Power Quality Improvement in Faulty Conditions using Tuned Harmonic Filters

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Abstract: The electrical power quality has become an important topic of discussion and research these days. As per IEEE 519 std. parameters of power quality measurement, are four in number, of which Total Harmonic Distortion is most widely used. This paper proposes the optimal planning of passive tuned harmonic filters for improvement of power quality in faulty conditions of electrical power system. The Total Harmonic Distortion analysis of power quality disturbances is carried out in the faulty conditions and in the presence of single tuned and double tuned harmonic filters. 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 single tuned and double tuned filters 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 fault, single tuned harmonic filter, double tuned harmonic filter.

I. INTRODUCTION

The continuous monitoring of power quality (PQ) has become imperative as occurrences of PQ disturbances are relatively sporadic and mostly unscheduled. Further when something goes wrong and the source of the problem needs to be investigated, whether upstream or downstream of the issue, PQ data is an absolute necessity [1]. Power quality is a term used to describe the most important aspect of the electricity supply. 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 [2]. Poor quality of electric power is normally caused by power line disturbances, such as impulses, notches, glitches, momentary interruption wave faults, voltage sag, swell, harmonic distortion and flicker resulting in misoperation or failure of end use equipments [3]. Poor quality may cause many problems that affect the load such as malfunction, instability, short lifetime and so on. According to the survey by IEEE transactions on Industrial Applications, power quality disturbances lead to losses of $4 billion to $10 billion in the USA alone [4]. 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 [5]. 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 [6]-[7]. 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. [8] defined PQ disturbances, 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. [9] 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. [10] classified PQ disturbances on basis of values of tails of histogram obtained from simulation results. Haibo He et al.[11] proposed a novel approach for the power quality disturbances classification based on the wavelet transform and self organizing learning array system. Devendra Mittal et al. [12] presented a method for improvement of electrical power quality under faulty conditions in electrical power system using three phase double tuned harmonic filter.

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 single tuned and double tuned harmonic filters. The four bus system with two load and two generator buses is simulated in MATLAB/Simulink environment. The power quality improvement
using three phase harmonic filters connected at generator bus during LG fault, LL fault, LLG fault, LLL fault and LLLG fault on the load bus has been studied. The analysis is carried out on the basis of Total harmonic Distortion (THD). The results obtained after simulation demonstrate the performance of three phase harmonic filters in improvement of power quality during faulty conditions of power system.

II. THREE-PHASE TUNED HARMONIC FILTERS

The passive harmonics filters are composed of passive elements: resistor (R), inductor (L) and capacitor (C). The common types of passive filters include single-tuned and double tuned filters, second-order, third-order and C-type damped filters. 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. The single tuned filter is the series combination of inductor (L) and capacitor (C) as shown in Fig. 1. 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 [13].

![Fig. 1 Single tuned harmonic filter](image1)

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 [14]. Chih-Ju et al.[15] presented that double tuned filter consists of a series LC circuit and a parallel RLC circuit as shown in Fig. 2. 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:

\[
f_m = \sqrt{f_1 \times f_2}
\]

(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 \( f_m \):

\[
Q = \frac{R}{L \times 2\pi f_m}
\]

(2)

![Fig. 2 Double tuned harmonic filter](image2)

III. TOTAL HARMONIC DISTORTION

Non-sinusoidal input, or supply, current is made up of fundamental current plus current components of higher frequencies. The total harmonic distortion (THD) is equal to the rms value of all the harmonics divided
by the rms value of fundamental component of the input current. Greater the value of THD greater is the harmonic content and hence greater is the distortion of input supply current [16]. The THD is given by the relation given below:-

$$THD = \frac{I_h}{I_{s1}} = \frac{\sqrt{I_2^2 - I_{s1}^2}}{I_{s1}} = \frac{\sum_{n=2}^{\infty} I_{sn}}{I_{s1}}$$

Where \( I_h \) = rms value of all the harmonic components combined

\( I_{sn} \) = rms value of nth harmonic content.

\( I_s \) = rms value of supply phase current including fundamental and harmonics.

**IV. PROPOSED POWER SYSTEM MODEL**

For power quality improvement using three-phase single tuned and double tuned harmonic filters during faulty conditions in the power system, the one line diagram of experimental set up consisting of four buses shown in Fig. 3 is used [17]. 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 \( \pi \) sections are taken as 100 Km. For simplicity the voltage levels at all points of the power system are taken as 33 KV. The three-phase tuned harmonic filters are 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.

![Proposed model of power system for improvement of PQ disturbances in faulty conditions using tuned harmonic filters](image)

**V. 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 [18]. For experimental improvement of power quality disturbances to reduce the impact of PQ disturbances on the generators three-phase single tuned and double tuned harmonic filter are used. The proposed model is simulated in MATLAB/Simulink environment for analysis of improvement in the power quality disturbances. The analysis of power quality improvement in the proposed model is based on the total harmonic distortion (THD). The simulation is carried out in three conditions viz. faulty system before filtering, faulty system after filtering using single tuned harmonic filter and faulty system after filtering using double tuned filter.
V.1 LG Fault in Power System

The power system model shown in Fig. 3 is simulated in MATLAB/Simulink environment with line to ground fault at bus no. 4 on phase-A. The THD analysis of voltage signal of phase-A during line to ground fault before filtering is shown in Fig. 4. The higher order frequency of integral multiple of fundamental frequency up to 500Hz is observed. The observed THD is 3.60%.

![Fig. 4 THD in Phase-A during LG fault before filtering](image)

The THD analysis of voltage signal of phase-A during line to ground fault after using single tuned filter is shown in Fig. 5. The higher order frequency of integral multiple of fundamental frequency up to 900Hz is observed. The observed THD is 2.65%.

![Fig. 5 THD in Phase-A during LG fault after filtering using single tuned filter](image)

The THD analysis of voltage signal of phase-A during line to ground fault after using double tuned filter is shown in Fig. 6. The higher order frequency of integral multiple of fundamental frequency up to 850Hz is observed. The observed THD is 1.26%.

![Fig. 6 THD in Phase-A during LG fault after filtering using double tuned filter](image)

V.2 LL Fault on Power System

The power system model shown in Fig. 3 is simulated in MATLAB/Simulink environment with double line fault between phases A and B at bus no. 4. The THD analysis of voltage signal of phase-A during double line fault before filtering is shown in Fig. 7. The higher order frequency of integral multiple of fundamental frequency up to 750Hz is observed. The observed THD is 3.52%.
The THD analysis of voltage signal of phase-A during double line fault after using single tuned filter is shown in Fig. 8. The higher order frequency of integral multiple of fundamental frequency up to 800Hz is observed. The observed THD is 1.35%.

The THD analysis of voltage signal of phase-A during double line to ground fault after using single tuned filter is shown in Fig. 10. The higher order frequency of integral multiple of fundamental frequency up to 200 Hz is observed. The observed THD is 7.55%.

The THD analysis of voltage signal of phase-A during double line to ground fault after using single tuned filter is shown in Fig. 11. The higher order frequency of integral multiple of fundamental frequency up to 650 Hz is observed. The observed THD is 2.01%.

V.3 LLG Fault on Power System

The power system model shown in Fig. 3 is simulated in MATLAB/Simulink environment with double line to ground fault between phases A and B at bus no. 4. The THD analysis of voltage signal of phase-A during double line to ground fault before filtering is shown in Fig. 10. The higher order frequency of integral multiple of fundamental frequency up to 200 Hz is observed. The observed THD is 7.55%.

The THD analysis of voltage signal of phase-A during double line to ground fault after using single tuned filter is shown in Fig. 11. The higher order frequency of integral multiple of fundamental frequency up to 650 Hz is observed. The observed THD is 2.01%.
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The THD analysis of voltage signal of phase-A during double line to ground fault after using double tuned filter is shown in Fig. 12. The higher order frequency of integral multiple of fundamental frequency up to 700 Hz is observed. The observed THD is 1.03%.

V.4 LLL Fault on Power System

The power system model shown in Fig. 3 is simulated in MATLAB/Simulink environment with three phase fault at bus no. 4. The THD analysis of voltage signal of phase-A during three phase fault before filtering is shown in Fig. 13. The higher order frequency of integral multiple of fundamental frequency up to 900 Hz is observed. The observed THD is 6.40%.

The THD analysis of voltage signal of phase-A during three phase fault after using single tuned filter is shown in Fig. 14. The higher order frequency of integral multiple of fundamental frequency up to 850 Hz is observed. The observed THD is 1.46%.
The THD analysis of voltage signal of phase-A during three phase fault after using single tuned filter is shown in Fig. 15. The higher order frequency of integral multiple of fundamental frequency up to 900 Hz is observed. The observed THD is 1.55%.

![Fig. 15 THD in Phase-A during LLL fault after filtering using double tuned filter](image)

V.5 LLLG Fault on Power System

The power system model shown in Fig. 3 is simulated in MATLAB/Simulink environment with three phase fault involving ground at bus no. 4. The THD analysis of voltage signal of phase-A during three phase fault involving ground before filtering is shown in Fig. 16. The higher order frequency of integral multiple of fundamental frequency up to 200 Hz is observed. The observed THD is 9.55%.

![Fig. 16 THD in Phase-A during LLLG fault before filtering](image)

The THD analysis of voltage signal of phase-A during three phase fault involving ground after using single tuned filter is shown in Fig. 17. The higher order frequency of integral multiple of fundamental frequency up to 350 Hz is observed. The observed THD is 6.70%.

![Fig. 17 THD in Phase-A during LLLG fault after filtering using single tuned filter](image)

The THD analysis of voltage signal of phase-A during three phase fault involving ground after using single tuned filter is shown in Fig. 18. The higher order frequency of integral multiple of fundamental frequency up to 950 Hz is observed. The observed THD is 3.19%.
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![Graph showing THD in Phase A during LLLG fault after filtering using double tuned filter](image)

The total harmonic distortion (THD) of voltage signal at generator bus no. 1 of proposed power system model during different faulty conditions when fault is created at bus no. 4 are shown in Table 1. The three conditions before filtering, after using single tuned filter and after using double tuned filter are discussed.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of Fault</th>
<th>THD Before Filtering</th>
<th>THD After Using Single Tuned Filter</th>
<th>THD After Using Double Tuned Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Line to Ground (LG)</td>
<td>3.60%</td>
<td>2.65%</td>
<td>1.26%</td>
</tr>
<tr>
<td>2</td>
<td>Double Line (LL)</td>
<td>3.52%</td>
<td>1.35%</td>
<td>1.14%</td>
</tr>
<tr>
<td>3</td>
<td>Double Line to Ground (LLLG)</td>
<td>7.55%</td>
<td>2.01%</td>
<td>1.03%</td>
</tr>
<tr>
<td>4</td>
<td>Three Phase Fault (LLL)</td>
<td>6.40%</td>
<td>1.46%</td>
<td>1.55%</td>
</tr>
<tr>
<td>5</td>
<td>Three Phase Fault involving ground (LLL)</td>
<td>9.55%</td>
<td>6.70%</td>
<td>3.19%</td>
</tr>
</tbody>
</table>

**VI. CONCLUSION**

An efficient but simple technique has been developed for improvement of power quality disturbances during faulty conditions using three phase tuned harmonic filters in the electrical power system. The proposed model of four bus system is simulated in the MATLAB/Simulink environment. The analysis of improvement of power quality during faulty conditions of power system using tuned harmonic filters is carried out using the total harmonic distortion. The results show that three-phase harmonic filters are effective in improvement of power quality in faulty conditions. The double tuned harmonic filter is comparatively more effective as compared to the single tuned harmonic filter. The THD reduces in all faulty conditions while using single tuned filter which further reduces on using double tuned filter. The tuned harmonic filters are effective in protecting the costly equipment of power system transients during faulty conditions.

**REFERENCES**


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BIOGRAPHIES

Sumit Kanwar studied at Rajasthan College of Engineering for Women and received the B.Tech. in Electrical Engineering from Rajasthan Technical University, Kota, India, in 2010. She received Master’s degree in Electrical Engineering from the Jagannath University, Jaipur, India in 2013 with specialization on Power System.

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