Harmonic Filter Design for Hvdc Lines Using Matlab

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ABSTRACT: *This paper presents harmonic filter design for HVDC lines using MATLAB version R2009a.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 the filtering device to the power system. Harmonics also increases overall reactive power demanded equivalent load. This paper deals with the design of three phase filter banks connected in parallel to achieve optimal control for harmonic elevation problems.*

KEYWORDS: *harmonic filter, sensitive loads, reactive power, three phase filter banks, optimal control, harmonic elevation problems.*

I INTRODUCTION

Advancement in technology of semiconductor devices has led to a revolution in electronic technology over the past decade. However rise in the power quality (PQ) problem is due to power equipments which include adjustable-speed motor drives (ASDs), electronic power supplies, direct current (DC) motor drives, battery chargers, electronic ballasts. The distortion in current is due to the nonlinearity of the resistor. The nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage. The concept of current distortion is illustrated in the figure 1.In figure 1 a sinusoidal voltage is applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown. From figure 1 we observe, the voltage is perfectly sinusoidal, the resulting current is distorted.

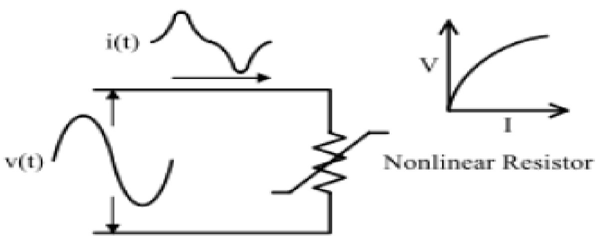

Figure.1 Current distortion caused by nonlinear resistance

The Non-linear loads seem to be the main source of harmonic distortion in a power distribution system. The Non-linear loads produce harmonic currents and inject it into the power distribution network at the point of common coupling (PCC).These harmonic current can interact negatively with a broad range of power systems equipment such as transformers, motors and produce more losses, overheating and overloading.

II SOLUTIONS FOR HARMONIC DISTORTION PROBLEMS

There are set of conventional solutions to the harmonic distortions which have existed for a long time. Some of them are as follows

1) The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. The passive filtering mechanisms do not depend upon an external power supply. Although simple, the use of passive elements does not respond correctly to the dynamics of the power distribution systems. Also the use of passive elements at high power level makes the filter heavy and bulky. The passive filters are known to cause resonance, thus affecting the stability of the power distribution systems. 2) The active power filter (APF) provides solution for harmonic distortion mitigation. The active filters are made of passive and active components and require an external power source. The APF utilize power electronics technologies to produce current components that

cancel the harmonic currents from the non-linear loads. With the APF the switching frequency noise requires additional filtering to prevent with other sensitive equipments.

3) The passive high-pass filter (HPF) used in addition to the conventional APF for mitigating harmonics. This combination is known to be hybrid APF.The main objective of hybrid APF is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonic mitigation.

III MATHEMATICAL ANALYSIS OF HARMONICS

3.1 TOTAL HARMONIC DISTORTION

The basic parameter that is used for the harmonic analysis is the total harmonic distortion (THD).The total harmonic distortion (THD) gives the common measurement indices of harmonic distortion.THD applies to both current and voltage and is defined as the root-mean-square (rms) value of the harmonics divided by the rms value of the fundamental and then multiplied by 100%.The THD is given by the following equation.

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^2}}{M_1} X\,100 \qquad (1)$$

Where M_h is the rms value of harmonic component h of the quantity M .

THD of the current varies from a few percent to more than 100%.THD of the voltage is usually less than 5%.Voltage THDs below 5% are widely considered to be acceptable, while values above 10% are definitely unacceptable and will cause problems for sensitive equipment and loads.The biggest problem with harmonics is voltage waveform distortion. We can calculate a relation between the fundamental and distorted waveforms by finding the sum of the squares of all harmonics generated by a single load, and then dividing this number by the nominal 50/60 Hz waveform value. We do this by a mathematical calculation known as Fast Fourier Transform (FFT) Theorem. This calculation method determines the total harmonics distortion (THD) contained within a nonlinear current or voltage waveform.

3.2 FOURIER SERIES

Fourier series are used in the analysis of periodic functions or periodic signals into the sum of oscillating function called sines and cosines. Many of the phenomena studied in engineering and science are periodic in nature eg. the current and voltage in an alternating current circuit. These periodic functions can be analyzed into their constituent components (fundamentals and harmonics) by a process called Fourier analysis. By definition, a periodic function, *f(t)* is that where *f(t)* = *f(t+T).* This function can be represented by a trigonometric series of elements consisting of a DC component and other elements with frequencies comprising the fundamental component and its integer multiple frequencies. This applies if the following so-called Dirichlet conditions are met:

If a discontinuous function, *f(t)* has a finite number of discontinuities over the period *T*

If *f(t)* has a finite mean value over the period *T*

If *f(t)* has a finite number of positive and negative maximum values

The expression for Fourier series expansion is given as follows,

$$ft) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t)] \qquad (2)$$

Where $\omega_0 = 2\pi / T$

We can further simplify equation (1), we get

$$f(t) = c_0 + \sum_{n=1}^{\infty} c_n \sin(n\omega_0 t + \phi_n) \qquad (3)$$

Where

$$c_0 = \frac{a_0}{2}, c_n = \sqrt{a_n^2 + b_n^2}, \phi_n = \tan^{-1}\left(\frac{b_n}{a_n}\right)$$

$(n\omega_0)n^{th}$ order harmonic of the periodic function

c_0 magnitude of the DC component

c_n *and* ϕ_n magnitude and phase angle of the n^{th} harmonic component

The component with n =1 is the fundamental component. Magnitude and phase angle of each harmonic determine the resultant waveform *f (t).*

The equation (3) can be written in complex form as,

$$f(t) = \sum_{n=1}^{\infty} c_n e^{jn\omega_o t} \qquad (4)$$

Where n=0, ± 1,±2

$$c_n = \frac{1}{T}\int_{-T/2}^{T/2} f(t) e^{-jn\omega_0 t} dt \qquad (5)$$

The main source of harmonics in power system is the static power converter. Under ideal operation condition, harmonics generated by a p pulse power converter are characterized by,

$$I_n = \frac{I_1}{n}, and \quad n = pl \pm 1 \qquad (6)$$

where n stand for the characteristic harmonics of the load; l=1, 2… and p is an integer multiple of six.

The figure below gives the example of harmonic spectrum

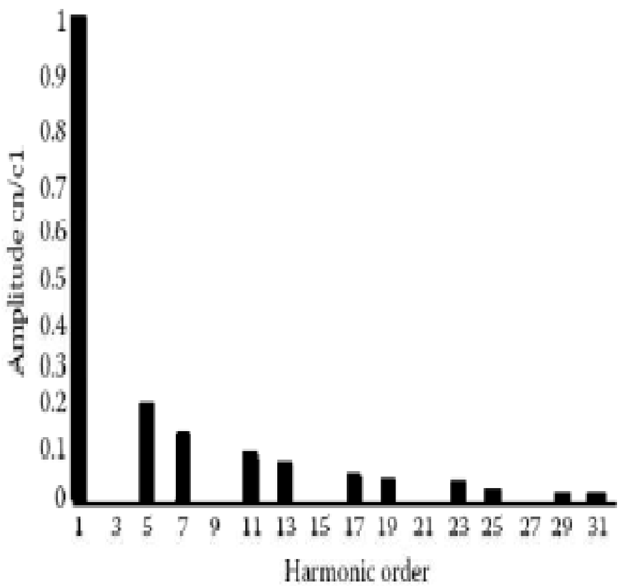

Figure 2. Example of harmonics spectrum

IV SIMULATION AND RESULTS

The figure 3 represents the simulink model of proposed system created in MATLAB.The three phase harmonic filters are connected between the buses B1 and B2 through breaker. For analysis of the harmonics two cases were taken. Case 1 with the three phase harmonics filters connected to the lines and the case 2 with the harmonic filters not connected to the lines.

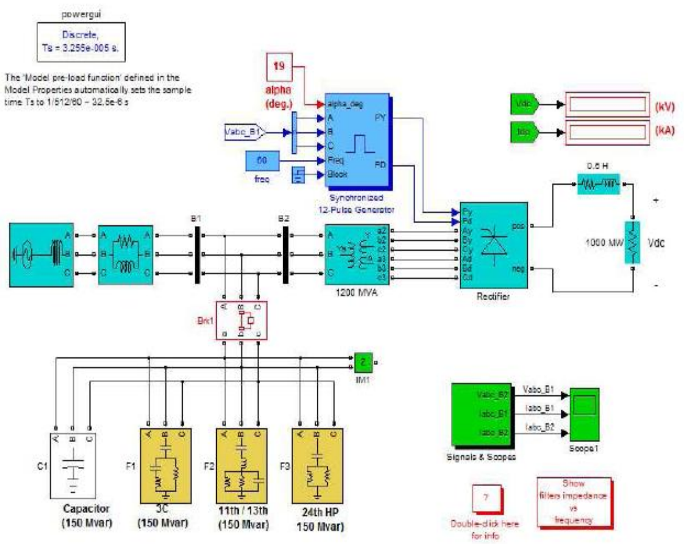

Figure 3. Simulink model of the proposed system

Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion and for power factor correction. Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into power system. The resulting distorted currents flowing through system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Harmonic filters are designed to be capacitive at fundamental frequency, so that they are used for producing reactive power required by converters and for power factor correction.The HVDC (High Voltage Direct Current) rectifier is built up from two 6-pulse thyristor bridges connected in series. The converter is connected to the system with a 1200-MVA three phase transformer (three windings).A 1000-MW resistive load is connected to the DC side through a 0.5 H smoothing reactor. The filters are made of the following four components of the powerlib/Elements library:

1. One capacitor banks (C1) of 150 Mvar modeled by a "Three-Phase Harmonic Filters "are used in HVDC line.

(i).One C-type high-pass filter to the 3rd (F1) of 150 Mvar

(ii).One double-tuned filter 11th /13th (F2) of 150 Mvar

(iii).One high-pass filter tuned to the 24th (F3) of 150 Mvar.

In order to achieve an acceptable distortion, several banks of filters of different types are usually connected in parallel. The combinations of different banks are derived from basic filters Butterworth Chebyshev and Cauer filters. The most commonly used filter types are

1. Band-pass filters, which are used to filter lowest order harmonics such as 5th ,7th ,11th ,13th etc.Band-pass filters can be tuned at a single frequency(single tuned filter) or at two frequencies(double-tuned filter)

2. High-pass filters, which are used to filter high-order harmonics and cover a wide range of frequencies. A special type of high-pass filter, the C-type high-pass filter, is used to provide reactive power and avoid parallel resonances. It also allows filtering low order harmonics (such as 3rd), while keeping zero losses at fundamental frequency.

The figure below shows the different types of three-phase RLC harmonic filter.

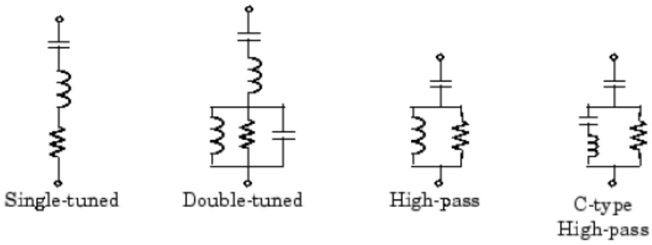

Figure 4. Different types of three-phase RLC harmonic filter

The simulink model of the proposed system is given in figure 2.The power converter usually act as nonlinear source injecting harmonics into the system. The three phase harmonic filter is installed between the buses B1 and B2.

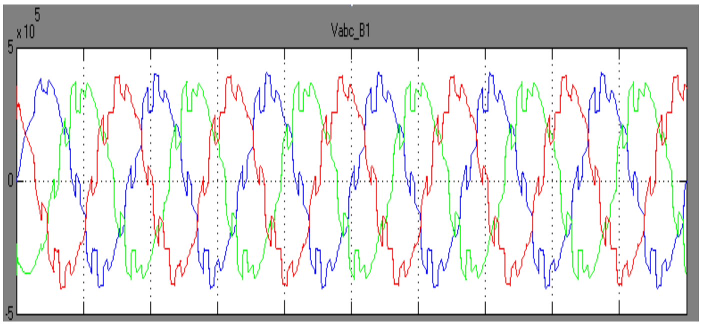

Figure 5. Three phase voltage at the bus B1 without harmonic filter

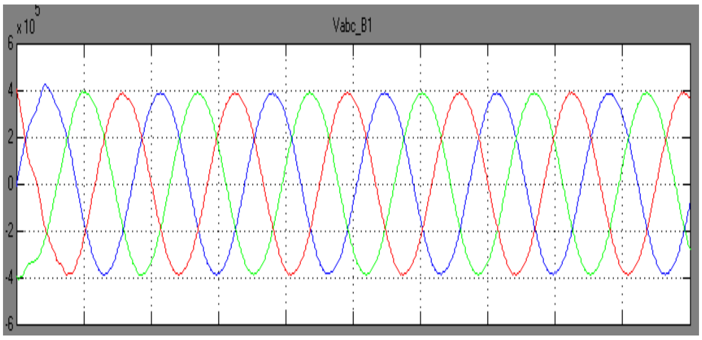

Figure 6. Three phase voltage at the bus B1 with harmonic filter

Figures 4 and 5 gives the simulation results of the three phase voltage at the bus B1 with and without harmonic filters. From figure 4 we observe that in the absence of three phase harmonic filters the three phase voltage at the bus B1 getting distorted due to the harmonics injected by the rectifier, which is the non-linear load in this case.

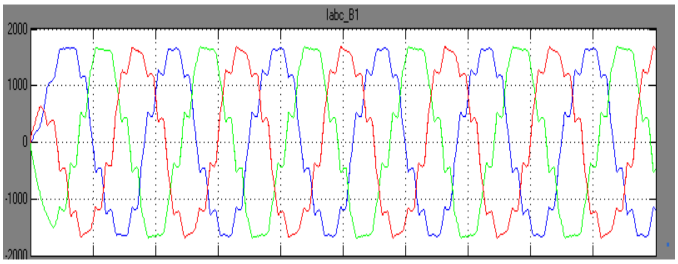

Figure 7. Three phase current at the bus B1 without harmonic filter

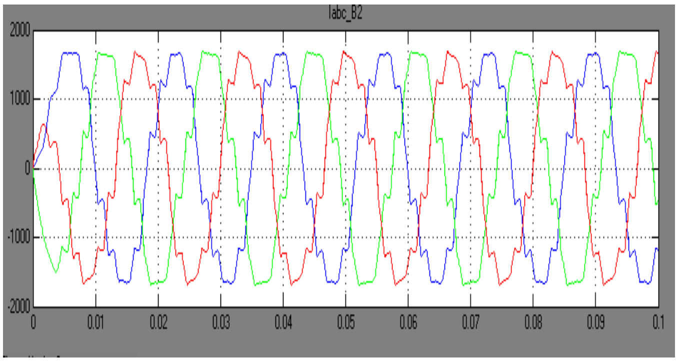

Figure 8. Three phase current at the bus B2 without harmonic filter

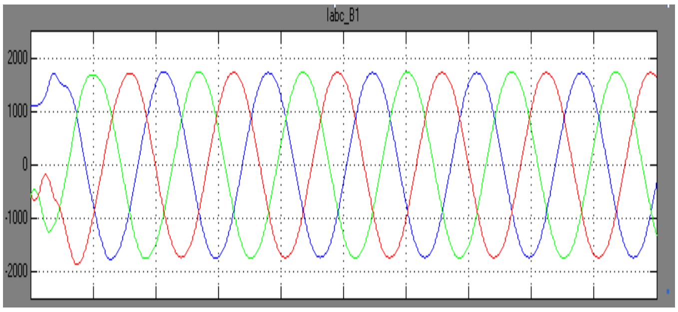

Figure 9. Three phase current at the bus B1 with harmonic filter

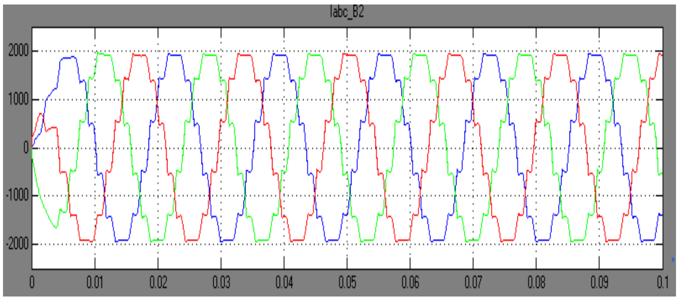

Figure 10. Three phase current at the bus B2 with harmonic filter

Figures 6 and 7 gives the simulation results of three phase currents at the buses B1 and B2 without harmonic filters. Figures 8 and 9 gives the simulation results of three phase currents at the buses B1 and B2 with harmonic filters. On comparison of figures 6,7 and 8,9 we observe that in the absence of three phase harmonic filters the three phase currents at the bus B1 and B2 getting distorted due to the harmonics injected by the non-linear load.

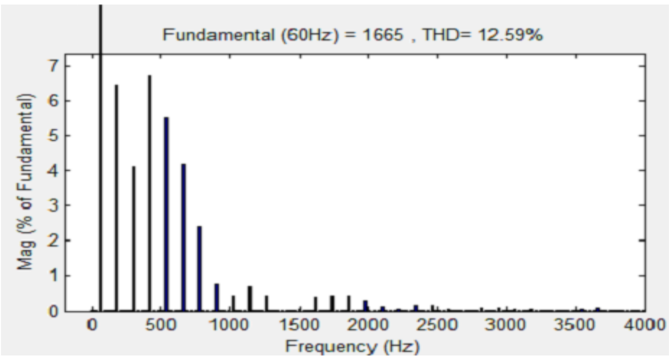

Figure 11. Harmonic spectrum of three-phase currents at bus B2 without harmonic filter

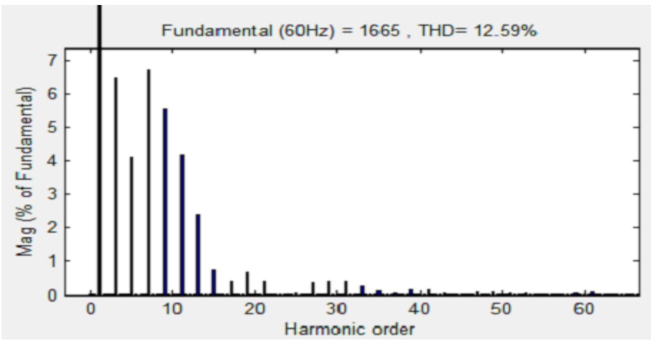

Figure 12. Harmonic order of three-phase currents at bus B2 without harmonic filter

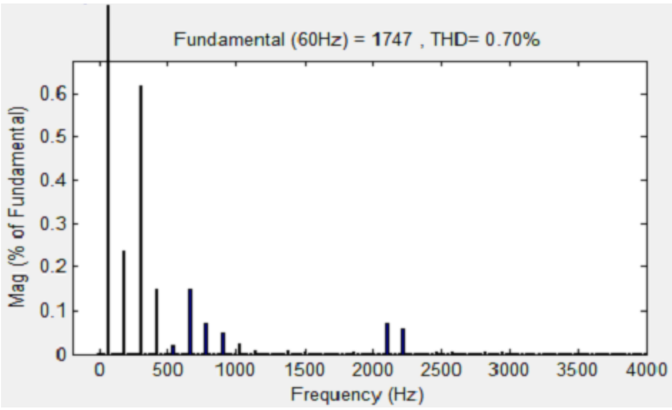

Figure 13. Harmonic spectrum of three-phase currents at bus B2 with harmonic filter

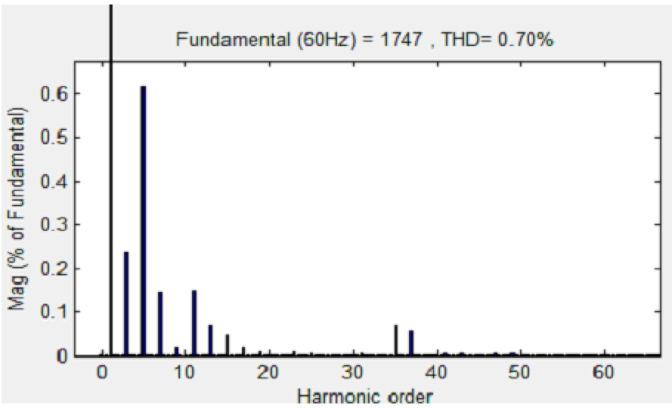

Figure 14. Harmonic order of three-phase currents at bus B2 with harmonic filter

On comparison on figures 10, 11 with figures 11, 12 we observe that the total harmonic reduction (THD) was considerably reduced from 12.59% for the case without harmonic filters to 0.70% for the case with harmonic filters. The simulation is performed for the test case with alpha 19 degree .Simulations can be performed for various values of alpha and the impact on the DC level and on generated harmonics can be noted.

V CONCLUSION

There will be an increasing economical impact on the operation of electrical power system due to losses in the system.In this study 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 filter used in this work for decreasing the voltage distortion and for power factor correction. The focus of this work is to have economical impact of the electrical power system through harmonics, distortion reduction and to increase the power quality of the system.

VI SCOPE OF FUTURE WORK

This is work can be extended in future with different filter combinations for decreasing the harmonics. Advanced modifications can be imparted to this filter design to address various power quality issues and to provide the end users with reliable source of power.

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