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Research Article

HARMONIC COMPENSATION ANALYSIS USING UNIFIED SERIES SHUNT COMPENSATOR IN DISTRIBUTION SYSTEM

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ABSTRACT
The huge boom observed in the use of electronic devices, in the last decades, has astonishing increased the mains harmonic content. The consequent undesirable effects are the primary cause of electromagnetic compatibility problems, sine wave distortion, extra dissipative losses, excessive neutral currents, even in equilibrated three-phase loads. Therefore a great amount of effort has been made in order to minimize all those unwanted and quite expensive effects. This paper focused on the harmonic compensation in distribution system. The series- shunt compensation of harmonics due to nonlinear load using USSC in this research is analyzed and simulated.

INTRODUCTION
Mitigation of power system harmonics can be categorized as corrective solutions and precautionary solutions. Corrective (remedial) solutions are the techniques to overcome the existing problems.
- The use of active and passive filters
- Reconfiguration of the feeders or reallocation of capacitor banks to overcome the resonance.

And precautionary (Preventive) solutions aim to avoid harmonics and their consequences.
- Phase cancellation or harmonic control in power convertors.
- Developing procedures and methods to control, reduce or eliminate harmonics in power system equipment; mainly capacitors, transformers and generators.

Passive filters consisting of capacitors, inductors and/or resistors can be classified into tuned filters and high-pass filters. They are connected in parallel with nonlinear loads such as diode/thyristor rectifiers, ac electric arc furnaces, and so in. Installation of such a passive filter in the vicinity of a nonlinear load is to provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. Before installing a passive filter, engineers should make elaborate investigations into the possibility of harmonic resonance and overloading on a case-by-case basis. However, these investigations may be accompanied by relatively high engineering cost. In addition, the final design of a passive filter should allow for component tolerance and variations. For example, initial inductor/capacitor tolerance typically ranges within 5%, and their variations occur due to temperature and other operating conditions (Rivas *et al.*, 2003). Pure active filters can be classified into shunt (parallel) active filters and series active filters from their circuit configurations. At present, shunt active filters are more preferable than series active filters in terms of form and function, and therefore series active filters are suitable exclusively for harmonic filtering. Two types of hybrid active filters for harmonic-current filtering of nonlinear loads were proposed in (Akagi, 1996), respectively. The proposal of the two hybrid filters has encouraged power electronics researchers/engineers to do further research on various hybrids active filters, concentrating on their practical use (Li *et al.*, 2005). The Unified Shunt Series Compensator (USSC) consists of back-to-back connection of two three phase active filters (AFs) with a common DC link. One of the AFs is connected in parallel with the utility and is called Parallel Active Filter (PAF) (Hideaki and Hirofumi, 1998.). The PAF works as current source and usually compensates for current quality problems of load and regulating of DC link. On the other hand, the second AFs connected in series with the utility and acts as Series Active Filter (Basu *et al.*, 2001) to compensate for voltage quality problems of utility. In this way, operation of USSC isolates the utility

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from current quality problems of load and in the same time, isolates the load from voltage quality problems of utility (USSC) is being used now-a-days.

USSC Installation in Distribution System

Before modeling the USSC, all distribution system components, i.e., lines and cables, loads, transformers, large motors and generators have to be converted into equivalent reactance (***X***) and resistance (***R***) on common bases. The main system component models are used in the formulation of impedance matrix for voltage sag calculation (Hannan and Mohamed, 2004). In steady state analysis, series and shunt inverters of the USSC are presented by two voltage sources Vdq and Vsh respectively as shown in Figure 1.

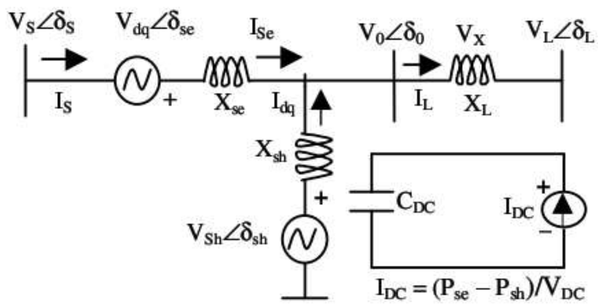

Figure 1: Equivalent circuit of USSC

X_{sc} and X_{sh} represents the reactance of the transformers associated with the series and shunt voltage source inverters, respectively. Therefore, voltage equation of series and shunt inverters can be expressed as follows:

$$V_s = -V_{dq} + I_{se}(jX_{se}) + V_0 \quad (1)$$

$$V_s + V_{dq} - I_{se}(jX_{se}) = V_{sh} + I_{dq}(X_{sh}) \quad (2)$$

$$I_s = I_{se} = I_{dq} + I_L = \frac{V_{sh} - V_0}{X_{sh}} + I_L \quad (3)$$

Where I_{sc} and I_{dq} are the series and shunt inverter currents, respectively.

The voltage across the distribution line reactance, X_L is

$$V_X = V_s + V_{dq} - I_{se}(jX_{se}) - V_L = V_0 - V_L = X_L.I_L \quad (4)$$

Where, I_L is distribution line current.

The voltage, V_X, across the distribution line can be changed by changing the inserted voltage, V_{dq}, which is in series with the distribution line. If we consider V_{dq}=0, the distribution line sending end voltage, V_S, leads the load voltage by an angle δ i.e $\delta_S - \delta_L$.

The resulting real and reactive power flows at the load side are P and Q, which are given as follows:

$$P_{ussc} = \frac{V_0.V_L}{X_L}\sin\delta \quad (5)$$

$$Q = \frac{V_0.V_L}{X_L}(1-\cos\delta) \quad (6)$$

With an injection of V_{dq}, the distribution line voltage V_0 will lead the load voltage V_L, and $\delta_0 > \delta_L$. , thus the resulting line current and amount of flow Will be changed. With a larger amount of V_{dq} injection, V_0 now lags the load voltage V_L, and $\delta_0 < \delta_L$.

Consequently, the line current and power flow will be reversed.

Harmonics Concepts

Harmonics have frequencies that are integer multiples of the waveform's fundamental frequency. For example, given a 50Hz fundamental waveform, the 2nd, 3rd, 4th and 5thharmonic components will be at 100Hz, 150Hz, 200Hz and 250Hz respectively (Balci and Hocaoglu, 2008). Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. The ideal sine wave has zero harmonic components. In that case, there is nothing to distort this perfect wave. Power sources act as non-linear loads, drawing a distorted waveform that contains harmonics. In presence of sinusoidal source voltage due to non-linear load the current which drawn via source is harmonic distorted. These harmonics can cause problems ranging from telephone transmission interference to degradation of conductors and insulating material in motors and transformers. Therefore it is important to gauge the total effect of these harmonics. Harmonic distortion can have detrimental effects on electrical equipment. Unwanted distortion can increase the current in power systems which results in higher temperatures in neutral conductors and distribution transformers. Higher frequency harmonics cause additional core loss in motors which results in excessive heating of the motor core. These higher order harmonics can also interfere with communication transmission lines since they oscillate at the same frequencies as the transmit frequency. If left unchecked, increased temperatures and interference can greatly shorten the life of electronic equipment and cause damage to power systems.

To evaluate the degree of harmonic distortion, an index named Total harmonic distortion, or THD, based on the IEEE definition, is defined as the summation of all harmonic components of the voltage or current waveform M_i compared against the fundamental component of the voltage or current M_1 (Afonso *et al.*, 2000):

$$THD = \frac{\sqrt{\sum_{i=2} M_i^2}}{M_1} \qquad (7)$$

The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

RESULTS AND DISCUSSION

Simulation and Results

In this section to investigate the effects of USSC on harmonic compensation due to nonlinear load is presented. At first to model the harmonic a programmable main ac source which insert harmonics to network is simulated. In Figure 2 the power network with presence of USSC is presented.

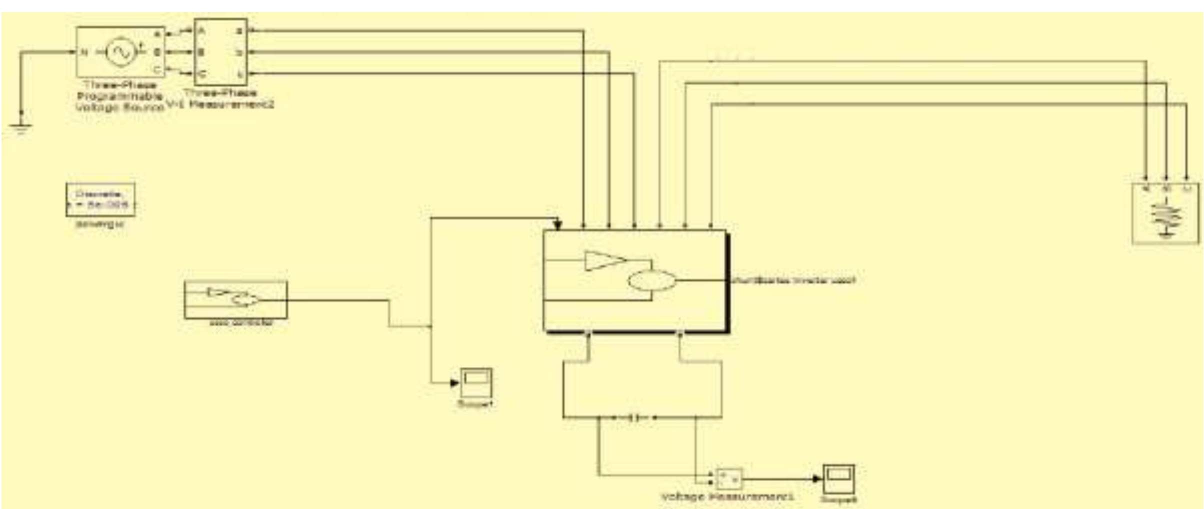

Figure 2: The USSC in network

As shown in Figure 3 the three phase voltage load which is distorted to harmonics is indicated.

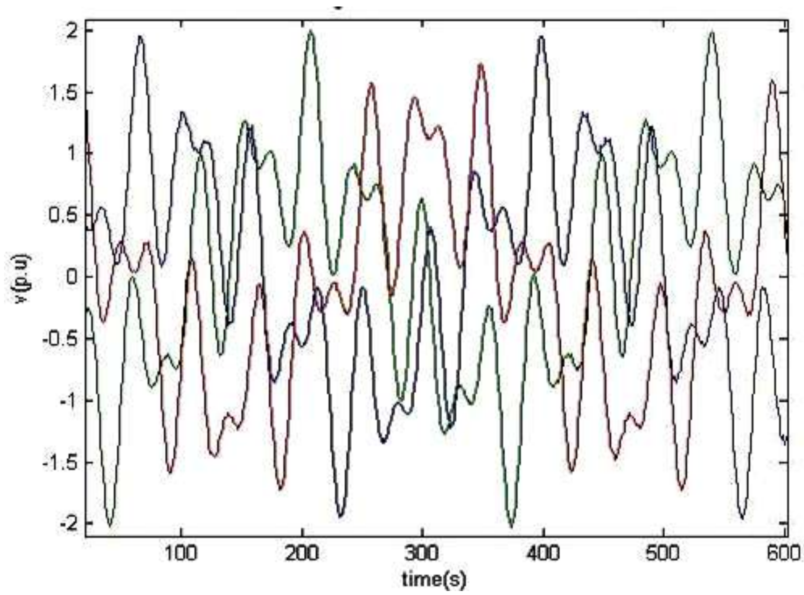

Figure 3: the three phase harmonic distorted voltages

To better understand the amount of harmonics value, the THD analysis of voltage wave is performed and the THD of none compensated voltage is shown in Figure 4.

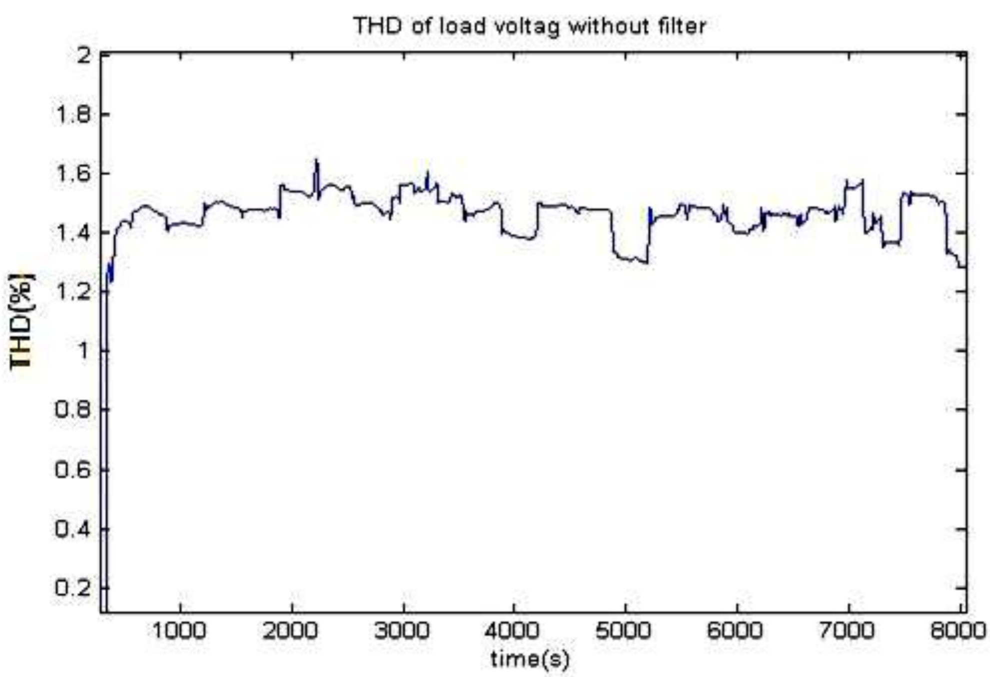

Figure 4: THD of load voltage without any compensation

To reduce the harmonics the USSC is connected to network. The ac voltage of load with presence of USCC is improved and to verify this matter the THD analysis is performed again. To show the effect of USSC on harmonic compensation, the THD of load voltage is presented in Figure 5.

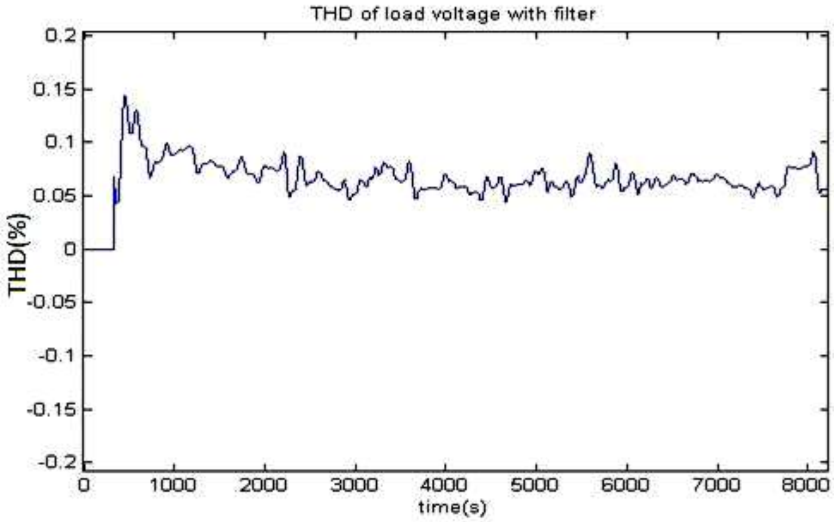

Figure 5: THD of load voltage without any compensation

As shown in figure, using USSC the THD of load is deceased and this verifies the effective role of USSC on harmonic mitigation.

Conclusion

This paper deals with harmonic compensation using unified series shunt compensator. The conventional of harmonic compensation methods are utilizing passive filters and active filters. But in this research due to multifunctional in power quality improvement a combination of two active filters is presented. The first active filter is connected to network as series connection and second active filter is connected to network as parallel connection. This connection of two active filters is named as unifies series shunt compensator (USSC). This type of compensation can improve a variety of power quality compensation. In other words, using USSC it is possible to improve various power quality problems including voltage sag/swell, harmonics, unbalanced voltage and flicker. It also can improve the power factor. Due to multi capability of USSC, this equipment is employed to improve power quality of network. In this research the focus is on the harmonic compensation and the results of this study are presented.

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