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A Novel Control of Harmonic Filters to Improve the Power System Network

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Abstract: ***Distortion of voltages and currents can affect the power system adversely causing power quality problems. Therefore, estimation of harmonics is of high importance for efficiency of the power system network. Non-linear devices such as power electronics converters can inject harmonics alternating currents (AC) in the electrical power system. The number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation has been increasing. To maintain the quality limits proposed by standards to protect the sensitive loads, it is necessary to include some form of filtering device to the power system. Harmonics also increases overall reactive power demanded by equivalent load. Filters have been devised to achieve an optimal control strategy for harmonic problems. To achieve an acceptable distortion, increase the power quality and to reduce the harmonics hence several three phase filter banks are used and connected in parallel. In this project, high order harmonics have been suppressed by employing variants of Butterworth, Chebyshev and Cauer filters. MATLAB/SIMULINK is used to generate and analyze the different harmonics magnitude and frequency. Investigated three-phase harmonics filters are shunt elements that are used in power systems for decreasing voltage distortion and for correcting the power factor.***

Keywords: Butterworth, Chebyshev, Cauer Filters, MATLAB, Harmonics.

1. Introduction

Power quality problems of energy distribution is not new, But until recently, the impact of these problems have become public awareness. Advance in technology of semiconductor devices has led to a revolution in electronic technology over the past decade and have more tendency in future. However rise in the PQ problem is due to power equipments which include adjustable-speed motor drives, electronic power supplies, direct current motor drives, battery chargers, electronic ballasts. The distortion in the current is due to nonlinearity of the resistor. These nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage. A simple circuit as shown in Figure 1.1 illustrates the concept of current distortion. In this case, a sinusoidal voltage is applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown. While the voltage is perfectly sinusoidal, the resulting current is distorted.

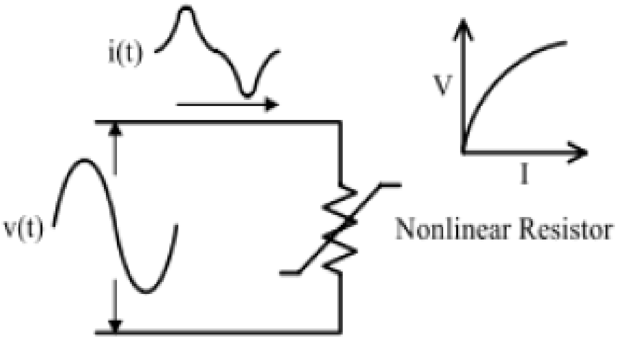

Figure 1.1: Current distortion caused by nonlinear resistance

Nonlinear loads seem to be the main source of harmonic distortion in a power distribution system. Non-linear load produce the harmonic currents and injected back to the power distribution network by the point of common coupling. These harmonics current can interact negatively with a broad range of power systems equipment, especially capacity, transformer and motors and produce more losses, overheating and overloading. There are set of conventional solutions to the harmonic distortion problems which have existed for a long time. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. They are known as passive filters, because they do not depend upon an external power supply and/or they do not contain active component such as transistors. Although simple, these conventional solutions that use passive elements do not always respond correctly to the dynamics of the power distribution systems. Over the years, these passive filters have developed to high level of sophistication. Some even tuned to bypass specific harmonic frequencies. However, the use of passive elements at high power level makes the filter heavy and bulky. Moreover, the passive filters are known to cause resonance, thus affecting the stability of the power distribution systems. As the regulatory requirements become more stringent, the passive filters might not be able to meet future revisions of a particular Standard. Remarkable progress in power electronics had spurred interest in active power filter for harmonic distortion mitigation. The active filters are made of passive and active components and require an external power source. The basic principle of APF is to utilize power electronics technologies to produce currents components that cancel the harmonic currents from the nonlinear loads. Previously, majority of controllers developed for APF are based on analogue circuits. As a result, the APF is inherently subjected to signal drift. Moreover, the utilization of fast switching transistors (i.e. IGBT) in APF application causes switching frequency noise to appear in the compensated source current. This switching frequency noise requires additional filtering to prevent interference with other sensitive equipments. The idea of hybrid APF has been proposed by several researchers. A low cost passive high-pass filter (HPF) is used in addition to the conventional APF. The harmonics filtering task is divided between the two filters. The APF cancels the lower order harmonics, while the HPF filters the higher order harmonics. The main objective of hybrid APF is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonics mitigation. Digital controller using digital signal processor or microprocessor is preferable, primarily due to its flexibility and immunity to noise signals.

2. Filters Used In Power System

Presence of harmonics has been a lot since the 1990's and has led to deterioration in the quality of power. Moreover, there has also been an increase in use of devices and equipments in power system also including the nonlinear loads and electronic loads used in residential areas there by loading the transmission and the distribution systems. This is because they operate at very low power factors which increases the losses in line and also causes poor regulation in voltage further leading the power plants to supply more power. Also, some nonlinear loads and electronics equipments are such that instead of drawing current sinusoidally they tend to draw current in short pulses thus creating harmonics. Some of the examples of nonlinear loads would be rectifiers, inverters, etc. Some of the examples of electronics equipments would be computers, scanners, printers, etc. Some of the major issues concerned with harmonics in nonlinear loads are overheating, temperature increase in generators, etc. These effects may result into permanent damage of the devices.

One of the way out to resolve the issue of harmonics would be using filters in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. The filters are widely used for reduction of harmonics. With the increase of nonlinear loads in the power system, more and more filters are required.

A. Roles of Filters in Power System

There are two types of filters
- The Passive Filters
- The Active Filters

Capacitors are frequently used in the Active and Passive filters for harmonics reduction. The Passive filters are used in order to protect the power system by restricting the harmonic current to enter the power system by providing a low impedance path. Passive filters consist of resistors, inductors and capacitors. The Active filters are mostly used in distribution networks for sagging in voltage, flickering, where there are harmonics in current and voltages, etc. Using the filter would result into a better quality of power. There is also a third type of filter which is used i.e. The Hybrid Filter. Hybrid filters are composed of the passive and active filters both.

1. Passive Filters

Passive filters consists of resistors, inductors and capacitors. They are not expensive and are often used to restrict the harmonic currents from entering the power system there by minimizing the effect of harmonics due to nonlinear loads. Also, the passive filters are kept close to the source of harmonic generation i.e. the nonlinear loads. Doing so, the passive filters produce better results in reducing the harmonic effect. Figure 1 shows a single phase representation of distribution system with the nonlinear load and passive shunt filter.

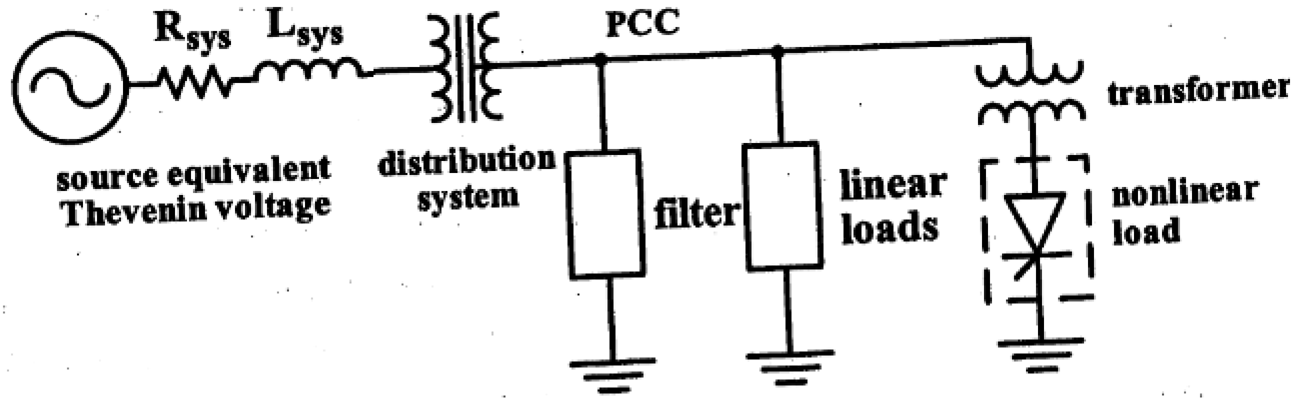

Figure 2.1: Single Phase Representation of Non Linear load and Passive Shunt filter

One of the most important aspects in installing the passive filters in the power system is that they should be installed based on the order of the harmonics that are supposed to be filtered. For example, in order to install a filter for the 3rd order of harmonics, it is required that the filter of 1st order of harmonics is already installed. In order to reduce the harmonic effect, the passive filters create a resonance frequency. This resonance frequency is kept away from the nonlinear load's harmonic distortion. Also, the passive filters are caliberated at a point which is a bit lower than the point at which the harmonics is supposed to be reduced so that, if there is any change in the parameters there is still margin for improvement. If this is not done, then there might be a condition in power system due to capacitance and inductance of filter that the resonance is shifted causing unfavourable conditions in the power system.

Types of Passive Filters

There are two types of passive filters:

- Shunt Passive Filters and
- Series Passive Filters

These filters are used for single phase and three phase power system. One important thing to note is that, more than one shunt and series passive filters can be used with and without each other in a system. Some of the basic differences between the shunt passive and series passive filters are as follows.

- The shunt passive filters carry only part of the total load current while the series passive filter carries full load current.
- The shunt passive filters are cheaper compared to the series passive filters so they are used more often than the series passive filters.

Figure 2.2 and 2.3 shows the single phase passive filter with shunt and series configuration respectively.

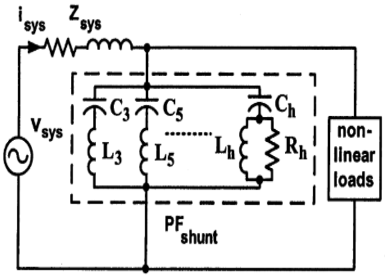

Figure 2.2: Single Phase Passive filter with Shunt Configuration

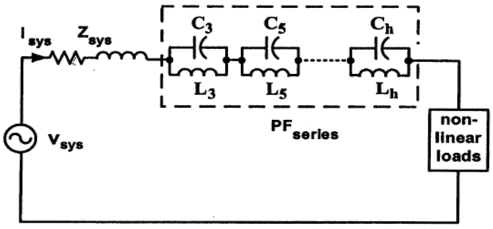

Figure 2.3: Single Phase Passive Filter with Series Configuration

Figure 2.4 and Figure 2.5 shows three phase three wire passive filter for shunt and series configuration respectively.

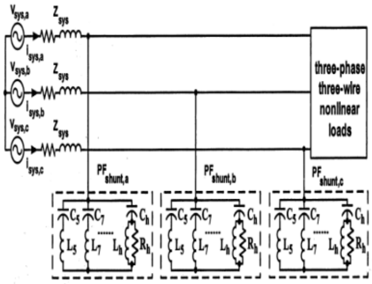

Figure 2.4: Three Phase, Three Wire Passive Filter for Shunt Configuration.

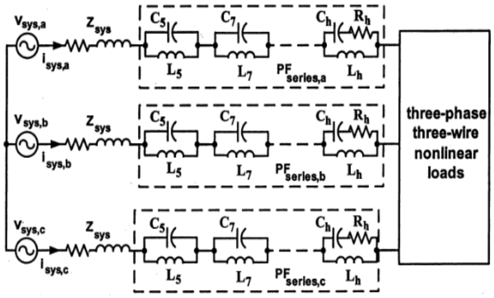

Figure 2.5: Three Phase, Three Wire Passive Filter for Series configuration

Normally more than 3 filters are connected in a system to reduce the harmonics. The first two filters are connected in order to reduce the effect of harmonics which are less effective and then a high pass filter is used.

2. Active Filters

Active filters are a perfect alternative to the passive filters. The active filters are used in a condition where the harmonic orders change in terms of magnitudes and the phase angles. In such conditions it is feasible to use the active elements instead of passive ones in order to provide dynamic compensation. The active filters are used in nonlinear load conditions where the harmonics are dependent on the time. Just like the passive filters, active filters can be connected in either series or parallel depending on the type of sources which create harmonics in the power system. The active filters minimize the effect of harmonic current by using the active power conditions to produce equal amplitudes of opposite phase there by cancelling the harmonics that are caused in the nonlinear components and replace the current wave from the nonlinear load.

Advantages of Active Filter over Passive Filter:

- One of the main advantages of using an active filter over the passive filter is that it can be used to reduce the effects of harmonics of more than one order.
- Active filters are also useful in flickering problems that are caused in the power system.
- One disadvantage of an active filter over a passive filter is that

Disadvantages of Active Filter over Passive Filter:

- Active filters cost more than the passive filters
- Active filters cannot be used for small loads in a power system
- Due to the presence of harmonics in both current and voltage, active filter may not be able to resolve the issue in certain typical applications.

For the conditions where both voltage and current are leading to a deterioration in power system, more complex filters are used which are made up of combination of active and passive filters. Such filters are called as Hybrid Filters.
Figure 2.8 and 2.9 shows single phase active filters in shunt and series configuration respectively.

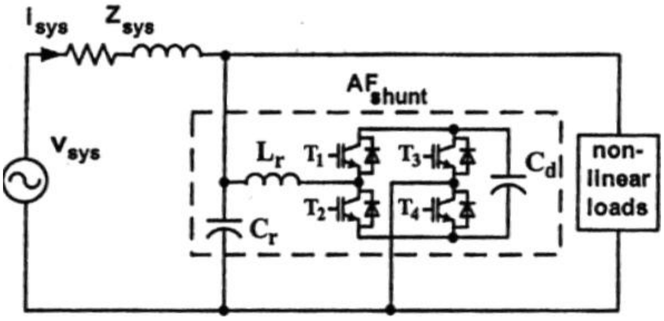

Figure 2.8: Single Phase Active Filter, Shunt Configuration

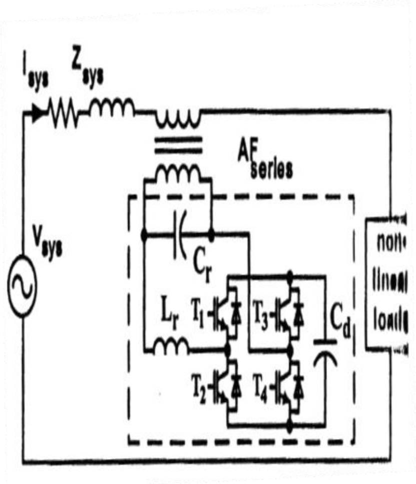

Figure 2.9: Single Phase Active Filter, Series Configuration

3. Harmonic Filters

3.1 Magnitude Function

Magnitude of the transfer function as the function of the frequency indicates how much is the certain frequency component is present in the transfer function. The frequency response *H(jω)* is the complex function of *ω*. For this reason it is interesting to study both the value of *H(jω)* and the phase *Φ(ω)*. *H(jω)* can be written as:

$$H(j\omega) = |H(j\omega)|e^{j\Phi(\omega)} \quad \text{.........(1)}$$

$$H(j\omega) = H_R(\omega) + jH_I(\omega) \quad \text{.........(2)}$$

where *HR(ω)* and *HI(ω)* is the real (even) and imaginary (odd) function of *ω*, respectively. The magnitude function is defined:

$$|H(j\omega)| \triangleq \sqrt{H_R^2(\omega) + H_I^2(\omega)} \quad \text{.......(3)}$$

Magnitude function is used to plot the spectrum of different filters. Figures 4.3, 4.4, 4.5, and 4.6 show the magnitude function of the different filters like Butterworth, Chebyshev and Cauer. Magnitude function can be expressed using the logarithmic scale: 20log(|*H(jω)*|) [dB]

3.2 Group Delay

The term group delay is used to refer to the average time delay imposed over the range of Frequencies the filter is designed to pass through. In other words group delay can be defined as the negative rate of change of phase with frequency. Figures 4.3, 4.4, 4.5, 4.6 and 4.7 show the group delay of the different types of filters like Butterworth, Chebyshev and Cauer. The mathematical expression can be defined as

$$\tau_g(\omega) \triangleq -\frac{\partial\Phi(\omega)}{\partial\omega} \quad \text{.........(4)}$$

The group delay is the even, rational function of *ω*. Applications which require a small variation in group delay are, e.g., video, EEG, EKG, FM (frequency modulation) signals, and digital transmission systems, where it is important that the waveform is retained.

3.3 Transfer Function

The System behavior is to describe i.e. properties which are in terms input and output signals. The ratio of output of the system to the input of the system in the Fourier domain

Considering its initial conditions to be zero is said to be transfer function. Without knowing the system (black box) we can calculate the transfer function of any system. When the transfer function operates on the input, the output is obtained. Numerator and denominator show the zeros and poles of transfer function of any system respectively. Stability and instability of the different filters are defined by poles and zeros is shown in figure 3.3, 3.4, 3.5, 3.6, 3.7 many discrete-time and digital systems such as digital filters can be described by difference equations with constant coefficient. The input-output relation for an Nth-order linear time invariant systems (LTI) system can be described by:

$$y(n) = \sum_{k=1}^{N} b_k y(n-k) + \sum_{k=0}^{M} a_k x(n-k) \quad \text{.........(5)}$$

A behavioral description of an LTI system is the transfer function which can be obtained by applying the z-transform to both sides of Equation 2.20. We get

$$H(z) = \frac{Y(z)}{X(z)} = \frac{\sum_{k=0}^{M} a_k z^{-k}}{\sum_{k=1}^{N} b_k z^{-k}} \quad \text{.........(.6)}$$

The transfer function for a linear time invariant system (LTI) system is a rational function in *z* and can therefore be described by a constant gain factor and the roots of the numerator and denominator polynomials. The roots of the numerator are called zeros, since no signal energy is transmitted to the output of the system for those values in the z-plane. The roots of the denominator are called poles. For a causal, stable system, the poles are constrained to be inside the unit circle, i.e., in the stop - band of the filter, in order to increase the attenuation in the stop-band. Another common case occurs in all-pass filters where the zeros are placed outside the unit circle. Each zero has a corresponding pole mirrored in the unit circle, so that:

$$Z_{zero} = \frac{1}{Z_{pole}}$$

3.4 Butterworth Filter

The mathematically simplest and therefore most common approximation is Butterworth filters. Butterworth filters are used mainly because they are easy to synthesize and not because they have particularly good properties. The filter order must be an integer, and we therefore, but not always, select N to the nearest highest integer. The finite zeros of a transfer function are the roots of the numerator. Hence, Butterworth filters have no finite zeros since the numerator is a constant. The transfer function of Butterworth filters can be calculated by equations 4.5 and 4.6. The number of zeros is equal to the number of poles. Hence, Butterworth filters have N transmission zeros at $s = \infty$ and N reflection zeros at $s = 0$. Butterworth filter has only poles and lacks finite zeros therefore all zeros lies at $s = \infty$. Butterworth filters are therefore said to be of all-pole type. The magnitude function is maximally flat at the origin and monotonically decreasing in both the pass-band and the stop-band as shown in figure 3.1. The variation of the group delay in the pass-band is comparatively large. However, the overall group delay is larger compared to the other filter approximations as shown in figure 3.1 . The magnitude and group delay of the Butterworth filters can be calculated by equations 3 and 4 respectively. This approximation requires a larger filter order than the other filter approximations to meet a given magnitude specification.

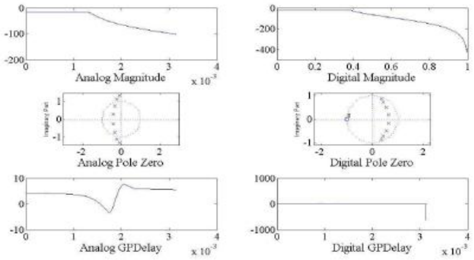

Figure 3.1

3.5 Signal Drift

The frequency of the signal must be accurately and adaptively tuned during changes (drift) in the center frequency of the signal.

3.6 Current Source Inverter

The current source inverter uses silicon-controlled rectifiers (SCRs), gate commutated thyristors (GCTs), or symmetrical gate commutated thyristors (SGCTs). This converter is known as an active rectifier or active front end (AFE). The DC link uses inductors to regulate current ripple and to store energy for the motor. The inverter section comprises gate turn-off thyristor (GTO) or symmetrical gate commutated thyristor (SGCT) semiconductor switches. These switches are turned on and off to create a pulse width modulated (PWM) output regulating the output frequency.

3.7 Voltage Source Inverter

The voltage source inverter topology uses a diode rectifier that converts utility/line AC voltage (50/60 Hz) to DC. The converter is not controlled through electronic firing like the current source inverter (CSI) drive. The DC link is parallel capacitors, which regulate the DC bus voltage ripple and store energy for the system. The inverter is composed of insulated gate bipolar transistor (IGBT) semiconductor switches. There are other alternatives to the IGBT: insulated gate commutated thyristors (IGCTs) and injection enhanced gate transistors (IEGTs).

3.8 Triplen Harmonics

Electronic equipment generates more than one harmonic frequency. For example, computers generate 3rd, 9th, and 15th harmonics. These are known as triplen harmonics. They pose a bigger problem to engineers and building designers because they do more than distort voltage waveforms. They can overheat the building wiring, because nuisance tripping, overheat transformer units, and cause random end-user equipment failure.

4. Simulation And Result Analysis

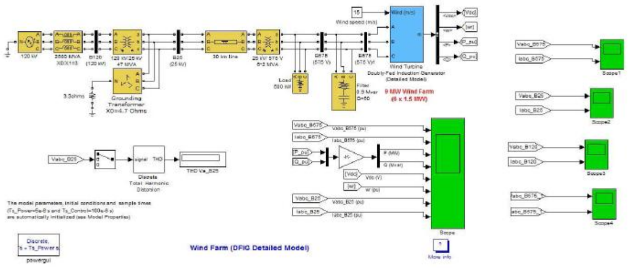

Figure 4.1 Simulation diagram

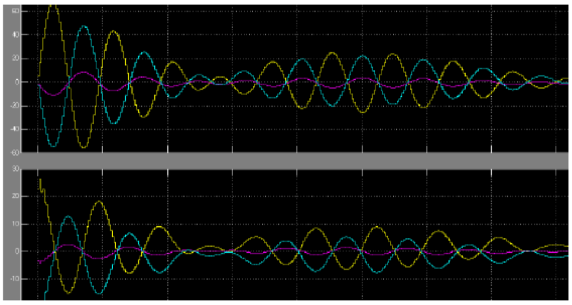

Figure 4.2 shows the voltage and current wave simulation result with filter

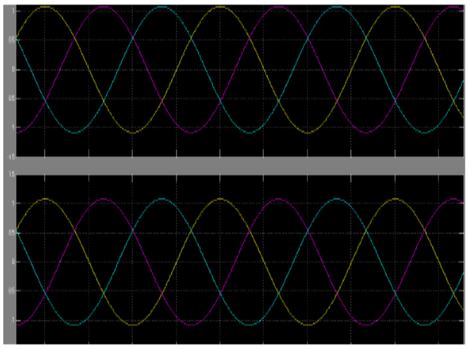

Figure 4.3 Simulation result of voltage wave form with and without filter for HDVC lines

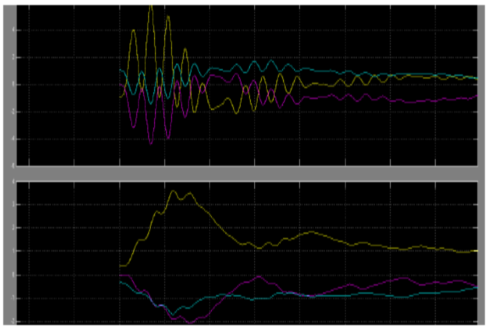

Figure 4.4 shows the current and voltage wave simulation result without filter

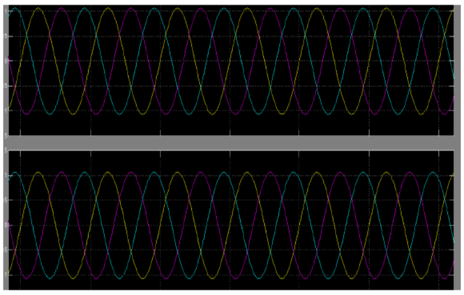

Figure 4.5 shows the voltage wave form with and without filter

5. Conclusion And Future Work

In this paper harmonics and power quality are analyzed. The fundamental frequency of the system which is 50/60 Hz and the harmonics are generated with the multiple of fundamental frequency. The amplitude of the harmonics is smaller than the fundamental frequency but the harmonics frequency is greater than the fundamental frequency. Therefore result shows that high-pass filter is used to suppress the high frequency component.

The different types of three phase filters are used in the HVDC line connected in parallel, in order to achieve an acceptable distortion. The HVDC model in MATLAB/ SIMULINK is used with different three phase filter banks to reduce the distortion and to increase the power quality of the system. Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion and for power factor correction.

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