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Unified Harmonic Compensator for Mitigating Harmonics Feeding Linear and Non-linear Loads

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Abstract: Power System is expanding to fulfill the power need of customers. The customers are using linear and nonlinear loads without seeing their effect on the quality of power. The internal structure, mathematical modeling and controlling of unified harmonic compensator are discussed in detail and its performance is analyzed in the distribution power system feeding linear and nonlinear loads. The results obtained are showing the effectiveness of unified harmonic compensator in improving the quality of power obtained at customers end. The waveforms of electrical parameters at the point of common coupling(PCC) are compared with and without compensator in the system. The control unit of shunt active filter is effectively generating the reference signal for power electronic devices used. This analysis will be helpful in designing and locating the compensator in the system to get the improved quality of power and can be expended to reduce the cost and size of this compensator.

Keywords: Power Quality, Harmonic Compensation, Active Power Filter, Unified Harmonic Compensator.

1. Introduction

The distortions in fundamental voltage/current are generally caused by the presence of harmonics and inter-harmonics in the power system. The non linear loads such as fluorescent / halogen lamp draw non linear currents which contains even or odd harmonics of small or high order respectively. In case of balanced loads all the harmonics except multiple of three are not being cancelled out, which further add up into the neutral conductor of the system. These harmonics overheats the system and the system needs special measures to reduce the amount of unwanted increased current. When there is presence of non linear loads such as power electronic converters, personal computers, the harmonics can produce resonance condition in the system [1]. In this condition the harmonics in the system are directly depend upon impedance of the line

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and the devices. The harmonics in transmission and distribution lines can even produce interference in the nearby telephone lines and may upset the sensitive devices of other customers connected to the same feeders [2]. Thus reducing quality and the capability of carrying the useful power to the user end which is unacceptable for both the electric utilities and the customers. The electric utilities are actively involved in delivering a sinusoidal voltage of fairly constant magnitude and frequency to their customers [3]. There are number of approaches or algorithms are proposed for harmonic compensations by researchers around the world.

There are many recommended practices/standards for harmonics control in power systems such as IEEE standard 519-1981 revised in 1992 and 2014 respectively and IEC standard of harmonics 61000-3-2 are given by these world renowned committees so as to protect and design the power system equipments. The power quality issues are majorly faced by the distribution power system because of the different types of customer loads [4-6]. When the distortions introduced in the system, the quality of power starts affecting the equipments and the equipments become unsafe to handle. The reduced quality affects the power consumers and the neighboring customers as well by increasing the electricity billing amount. However the developments in power electronics based power quality improvement devices/controllers have lead power system engineers to contribute in meeting up the power quality challenges faced by the utility and customers [6-7].

The studies have been done to forecast/ predict the power quality problems before they start impacting the system. To analyze the future system performance i.e. efficiency, reliability, safety and its ability to expand to serve the consumers, several studies are carried out. The electronically switched non-linear loads distort the fundamental current/voltage waveforms and the system takes time to reach the steady state. [7]. Therefore reducing the voltage and current distortions to acceptable level is a challenge in power system operation. The generation and transmission of electrical power is at the nominal values of frequency and voltage, while the power utilization is more dependent on controlling of frequency and voltage.

In this paper a mathematical model of the unified harmonic compensator (UHC) is developed for distribution system of 11KV, 50Hz feeding the commonly used linear and non-linear loads at 220V, 50Hz.The mathematical model is being developed and simulated using MATLAB/ simulink toolbox to observe the electrical parameters of the system without and with UHC for the combination of linear and nonlinear loads. Hence the performance of unified harmonic compensator is analyzed. The paper is divided into various sections firstly explaining the internal configuration of UHC, mathematical modeling, controlling of shunt active filter so that the quality of power can be maintained at the PCC as per the specified standards.

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2. Unified Harmonic Compensator

The basic block diagram of a single phase unified harmonic compensator is given in Figure 1. The active power filters(APF) connected to the system in series and shunt are also known as voltage source inverters are connected through DC-link capacitor provides voltage and current harmonics compensation simultaneously [8]. At the PCC a shunt APF is connected to detect the variations in fundamental current component and with the help of control unit i.e. pulse width modulation based current controller and power circuit the reference and gate signals are generated for the operation of shunt filter.

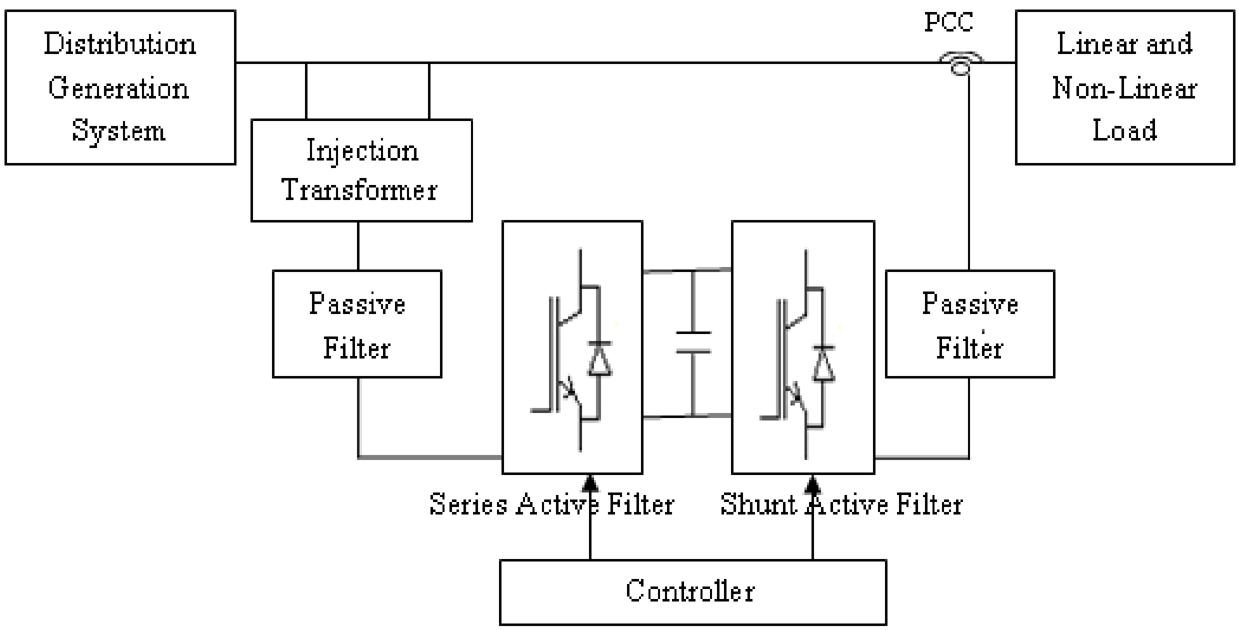

Figure1. Block Diagram Representation of UHC

The voltage across DC- link is maintained so that the variations in voltage can be controlled with the help of series filter [9]. The voltage harmonics are comparatively less effective than the current harmonics in single phase distribution systems. Thus to stabilize the system performance the current harmonics are compensated and the control scheme of shunt APF is elaborated below.

2.1 Mathematical Model Unified Harmonic Compensator

Considering voltage V_S is the source voltage, current I_S is the source current, voltage V_l is the load voltage, current I_l is the load current, voltage V_{CC} at PCC, voltage Vsr injected by series

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APF in the system and the current Ish injected by shunt APF in the system. Assuming the reference voltage V_l, and the power factor of the load is $\cos\Phi_1$(lagging).

$V_l = V_l$ at an angle 0^0 (1)

$I_l = I_l$ at an angle $- \Phi_l$ (2)

$Vcc = V_l (1+K)$ at angle of 0^0 (3)

Where factor 'K' represents the fluctuations in V_S and represented as

$K = (Vcc - V_l) / V_l$ (4)

The injection of voltage by series APF is given below

$Vsr = V_l - Vcc = -K V_l$ (5)

Assuming the UHC to be lossless i.e . the active power required by the load is equal to the input at PCC and provides I_S with unity power factor[10]. Hence the input active power at PCC for the given load condition can be expressed below

$Pcc = P_l$ (6)

$Vcc = V_l * I_l * Cos\Phi_l$ (7)

$V_l = (1+K) * Is = V_l * I_l * Cos\Phi_l$ (8)

$Is = I_l / (1+K) * Cos \Phi_l$ (9)

The equation (9) suggests that the I_S depends on K, however angle Φ_l and load current I_l are constant for linear load. The complex power absorbed by the series APF is,

$S_{Sr} = V_{Sr} * Is$ (10)

$Psr = Vs*Is*Cos\Phi s = -K*V_l*Is*Cos\Phi s$ (11)

$Q_{Sr} = V_{Sr} * Is * Sin\Phi s$ (12)

$\Phi_S = 0$ since unified power quality conditioner has unity power factor

$Psr=Vsr*Is= -K*V_l*Is$ (13)

$Q_{Sr} \approx 0$ (14)

The power consumed by the shunt APF is

$S_{Sh} = V_l*I_{Sh}$ (15)

The current output (load harmonic current and reactive current) of the shunt APF , is the difference between the I_S (source current) and I_L (load current) [11] expressed below.

$I_{Sh} = Is - I_l$ (16)

Whereas

$I_{Sh} = Is$ (at an angle 0^0) - I_l (at an angle) $- \Phi_l$ (17)

$I_{Sh} = Is - (I_l* Cos\Phi_l - j* I_l * Sin\Phi_l)$ (18)

$I_{Sh} = (Is - I_l* Cos\Phi_l) + j* I_l * Sin\Phi_l$ (19)

$P_{Sh} = V_l*I_{Sh}*Cos\Phi_{Sh}$ (20)

$P_{Sh} = V_l* ((Is - I_l)*Cos\Phi_l))$ (21)

During the normal working condition, the reactive power from the source flows to the load and the UHC is not connected in the circuit. While during the operating condition of UHC, the

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reactive power required by the load is provided by the shunt APF. From equation (4), if K is less than zero (it generally happens during the voltage sag at the source end), then the voltage V_{cc} at PCC must have lesser value than the load voltage (V_l), then from equation (13), the series APF supplies the active power (P_{sr}) to the load. From equation (9), it has been observed that the source current I_s will be more than the normal rated current.

Therefore to maintain the power balance in the network and the voltage across DC-link within the range the required active power is taken from the source itself [8-10]. Again from equation (4), if K is greater than zero (this condition is possible during the voltage swell at the source end), then the value of V_{cc} is greater than the V_l and the active power (P_{sr}) is absorbed from the source. If K = 0, then there is no exchange of power takes place through the UHC, which is the normal working condition of the distribution system.

2.2 Controlling Shunt Active Power Filter

The load current (I_l) is detected using the hall effect sensors in the system, which is compared to the set reference signal using zero detection method. If the variations in signal are not found then the control loop need not to run meanwhile the voltage across DC-link capacitor is also detected and compared to the reference (V_{dc}) after passing though a low pass passive filter. However when there is change in the detected current the PWM technique based current controller is used to control the output of APF by generating the gate pulses for the power electronic switching devices

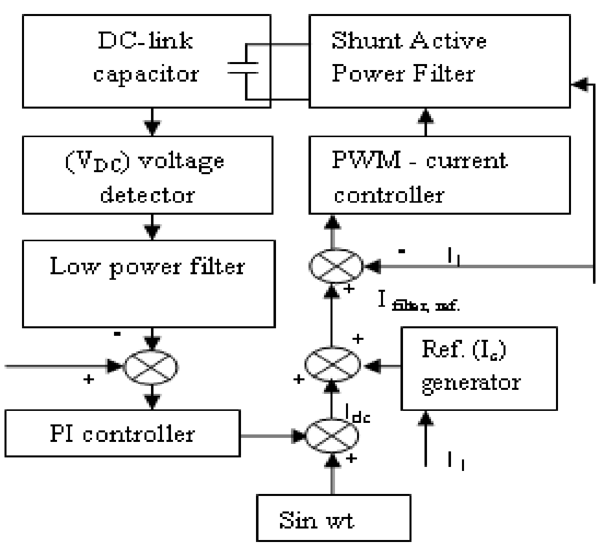

Figure 2. Flow of Control of Shunt Active Filter

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The load current also depends upon the type of load such as linear, nonlinear balanced or unbalanced [9]. Therefore it is necessary to locate such kind of loads to maintain the quality of power in distribution system.

2.3 Harmonics Mitigation using Unified Harmonic Compensator

Harmonics are undesirable components in the sinusoidal waveform of the alternating power systems, which affect the efficiency and life of equipments. The presence of harmonics can be detected by monitoring the system and can be illuminated with the help of filters. The harmonics are categorized such as even and odd, lower order and higher order. The harmonics produced due to the nonlinear loads are generally low order odd harmonics which affect adversely on the systems' fundamental voltage and current. The odd harmonics are generally produced by nonlinear loads are the non-sinusoidal waveform symmetric above and below its average centerline and are the odd integer multiples of the fundamental frequency component. The sequenced voltages and currents at the PCC becomes highly distorted due to rapid switching of electronicdevices.

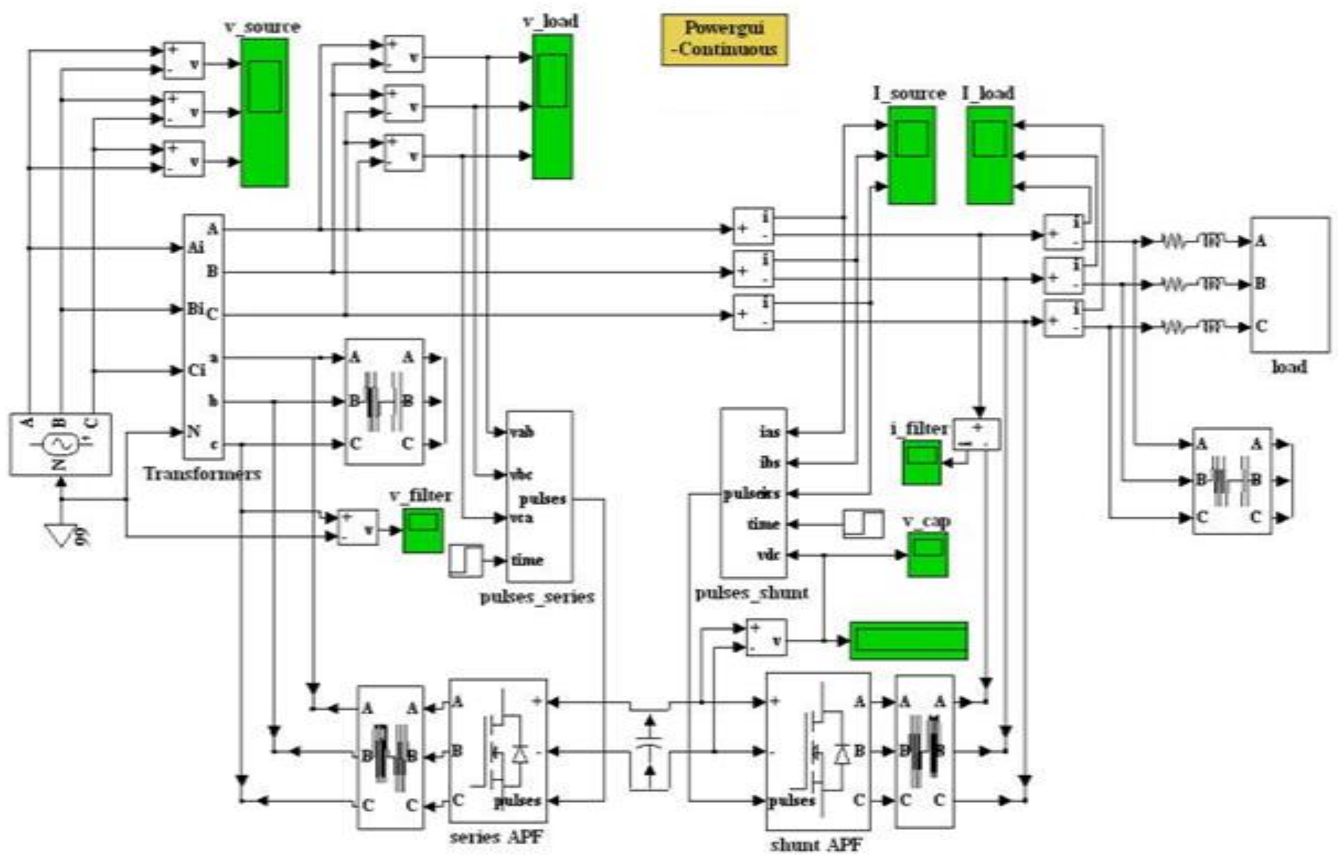

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Figure 3. Simulation Model of Unified Harmonic Compensator

Harmonics compensation and elimination can be performed on distribution systems with the passive, active and hybrid filters. The passive filters and can be employed for small systems because they became bulky and difficult to handle for medium and large systems. Thus active and hybrid filters are preferred for medium and large systems contain sophisticated power electronics components which can be controlled manually, automatically and supervised for the efficient output. The pulse width modulation (PWM) control is used to limit the operation of APFs by injecting the inverse of harmonic waveforms at different phase angles to compensate their effect as explained in the above section.

The simulation model of the UHC employed in distribution system is shown in Figure 3. The series and shunt filters have separate control units so as to generate the gate signals o reference signals for their efficient operation.

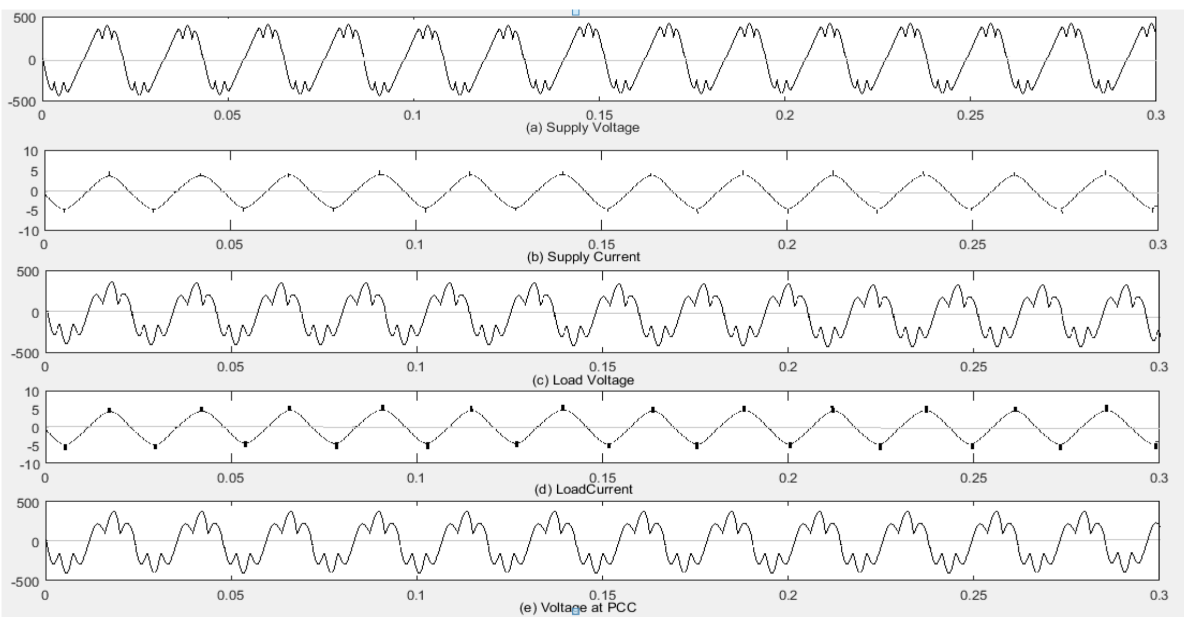

Figure 4(a). Electrical parameters of the system without UHC

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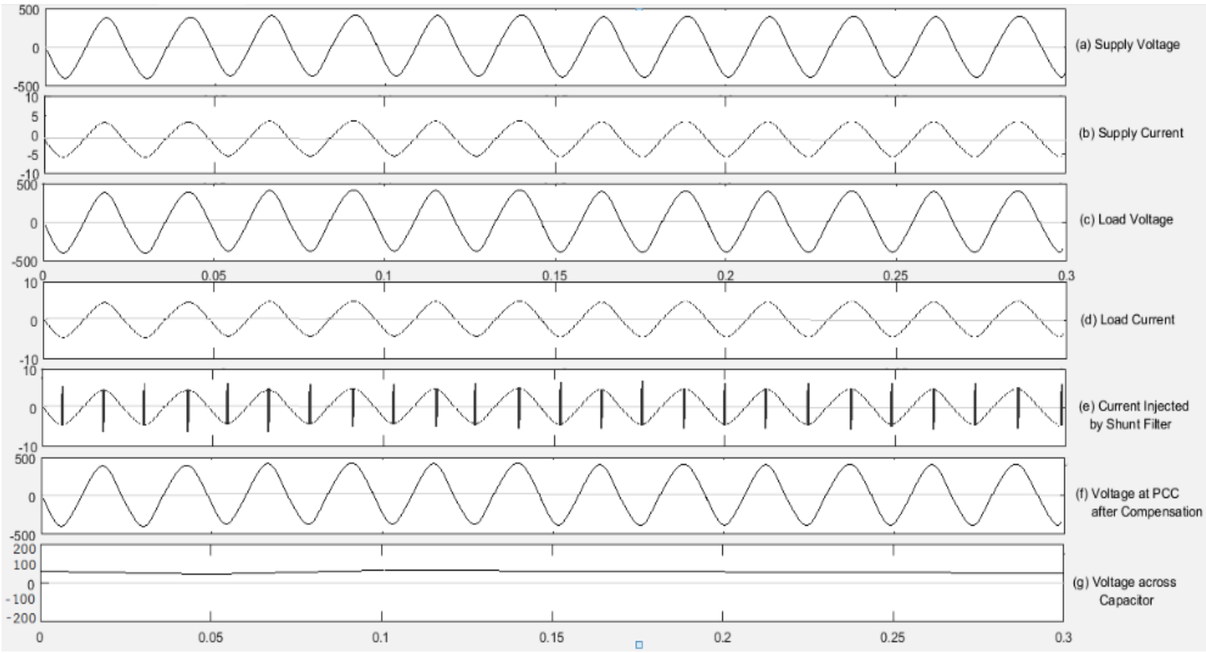

Figure 4(b). Electrical parameters of system with UHC

The electrical parameters of the system i.e. supply current, supply voltage, load current, load voltage and compensating current waveforms at a PCC without and with UHC in Figure 4(a) and Figure 4(b) respectively. The detailed analysis of the total harmonic distortions i.e. voltage and current harmonics together at the PCC is done to see the performance of unified harmonic compensator.

Conclusion

The distribution system is analyzed by incorporating a unified harmonic compensator at the PCC. This paper is presenting the performance of unified harmonic compensator in a system containing nonlinear loads effect the quality of power. The mathematical modeling and simulation of UHC is done and the change in electrical parameters of the system with and without it in the system is analyzed. It has been found that the odd current harmonics affects the quality of power more than the even current and even/odd voltage harmonics. It has been also observed the system performs better with UHC when there is presence of harmonics/distortions than without it.

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