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Electrical Power Quality Improvement In Faulty Conditions Using Three-Phase Double Tuned Harmonic Filter

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Abstract:

The Electrical power quality issue has attained considerable attention in last decade due to large penetration of power electronics based loads and microprocessor based controlled loads. Power quality has become an important topic of discussion and research, especially in a deregulated environment. As per IEEE 519 std. these parameters of power quality measurement are four in number, of which Total Harmonic Distortion is most widely used. The power quality disturbances decrease the efficiency of power system equipments such as generators. Therefore the issue of power quality is important to both the consumers and the utility of electric power. There are many facets of power quality disturbances and each has its own source and mitigation techniques. The power system faults are important source of power quality disturbances. This paper deals with power quality improvement in four bus system during faulty conditions using double tuned filter to reduce the effects of disturbances on the generators. The four bus system having two load and two generator buses is modeled in MATLAB/Simulink environment. A fault is created near the load bus and power quality disturbances are detected near the generator bus and improved using double tuned filter near the generator bus under study. The Matlab results show the performance of double tuned filter in improvement of power quality disturbances during faulty conditions.

Keywords: *power quality disturbances, total harmonic distortion, power system faults, matlab/ simulink.*

1.Introduction

Power quality has been a research issue in the power engineering community since the past decade. Electrical power system is expected to deliver undistorted sinusoidal rated voltage and current continuously at rated frequency to the consumers. In recent years, grid users have detected an increasing number of drawbacks caused by electric power quality (PQ) variations and PQ problems have sharpened because of the increased number of loads sensitive to PQ and have become more difficult to solve as the loads themselves have become important causes of degradation of quality [1]. Transmission line relaying involves the three major tasks: detection, classification, and location of the fault. It must be done as fast and accurate as possible to de-energize the faulted line and protecting the system from the harmful effects of the fault. With the wide application of high power electronics switchgears, problems of power quality are becoming more serious day by day [2]-[3]. A number of papers have been published during the last several years on detections and classification of power quality disturbances. The approach of neural networks has been used by [4] for the purpose of PQ disturbance detection. The use of continuous wavelet transform (CWT) to analyze non-stationary harmonic distortion has been proposed by [5]. Studies on PQ assessment by using a dynamic orthogonal wavelet were carried out by [6]. An improved Hilbert-Huang method for analysis of time varying waveforms in power quality has been proposed by [7]. The discrete wavelet transform and S-transform based neural classifier scheme for time series data mining of power quality events occurring due to power signal disturbances has been proposed by [8].

Most of papers published on power quality are concerned with the customer related issues and classification of power quality disturbances. This paper aims improvement of power quality in faulty conditions of power system using three phase double tuned harmonic filter. The four bus system with two load and two generator buses is simulated in MATLAB/Simulink environment. The power quality improvement using double tuned filter connected at generator bus during LG fault, LL fault, LLG fault, LLL fault and LLLG fault on the load bus has been studied. The results obtained after simulation demonstrate the use of double tuned filter in power quality improvement in faulty conditions of power system.

2.Power Quality Disturbances In Power System

The term power quality (PQ) is generally applied to a wide variety of electromagnetic phenomena occurring within a power system network. Power quality is predominantly a customer issue. Power quality can be defined as any problem manifested in voltage, current, or frequency deviation that results in failure or mal-operation of electric equipment [9]. The electric power quality is also defined as a term that refers to maintaining the near sinusoidal waveform of power system bus voltages and currents at rated magnitude and frequency. Thus electric power quality is often used to express voltage quality, current quality, reliability of service, quality of power supply etc. [10]. Power quality issue is also important for the utility companies. They are obliged to supply consumers with electrical power of acceptable quality.

The power quality disturbances depend on amplitude or frequency or on both frequency and amplitude. Based on duration of existence of PQ disturbances, events can be divided in short, medium or long type. The classification and identification of each disturbance are usually carried out from standards and recommendations depending on where the utilities operate (e.g. IEEE in the U.S.). Inigo Monedero *et al.* [11] defined PQ disturbances, which is given in Table I, based on the UNE standard in Spain which defines the ideal signal as a single-phase or three-phase sinusoidal voltage signal of 230 V_{RMS} and 50Hz. D. Saxena *et al.* [12] classified various PQ events in to five groups viz. short duration variation, long duration variation, transients, voltage imbalance and waveform distortion. S.Edwin Jose *et al.* [13] classified PQ disturbances on basis of values of tails of histogram obtained from simulation results. Subhamita Roy *et al.*[14] presented classification of power quality disturbances using features of signals based on the energy of the distorted signals. The multi-resolution analysis technique of DWT is employed on the distorted signals to extract the energy distribution features at different levels of resolution. Haibo He *et al.*[15] proposed a novel approach for the power quality disturbances classification based on the wavelet transform and self organizing learning array system.

3.Three-Phase Double Tuned Harmonic Filter

Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion and for power factor correction. The three-phase harmonic filter is built of RLC elements. The resistance, inductance and capacitance values are determined from the filter type, reactive power at nominal voltage, tuning frequencies and quality factor. Passive filter has been widely used in filtering harmonics in power system because it has a simple structure, low cost and high reliability. Usually, there are multiple frequency harmonics in a power system, so a group of parallel single tuned filters are needed to filter harmonics. This filtering method covers a large area and has a high cost [16]. Double tuned filter performs the same function as two single tuned filters connected in parallel although it has certain advantages of lower cost, low losses and lower impedance magnitude at the frequency of parallel resonance that arises between the two tuning frequencies [17]. Chih-Ju *et al.*[18] presented that double tuned filter consists of a series LC circuit and a parallel RLC circuit as shown in Figure 1. If f_1 and f_2 are the two tuning frequencies, both the series circuit and parallel circuit are tuned to approximately the mean geometric frequency given by the relation:

$$f_m = \sqrt{f_1 \times f_2} \qquad (1)$$

The quality factor Q of the double tuned filter is defined as the quality factor of the parallel L, R elements at the mean frequency f_m:

$$Q = \frac{R}{L \times 2\pi f_m} \qquad (2)$$

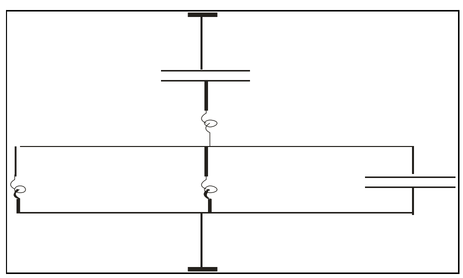

Figure 1: Double tuned harmonic filter

4.Proposed Power System Model

For power quality improvement using three-phase double tuned harmonic filter during faulty conditions in the power system, the one line diagram of experimental set up consisting of four buses shown in Figure 2 is used [19]. The buses 1 & 2 are taken as generator buses and buses 3 & 4 are taken as load buses. The line length of all the four π sections are taken as 100 Km. For simplicity the voltage levels at all points of the system are taken as 33 KV. The three-phase double tuned harmonic filter is installed near the generator bus 1 to protect the generator from power system disturbances during faulty conditions. The fault is located at bus no. 4 in all faulty conditions considered in the study. All the measurement of the voltage signals are taken on bus no. 1 at generating station.

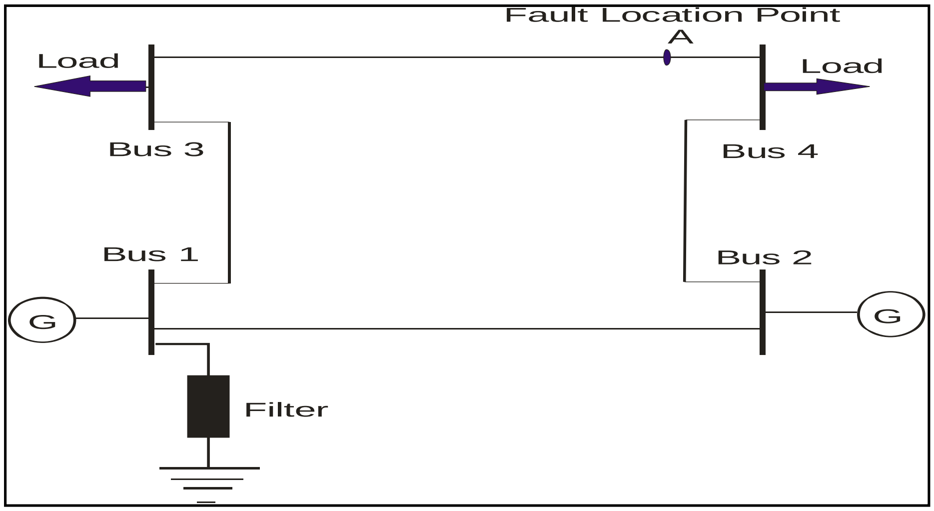

Figure 2: Proposed model of power system for improvement of PQ disturbances in faulty conditions

5.Power System Simulation And Discussion

Power system faults are abnormal events which are not part of normal operation and unwanted by the network operator. After fault occurs in the power system, a non-linear signal of transient travelling wave is generated and runs along faulted transmission line to both ends of the line. Those travelling waves contain information about fault nature. The fault initial travelling wave has a wide frequency spectrum from DC component to high frequencies. When such fault travelling wave arrives at the substation bus bar, it will change incisively, i.e. travelling wave head will present the sudden change in the time-frequency diagram. In that way, travelling wave arrival to the measuring point (usually the busbar voltage transformers) exactly a moment of sudden change recorded on measuring substation [20]. For experimental improvement of power quality disturbances to reduce the impact of PQ disturbances on the generators three-phase double tuned harmonic filter is used. The proposed model is simulated in MATLAB/Simulink environment for analysis of improvement in the power quality disturbances.

6.Power System In Healthy Condition

The power system model shown in Figure 2 is simulated in MATLAB/Simulink environment in healthy condition. The Voltage signal of phase-A and Fourier signals on phase-A are shown in Figure 3 and Figure 4 respectively. In healthy condition the voltage in all the three phases are identical. The symmetrical wave of 50Hz frequency is obtained. The Fourier analysis of the voltage signals also show the symmetry in healthy conditions.

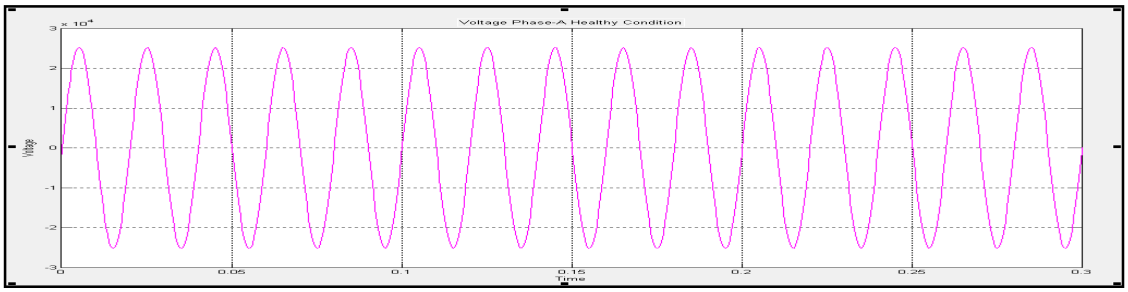

Figure 3: Voltage signal on phase-A at bus-1 in healthy condition

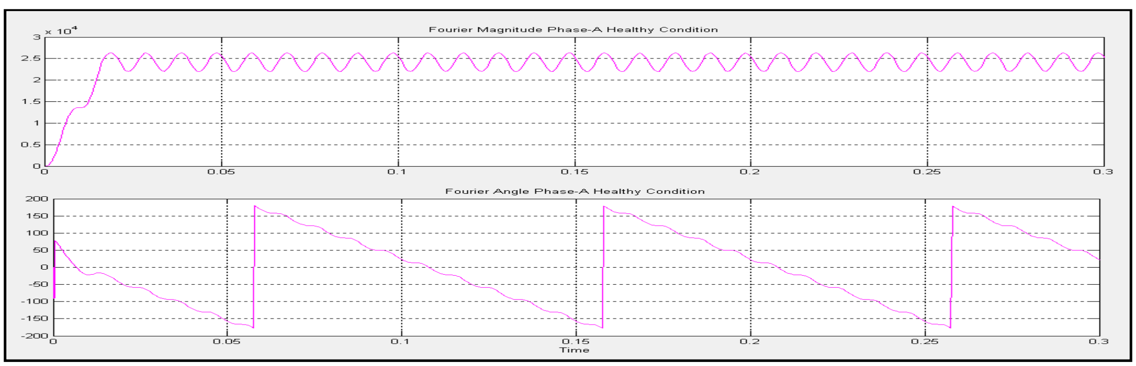

Figure 4: Fourier analysis of voltage signal on phase-A at bus-1 in healthy condition

7.LG Fault In Power System

The power system model shown in Figure 2 is simulated in MATLAB/Simulink environment with line to ground fault at bus no. 4 on phase-A. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 are shown in Figure 5, and Figure 6 respectively. The multiple voltage spikes of magnitude of the order 10^6 are obtained on the faulty phase. The presence of multiple voltage spikes is also validated by the Fourier analysis of signal.

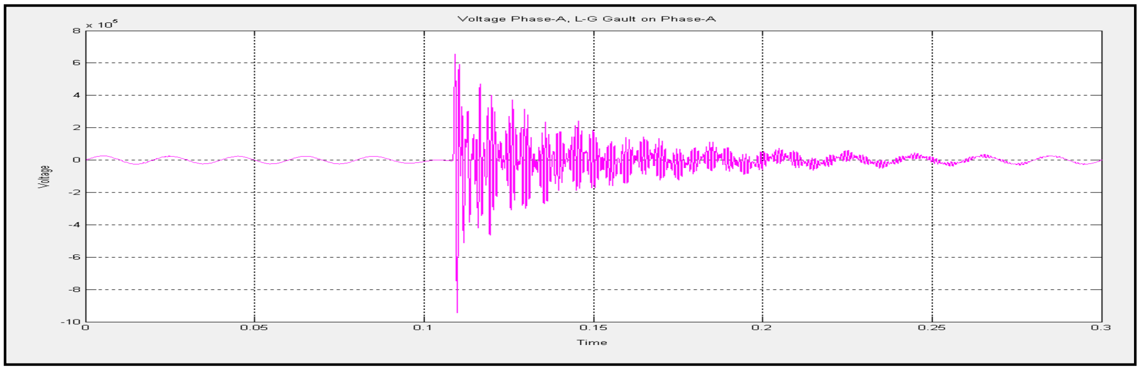

Figure 5: Voltage signal on Phase-A at bus-1 with LG fault on phase-A at bus-4

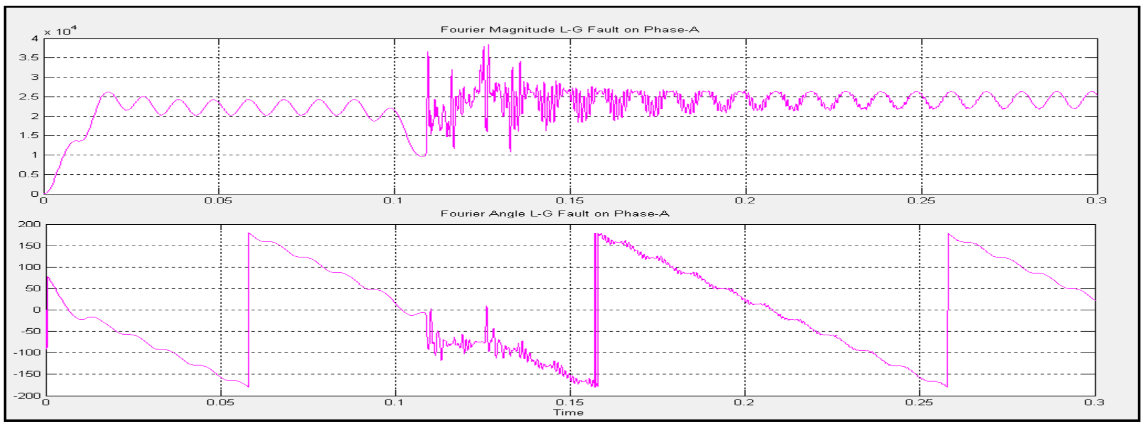

Figure 6: Fourier analysis of signal on phase-A at bus-1 with LG fault on phase-A at bus-4

Three-phase double tuned harmonic filter is connected at generator bus-1. In the presence of three-phase double tuned harmonic filter with star grounded connected at generator bus-1, the multiple voltage spikes decreases in number and approaches sinusoidal waveform. The magnitude of voltage spikes also reduces from the order of 10^6 to 10^4. The decrease in disturbances is also validated by the Fourier analysis. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 with star grounded three-phase doubled tuned harmonic filter connected at bus-1 are shown in Figure 7, and Figure 8 respectively.

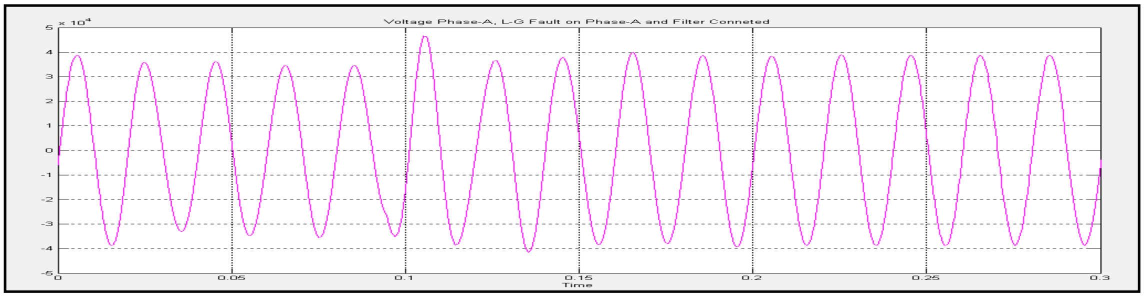

Figure 7: Voltage signal on phase-A at bus-1 with filter connected during LG fault on phase-A at bus-4

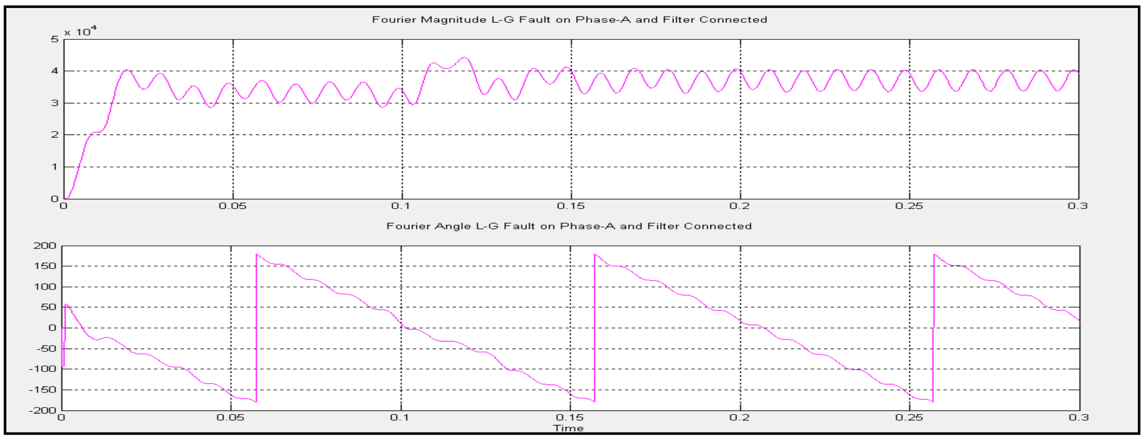

Figure 8: Fourier analysis of voltage signal on phase-A at bus-1 with Filter connected during LG fault on phase-A at bus-4

8.LL Fault On Power System

The power system model shown in Figure 2 is simulated in MATLAB/Simulink environment with double line (LL) fault at bus no. 4 on phases A & B. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 are shown in Figure 9, and Figure 10 respectively. The multiple voltage spikes of magnitude of order 10^7 are detected on the faulty phases. The presence of multiple voltage spikes of high magnitude is confirmed by the Fourier analysis of voltage signal.

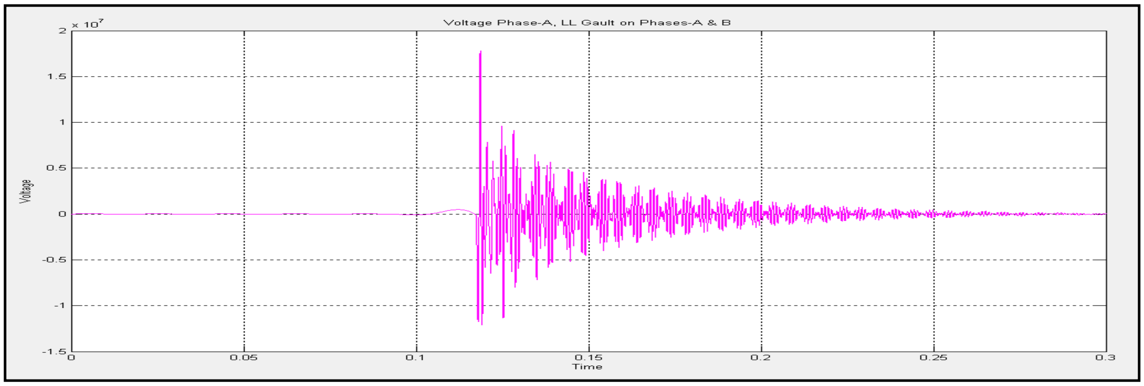

Figure 9: Voltage signal on phase-A at bus-1 with LL fault on phases A & B at bus-4

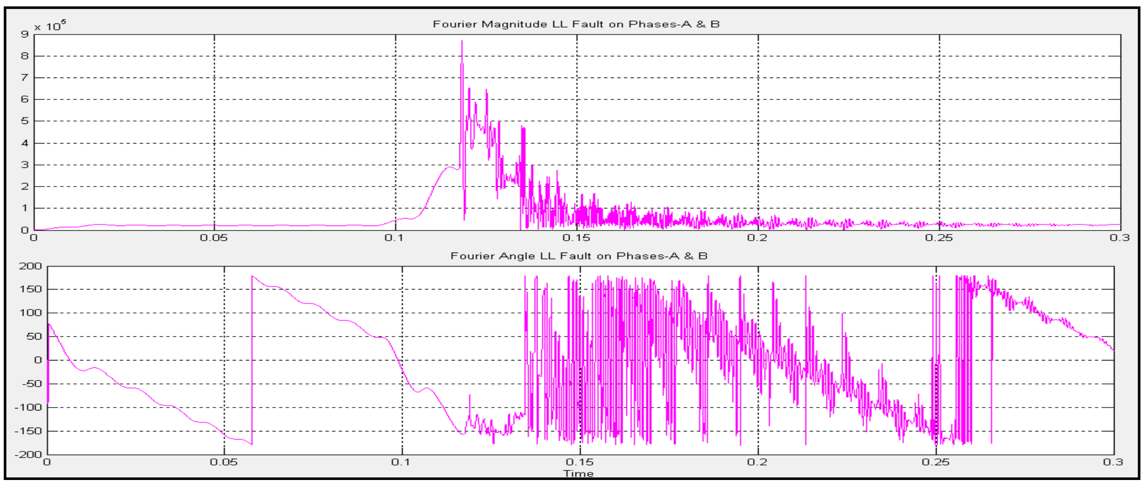

Figure 10: Fourier analysis of voltage signal on phase-A at bus-1 with LL fault on phases-A&B at bus-4

Three-phase double tuned harmonic filter is connected at generator bus-1. In the presence of double tuned harmonic filter with star neutral connected at generator bus-1, the multiple voltage spikes decreases in number. The magnitude of voltage spikes also reduces from the order of 10^7 to 10^5. The decrease in disturbances is also validated by the Fourier analysis. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 with star neutral three-phase doubled tuned harmonic filter connected at bus-1 are shown in Figure 11, and Figure 12 respectively.

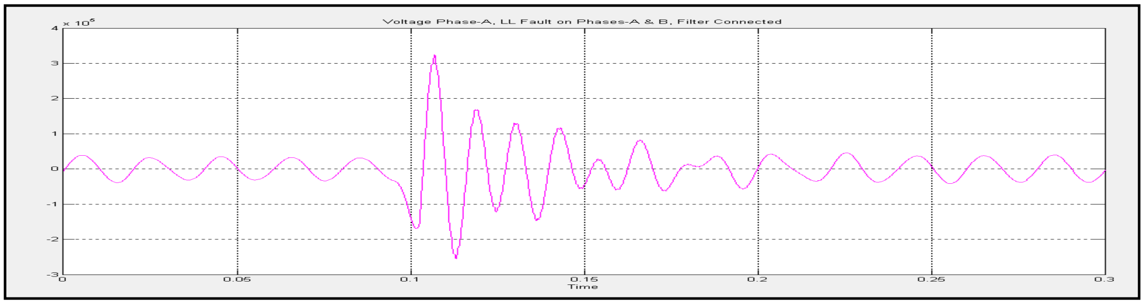

Figure 11: Voltage signal on phase-A at bus-1 with filter connected during LL fault on phases A & B at bus-4

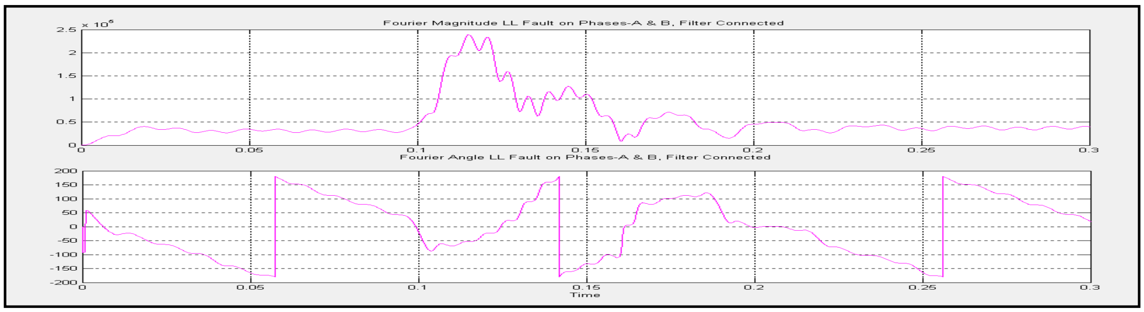

Figure 12: Fourier analysis of voltage signal on phase-A at bus-1 with filter connected during LL fault on phases-A&B at bus-4

9.LLG Fault On Power System

The power system model shown in Figure 1 is simulated in MATLAB/Simulink environment with double line to ground (LLG) fault at bus no. 4 on phases A & B. The voltage signal of phase-A and Fourier signals on phase-A at bus no. 1 are shown in Figure 13, and Figure 14 respectively. The multiple voltage spikes of the magnitude of order 10^8 are detected on the faulty phases. The presence of multiple voltage spikes of high magnitude is confirmed by the Fourier analysis of voltage signal.

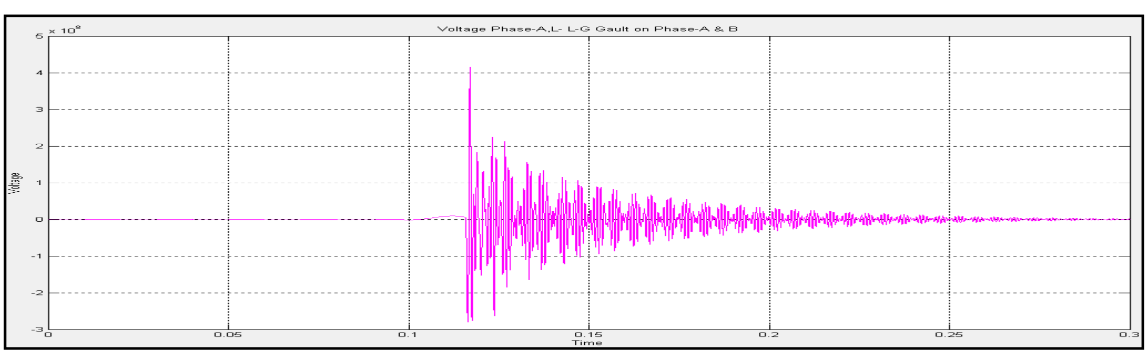

Figure 13: Voltage signal on phase-A at bus-1 with LLG fault on phases A & B at bus-4

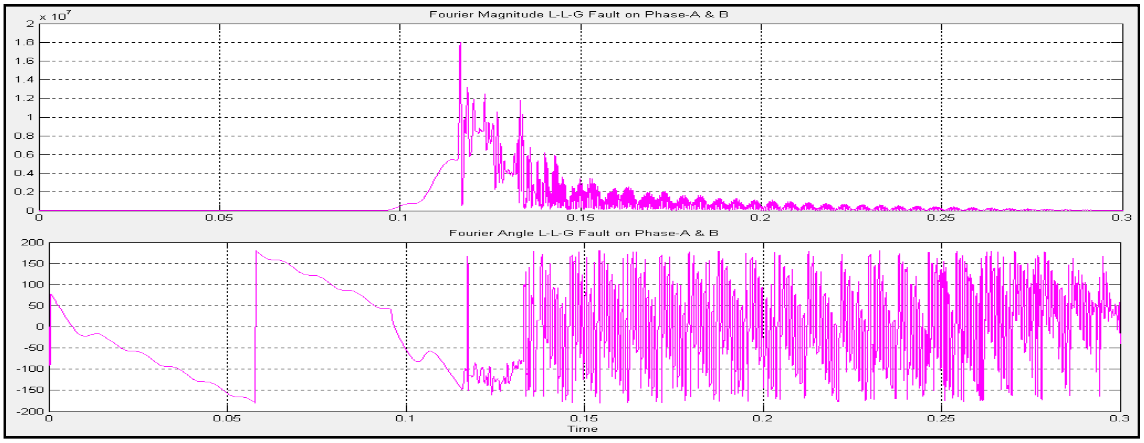

Figure 14: Fourier analysis of voltage signal on phase-A at bus-1 with LLG fault on phases-A&B at bus-4

Three-phase double tuned harmonic filter is connected at generator bus-1. In the presence of three-phase double tuned harmonic filter with star grounded connected at generator bus-1, the multiple voltage spikes decreases in number and approaches sinusoidal waveform. The magnitude of voltage spikes also reduces from the order of 10^8 to 10^4. The decrease in disturbances is also validated by the Fourier analysis. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 with star grounded three-phase doubled tuned harmonic filter connected at bus-1 are shown in Figure 15, and Figure 16 respectively.

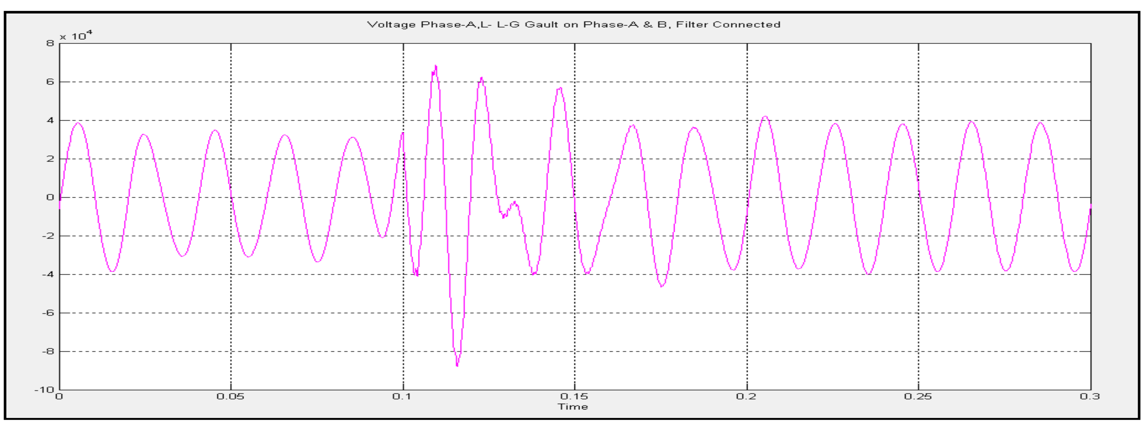

Figure 15: Voltage signal on phase-A at bus-1 with filter connected during LLG fault on phases A & B at bus-4

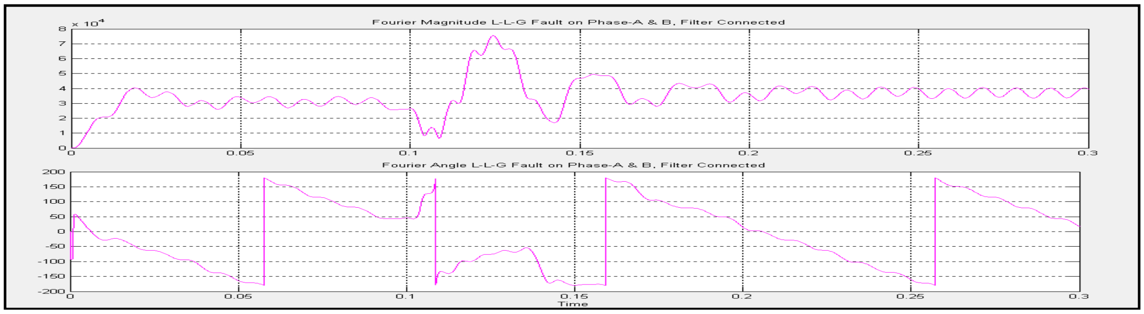

Figure 16: Fourier analysis of voltage signal on phase-A at bus-1 with filter connected during LLG fault on phases-A&B at bus-4

10.LLL Fault On Power System

The power system model shown in Figure 2 is simulated in MATLAB/Simulink environment with three phase (LLL) fault at bus no. 4. The voltage signal of phase-A and Fourier signals on phase-A at bus no. 1 are shown in Figure 17, and Figure 18 respectively. The voltage swell and spikes at certain points of waveform are detected on the phase voltage of the system. The presence of voltage swell in the system voltage because of LLL fault on the system is confirmed by the Fourier analysis of voltage.

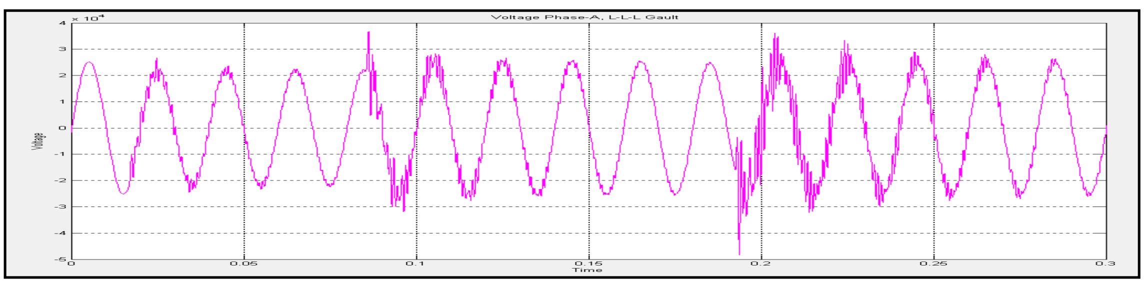

Figure 17: Voltage signal on phase-A at bus-1 with LLL fault at bus-4

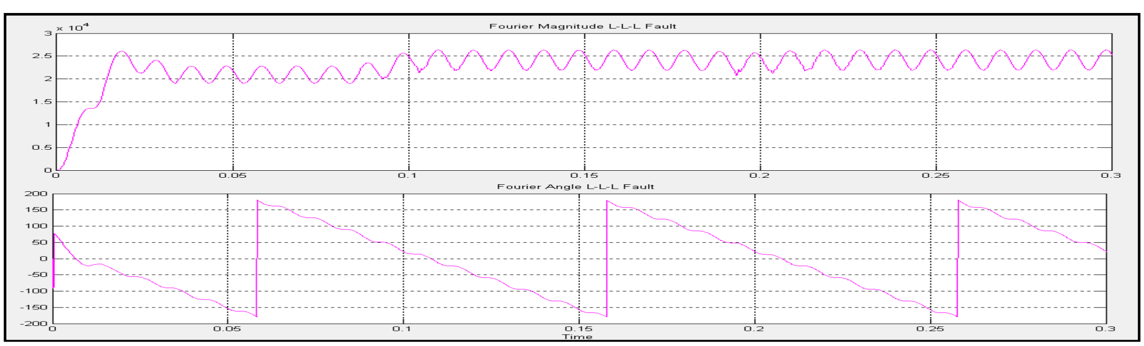

Figure 18: Fourier analysis of voltage signal on phase-A at bus-1 with LLL fault on bus-4

Three-phase double tuned harmonic filter is connected at generator bus-1. In the presence of three-phase double tuned harmonic filter with star neutral connected at generator bus-1, the voltage waveform is smoothened and approaches the sinusoidal waveform. The voltage swell is still present. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 with star neutral three-phase doubled tuned harmonic filter connected at bus-1 are shown in Figure 19, and Figure 20 respectively.

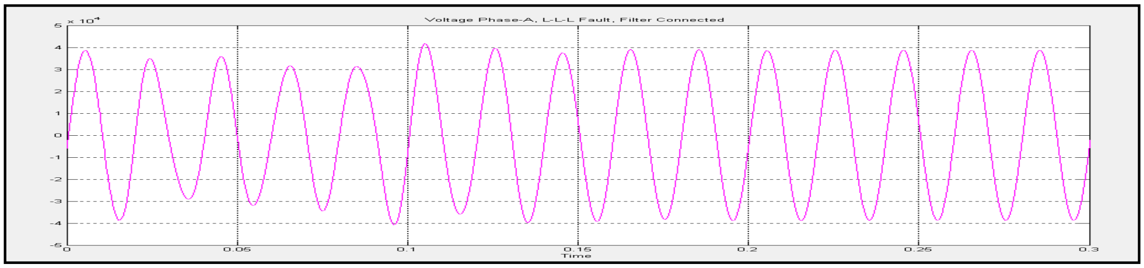

Figure 19: Voltage signal on phase-A at bus-1 with filter connected during LLL fault on phases A & B at bus-4

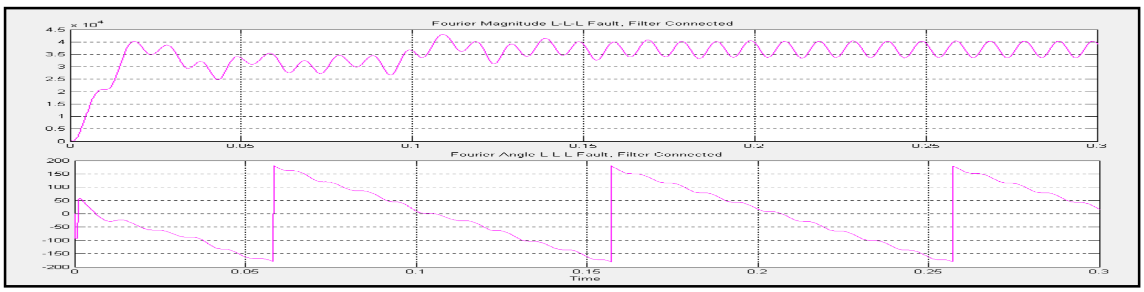

Figure 20: Fourier analysis of voltage signal on phase-A at bus-1 with filter connected during LLL fault on phases-A&B at bus-4

11.LLLG Fault On Power System

The power system model shown in Figure 2 is simulated in MATLAB/Simulink environment with three phase fault (LLLG) including ground at bus no. 4. The voltage signal of phase-A and Fourier signals on phase-A at bus no. 1 are shown in Figure 21, and Figure 22 respectively. The multiple voltage spikes of high frequency persist for long time in case of LLLG fault on the system. The magnitude of voltage spike is detected of the order of 10^6. The presence of high frequency voltage spikes is confirmed by the Fourier analysis of voltage signal.

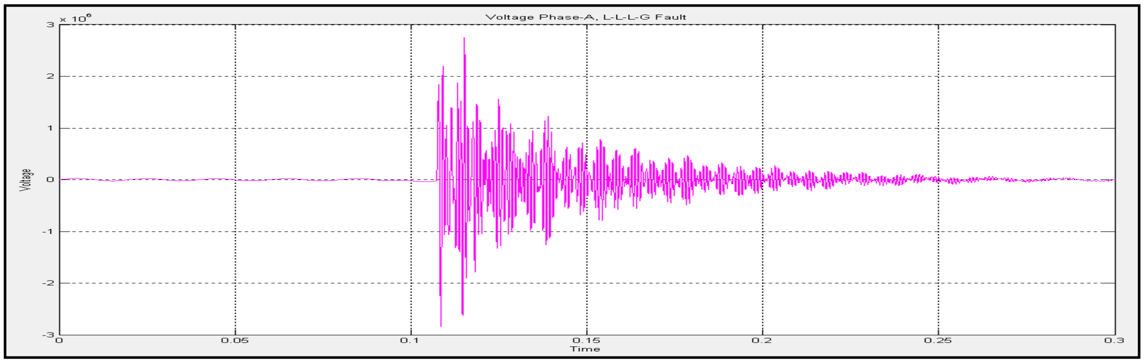

Figure 21: Voltage signal on phase-A at bus-1 with LLLG fault on bus-4

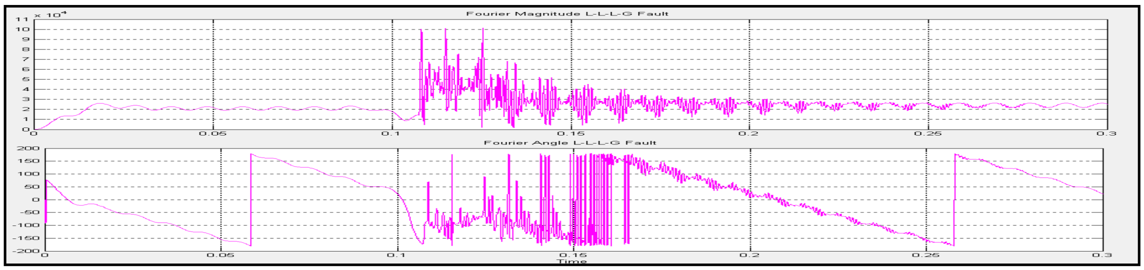

Figure 22: Fourier analysis of signal on phase-A at bus-1 with LLLG fault on bus-4

Three-phase double tuned harmonic filter is connected at generator bus-1. In the presence of three-phase double tuned harmonic filter with star grounded connected at generator bus-1, the multiple voltage spikes decreases in number and frequency of spikes is also get reduced significantly. The magnitude of voltage spikes also reduces from the order of 10^6 to 10^5. The decrease in disturbances is also validated by the Fourier analysis. The voltage signal of phase-A and Fourier signal on phase-A at bus no. 1 with star grounded three-phase doubled tuned harmonic filter connected at bus-1 are shown in Figure 23, and Figure 24 respectively.

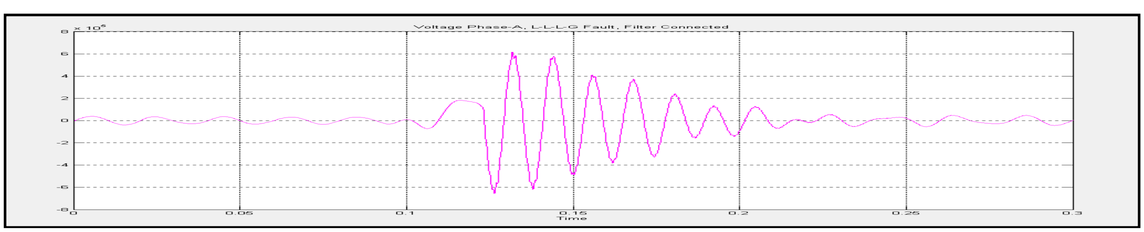

Figure 23: Voltage signal on phase-A at bus-1 with filter connected during LLLG fault on phases A & B at bus-4

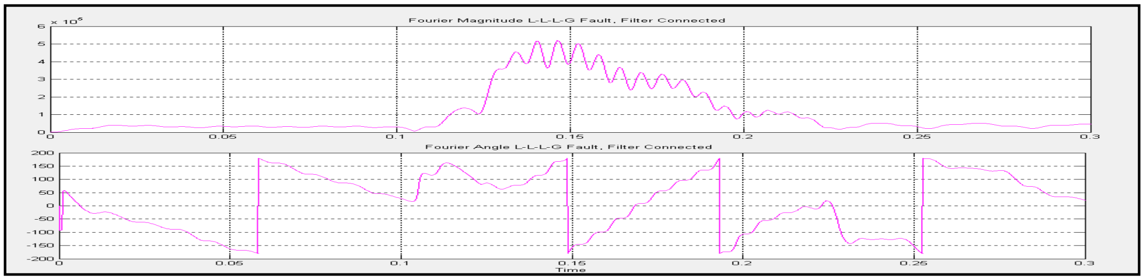

Figure 24: Fourier analysis of voltage signal on phase-A at bus-1 with filter connected during LLLG fault on phases-A&B at bus-4

12.Conclusion

An efficient but simple technique has been developed for improvement of power quality disturbances during faulty conditions using three phase double tuned harmonic filter in the electrical power system. The proposed model of four bus system is simulated in the MATLAB/Simulink environment. The results show that three-phase double tuned harmonic filter is effective in reducing the magnitude and frequency of voltage spikes though the voltage swells does not improve significantly. The three-phase double tuned harmonic filter with star grounded is most effective in improvement of power quality disturbances in faults involving ground and three-phase double tuned harmonic filter with star neutral is effective for improvement of power quality disturbances in faults without ground.

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