A Novel Method for the Current Harmonic Elimination of Industrial Power System Using Single Tuned Shunt Passive Filter

MANSOOR AHMED SOOMRO*, MUHAMMAD ASLAM UQAILI**, AND ZUBAIR AHMED MEMON***

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ABSTRACT

The automation of IPS (Industrial Power System) has brought about several advantages of increased productivity and efficiency but it suffers from incompatible problems of overheating, noise, complexity etc, which disturb its smooth and fault tolerant implication. When the resonance condition is reached, these effects become detrimental and disturb the whole power system. The purpose of this research work is to include single tuned shunt type passive filter for harmonic elimination of the components used in industrial power system. For this purpose, MATLAB simulation using sim Power system tool has been used to analyze the effects of current harmonics. Third harmonic effects have been removed by the addition of six pulse converter technique. The simulation results show that implication of single tuned shunt (parallel connected) passive filter removes effects of succeeding order current harmonics i.e. fifth, seventh and eleventh etc. which are causing substantial damage to industrial power system. The effects of current harmonics can be solved by installing without and with the application of proposed filter. Further, it is observed that these filters contribute in reduction of THD (Total Harmonic Current Distortion) followed by improvement in power factor. These results are taken considering limits of IEEE 519-1992 standards.

Key Words: Automation, Industrial Power System, Resonance, Single Tuned, Shunt Passive Filter, Sim Power System, Total Harmonic Current Distortion, Power Factor.

1. INTRODUCTION

In IPS network, nonlinear loads inject significant amount of harmonic currents. These current distortions not only affect the supply waveforms but also create disinfections towards loads pertaining to power system components [1-4]. The various loads include induction motors, synchronous generators, distribution transformers and various types of metering, instrumentation, protection and control equipment [5]. Therefore, considering these grave concerns, there is optimal need for the elimination of substantially growing harmonic effects in IPS.

Three-phase, 6-pulse converter facilitates DC (Direct Current) bus voltage for machines and equipment used in proposed system. This introduces phase multiplication technique which significantly eliminate third order harmonics. However, it pollutes the AC power line with succeeding dominant harmonic orders like fifth, seventh and eleventh etc. Harmonic pollution is due to commencement of power electronic devices readily available at power centers [6]. Harmonic power generates various problems i.e. harmonic resonances, harmonic losses, interference with electronic equipment etc [7].

* Lecturer, ** Professor, and *** Assistant Professor,
Department of Electrical Engineering, Mehran University of Engineering & Technology, Jamshoro

Passive harmonic filters are therefore, construed to provide a path that diverts the severity of harmonic effects from industrial power system [3]. These filters provide characteristics of relatively inexpensive compared to other means of harmonic elimination methods. Further, it improves system power factor by injecting reactive power to the system [8]. Single tuned shunt passive filters are commonly used passive harmonic filters developed at a frequency significantly higher than system frequency. The series tuned connection of these filters offer reduced impedance values for relevant current harmonics. The parallel (shunt) connection is preferred for industrial power system. Total current harmonic distortion commonly abbreviated as THDi is kept less than allowable limits i.e. 5% in accordance with specification of IEEE 519-1992 standards. The proposed filter retains the capability to divert the effects of current harmonics from their usual path. For example: if the system is tuned at a frequency (i.e. 250Hz) then the current at this particular frequency is grounded to avoid further damage to the power system. Additionally, the proposed system is incompatible to work at higher frequencies. These filters may further be classified as series resonant type and trap type. They offer the characteristics of low impedance and therefore provide least path for the current flow at resonant frequency.

This paper uses of single tuned shunt passive filter to eliminate dominant current harmonics in order to achieve economic and fault tolerant solution of IPS.

2. PASSIVE FILTERS

These filters include RLC elements configured and tuned to serve the purpose of harmonics control. The following Fig. 1. depicts the types of passive filter arranged with their schematic diagrams.

Single tuned filter constitute the characteristics of readily available, economical type of shunt passive filter and is frequently sufficient for the power system applications [4, 9]. These filters are used as series tuned filters to decrease the harmonic currents. These filters provide least impedance path to IPS by connecting them in shunt configuration. As a result current harmonics are diverted from their normal path.

Passive filters use HPF (High-Pass Filter) [9] having the tendency to cover wide range of frequencies is used to drive out higher order harmonic frequencies. Three forms of high pass filter are given in Fig. 1. 1st order HPF has the disadvantage of high power loss at fundamental frequency of the system; therefore it is not commonly used. 2nd order HPF is simple to implement. It provides fine filtration characteristics thereby reducing harmonic frequency [9]. 3rd order HPF outweighs the characteristics of fine harmonic filtration when compared with 2nd order HPF. However, it is not commonly applicable for low and medium voltage application because it does not justify the economy, reliability and complexity factors [6].

3. DESIGN CONSIDERATIONS OF THE SINGLE TUNED FILTER

Single tuned filter is simple and economical in construction. For design purposes, the selection of appropriate size of capacitor is essential which provides considerable power factor at fundamental frequency. Fig. 1. shows schematic diagram of the single tuned filter. The impedance versus frequency curve of the single tuned filter shows that impedance value is high at fundamental frequency which gradually decreases to 250 Hz i.e 5th harmonic frequency and then again impedance value increases linearly with frequency as shown in Fig. 2.

The following equation expresses the equivalent impedance of the filter given by:

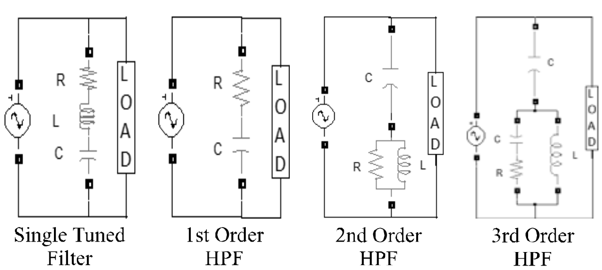

FIG. 1. VARIOUS CONFIGURATIONS OF PASSIVE FILTERS

$$Z = R + j\left[\omega L - \frac{1}{\omega C}\right] \tag{1}$$

Equation (1) contains RLC elements commonly known as passive elements e of the filter along with angular frequency of the power system.

The zero reactance of the filter is the fundamental cause of the resonant condition. The Equation (2) shows that impedance of the filter and resistance are equal.

$$Z = R \tag{2}$$

The harmonic frequency for which filter is to be designed is determined by the value of ω that causes series resonance. This resonance frequency is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

Tuning order is the ratio of the harmonic frequency to the fundamental frequency of the system. Then, inductive reactance and capacitive reactance at the tuning frequency can be expressed as:

$$X_{Lh} = h\omega_L \tag{4}$$

Also,

$$X_{Ch} = \frac{1}{h\omega_C} \tag{5}$$

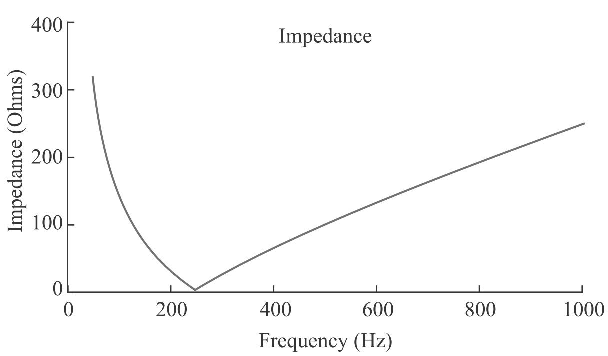

FIG. 2. IMPEDANCE- FREQUENCY CHARACTERISTIC CURVE OF THE SINGLE TUNED FILTER

Since the net reactance shows zero value at resonance frequency, then

$$X_{Lh} = X_{Ch} \tag{6}$$

The following formula is used to determine harmonic order (h) given as:

$$h = \sqrt{\frac{X_C}{X_L}} = \frac{f_h}{f_f} \tag{7}$$

Where, f_h is the harmonic frequency and f_f is the fundamental frequency of the power system.

Quality Factor (Q): The quality factor described here is based on resonance condition. Equation (8). shows that quality factor varies inversely with resistance of the filter, whereas, inductive or capacitive reactance has direct relationship with the quality factor. Since, quality factor depends upon resistance therefore this parameter is used to measure the sharpness of the tuning process. Quality factor can mathematically be expressed by equation:

$$Q = \frac{X_{Lh}}{R} = \frac{X_{Ch}}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{8}$$

The resistive value of the filter can be obtained by selecting the quality factor in the range of $20<Q<100$ [10].

The larger value of the quality factor brings about sophisticated results in harmonic reduction. It is necessary to take optimal care of harmonic current frequencies irrespective of other frequencies for which single tuned shunt passive filter is designed because these harmonic current frequencies are detrimental as they follow least impedance path. These harmonic currents contribute in increased power loss. MATLAB software is used to perform computer based harmonic simulation for analyzing the performance of single tuned shunt passive filters.

4. SELECTION OF FILTERS

The magnitude of THD is higher for lower order harmonic frequencies as compared to higher order harmonic frequencies. Therefore, design of single tuned filter definitely helps to suppress the THD of lower order harmonic frequencies. For suppressing the harmonics of 6-pulse Bridge converter three single tuned filters are used in parallel configuration. These filters reduce the amplitude of fifth, seventh and eleventh order harmonics [11].

5. SIMULATION RESULTS

The simulation model using single tuned shunt passive filter is shown in Fig. 3. This model determines the characteristics of supply current and supply voltage waveforms. Table 1. specifies the simulation parameters followed by the corresponding ratings of the simulink model.

The simulation results before and after the application of proposed filter is detailed below:

5.1 Harmonic Filtering Characteristics without Passive Filter

Fig. 4 shows the simulation results of the waveform of supply voltage and supply current before the application of passive filter. These results suggest that supply current is distorted due to the loads related to IPS.

TABLE 1.SIMULATION PARAMETERS [12]

Supply Phase Voltage	220rms
Supply Inductance	1.6mH
Rectifier Front-End Inductance	23mH
Load Capacitance	50μF
Load Resistance	78Ω

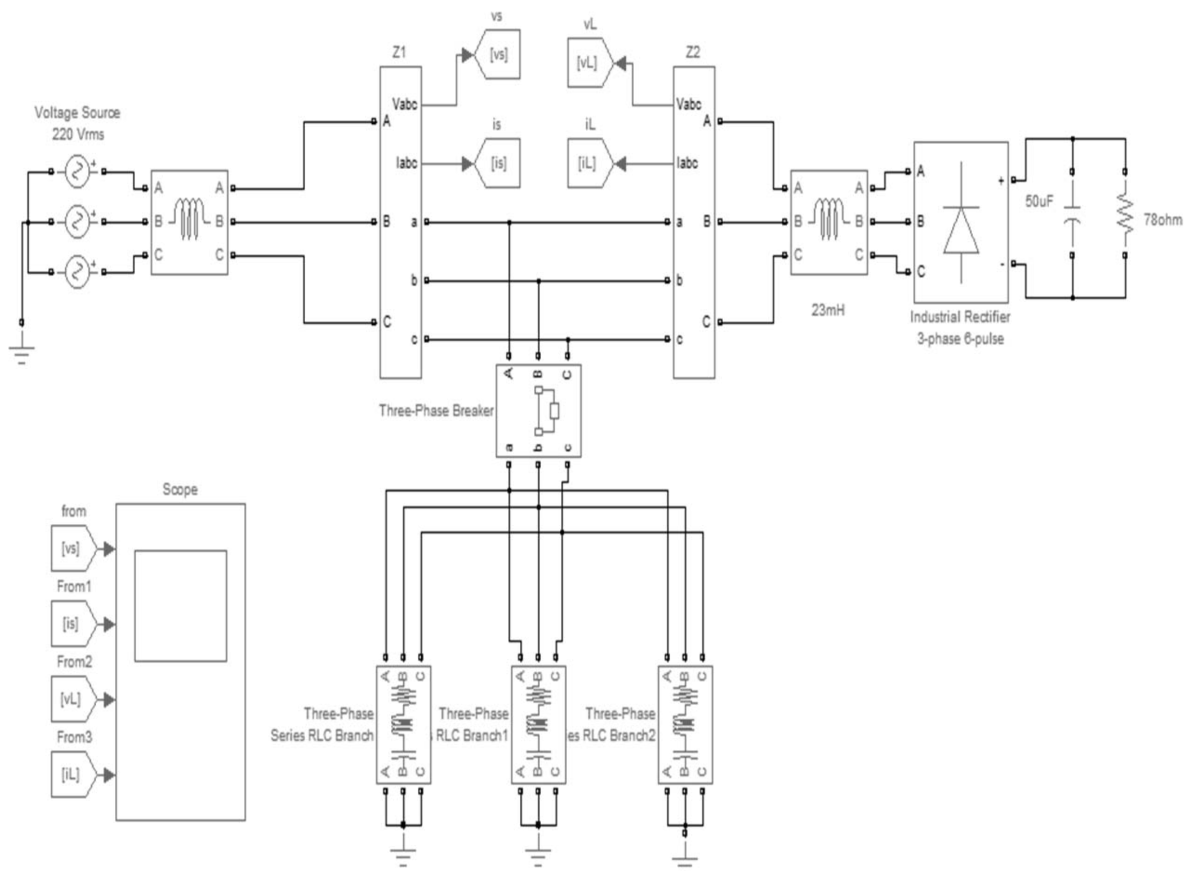

FIG. 3. SIMULATION MODEL OF INDUSTRIAL POWER SYSTEM USING SINGLE TUNED SHUNT PASSIVE FILTERS

The spectrograph showing THD values of current harmonics is shown in Fig. 5.

5.2 Harmonic Filtering Characteristics without Passive Filter

After the use of single tuned shunt passive filter, the results suggest that supply current waveform is sinusoidal irrespective of various loads pertaining to IPS as shown in Fig. 6.

The simulation results are shown trough spectrograph as shown in Fig.7. The obtained values are less than the prescribed limits of IEEE 519-1992 recommended practices. Further, the spectrograph shows that amplitudes of fifth, seventh and eleventh order harmonics have THD value of current harmonics less than 5% as shown in Fig. 7.

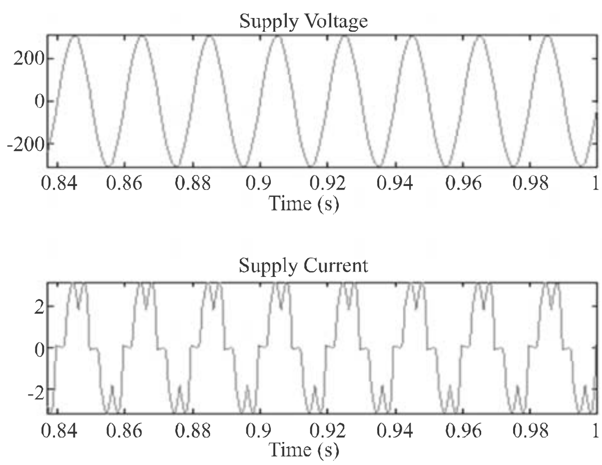

FIG. 4. SUPPLY VOLTAGE AND SUPPLY CURRENT WITHOUT PASSIVE FILTER

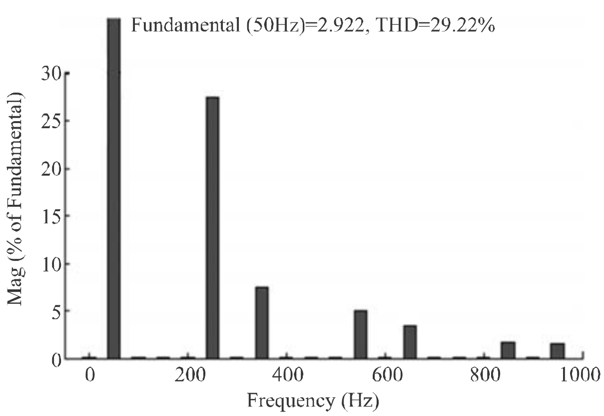

FIG. 5. SPECTRUM OF SUPPLY CURRENT WITHOUT PASSIVE FILTER

6. CONCLUSION

Current harmonics have substantial impact in making the components of IPS dysfunctional thereby affecting reliability, regulation and efficiency of the system. To analyze the effects of severity of current harmonics, Software based designed model using single tuned shunt type passive filter is used in this research work. Simulation results are taken without and with the installation of passive filter using MATLAB. The proposed filters control supply current harmonics at low and medium voltage levels of IPS less than 5% which is in accordance with limits of IEEE 519-1992 standards.

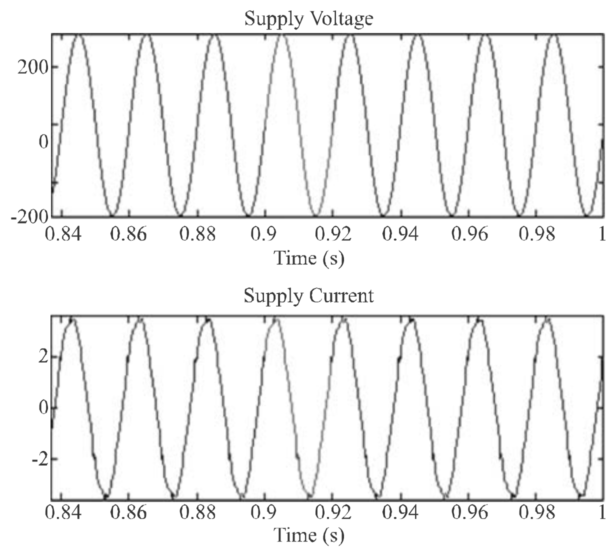

FIG. 6. SUPPLY VOLTAGE AND SUPPLY CURRENT WITH PASSIVE FILTER

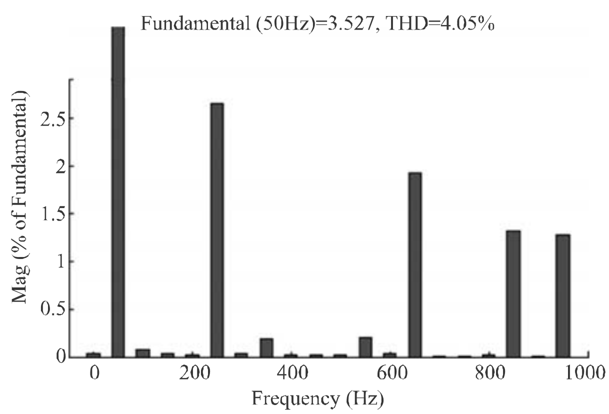

FIG. 7. SPECTRUM OF SUPPLY CURRENT WITH PASSIVE FILTER

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