveform superimposed on the respective fundamental frequency waveform is known as power system harmonics. Harmonics are mainly produced by non-linear loads such as diodes, arc furnaces etc.

Harmonics can be defined as, a sinusoidal component of periodic wave having frequency that is an integral multiple of the fundamental frequency. Thus for a power system with f_o fundamental frequency, the frequency of the nth order of harmonic is n f_o. Harmonics are often used to define distorted sine waves associated with mmf fluxes, currents and voltages of different magnitudes and frequencies.

B. Total Harmonic Distortion

Total Harmonic Distortion (THD) measures the effective value of harmonic component in a voltage or current waveform.
Where, \( M_h \) represents the rms value of harmonic component of a quantity.

In this paper, the harmonic content of a voltage or a current waveform is computed by calculating THD of the waveform using FFT tool of MATLAB/Simulink.

2. HARMONICS ELIMINATION USING SHUNT ACTIVE FILTERS

The active filters have been employed for harmonic reduction to overcome several drawbacks of passive harmonic filters, such as, they can only filter selective frequencies of dominant magnitude; their operation cannot be limited to a certain load and so on.

A. Shunt Active Filters

Fig.2 shows the scheme of a shunt active filter

The principle of operation of shunt active filter lies in the elimination of those components of non-linear load current which are not active current i.e. non-sinusoidal and out of phase with the corresponding phase voltages. From the measured values of phase voltages (\( v_a, v_b, v_c \)) and load currents (\( i_a, i_b, i_c \)), the controller calculates the reference currents (\( i_{aR}, i_{bR}, i_{cR} \)) used by the inverters to produce compensation currents.

In this paper, two six pulse shunt active filters are connected parallel to generate a 12 pulse output and the controlling is done on the basis of p-q theory.

B. The p-q Theory

“The Generalised Theory of the Instantaneous Reactive Power in Three – Phase Circuits”, also known as p-q theory was proposed by Akagi in 1983. As per this theory, the three phase voltages and currents in a-b-c coordinates are transformed into \( \alpha-\beta-0 \) coordinates through an algebraic transformation (Clarke transformation) and then the instantaneous power components are calculated.

\[
\begin{bmatrix}
    v_0 \\
v_a \\
v_\beta
\end{bmatrix} = \sqrt{3} \begin{bmatrix}
    \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
    1 & -\frac{1}{2} & -\frac{1}{2} \\
    0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix} \begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix} ---- (1)
\]
\[
\begin{bmatrix}
    i_0 \\
    i_a \\
    i_b \\
\end{bmatrix} = \sqrt{2} \begin{bmatrix}
    \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
    1 & -\frac{1}{2} & -\frac{1}{2} \\
    0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix} \begin{bmatrix}
    i_a \\
    i_b \\
    i_c \\
\end{bmatrix} \quad \text{(2)}
\]

\( p_0 = v_0 i_0 \) - instantaneous zero sequence power
\( p = v_a i_a + v_b i_b \) - instantaneous real power
\( q = v_a i_a - v_b i_b \) - instantaneous imaginary power

Among all the power components, only \( p_0 \) and \( p \) are desirable, as these components correspond to energy transferred from source to the load and the other quantities can be compensated using a shunt active filter.

3. SIMULATION MODEL

The simulation model (Refer Fig.3) has been prepared using the MATLAB/Simulink Sim Powersystem toolbox. Two six pulse active shunt filters have been connected in parallel.

A load of 50 MW is connected to the system which contributes to the addition of harmonics in the current and voltage. The source and load voltage and current waveforms have been obtained using a scope and the harmonic content is evaluated by calculating the THD concentration through FFT tool of MATLAB/Simulink.

4. SIMULATION RESULTS

Figure 4 illustrates the waveforms of source and load voltage and current respectively. Further the THD percentage of the waveforms of source voltage, source current, load voltage and load current are also depicted in the figures 5, 6, 7 & 8.

In Fig. 5 and Fig. 6, the THD concentration of load current and load current is shown. Observing the figures, we can conclude that after connecting shunt active filter in the system, the total harmonics distortion reduces from 31.06\% to 0.01\%.

Similarly, Fig. 7 and Fig. 8 depict the THD concentration of load voltage and source voltage respectively. It is observed that the THD \% reduces from 0.03\% to 0.00\%.

Thus, it is proved from the simulation results that the proposed shunt active filter is quite efficient in harmonic compensation.
Fig. 3 Simulation Model of the implemented shunt active filter for harmonics elimination in power system.

Fig. 4. Waveforms of Source current and voltage and load current and voltage.
Fig. 5 THD of Load Current

Fig. 6 THD of Source Current
The above results show that the harmonics in the current have reduced from 31.06% to 0.01%.

Fig. 8 THD of Source Voltage

The above results show that the harmonics in the current have reduced from 31.06% to 0.01%.
The above results show that the harmonics in the voltage have reduced from 0.03% to 0.00%.

5. CONCLUSION

In this paper, shunt active filter is presented as a cost-effective and reliable solution to power quality problems, especially, to harmonics mitigation issues. The controlling mechanism of the shunt active filter is based on the p-q theory, which proves to be a powerful tool and allows simpler implementation with minimum requirement of additional hardware. The filter presents good dynamic and steady-state response and it can be a much better solution for power factor and current harmonics compensation than the conventional approach (capacitors to correct the power factor and passive filters to compensate for current harmonics). Besides, the shunt active filter can also compensate for load current unbalances, eliminating the neutral wire current in the power lines. Therefore, this active filter allows the power source to see an unbalanced reactive non-linear load, as a symmetrical resistive load. The proposed solution facilitates the use of several low – power active filters in the same facility, close to each problematic load, preventing the circulation of current harmonics, reactive currents and neutral currents through the facility power lines. This solution facilitates reduction in power line losses and voltage drops and avoids voltage distortion at the load terminals.

REFERENCES