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Research Article

# Analysis and elimination of harmonics by using passive filters

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**Abstract**

**This paper presents harmonic analysis and passive filter design for an industrial installation. A system is designed under MATLAB / Simulink platform that consist of universal bridge with pulse generator to supply a DC load. Harmonic distortion levels of system currents and voltages are obtained by using Fast Fourier Transform (FFT) analysis and also waveform graphs are given to show distortion. Then passive harmonic filters are designed step by step to eliminate harmonics on system. As the designed filters are applied on system, results show that harmonic distortion decreased. FFT analysis is performed for filtered design to obtain effect of designed filters on system. Also current and voltage waveform graphs are given for comparison.**

**Keywords:, Harmonic analysis, Harmonic Distortion Passive Harmonic Filter, Power System Harmonics,**

## 1. Introduction

In recent years, a significant development in power electronic devices has been reported and the cost of these devices has been fallen due to increase in demand and presence of many competitors in the market. The power electronic equipment have significant contribution in energy saving and more efficient use of electricity and, also the power handling capacity of modern power electronics devices such as power diodes, silicon controlled rectifiers (SCR) and insulated gate bipolar transistor (IGBT) are very large (Cengiz, Mamiş, 2015). Therefore, such power devices are widely used in power converters, variable speed motor drives and computers etc. However, the operation of these power electronic devices causes a nonsinusoidal current taken from the power source (Kumar and Zare, 2014). According to (Alhazmi, 2014), harmonics can be defined as a sinusoidal wave (current or voltage), having frequencies that are integer multiples of the frequency at which the supply system has designed to operate. Distorted waveforms can be produced by merging harmonics with the fundamental wave.

## 2. Power System Harmonics

It is very important to produce, transmit, and submit voltage in the shape of a sine curve with a 50 Hz frequency (Cengiz, 2015). However, because of the side effects caused by network elements and consumers, which vary depending on the system, the sinusoidal waveforms of basic electrical parameters such as flux, current, and voltage can be converted into harmonic, inclusive, and undesirable waveforms that are proportional to multiples of 50 Hz, which can be considered the fundamental frequency (Kamath, 2001; Buso, 1998). To remove harmonics, typically passive filters are used for their low cost. Because the values of the elements used in passive filters (i.e. capacitor, coil, and resistance) vary with standard frequency (Rustemli and Cengiz, 2014).

Total harmonic distortion for voltage and current can be described as given in (1) and (2) respectively,

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \tag{1}$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \tag{2}$$

Nonlinear loads affect the system by generating harmonic currents and voltages. Power electronic components, transformers, uninterruptible power supplies (UPS), converters and high-power induction motors are some power system elements that cause harmonics . Harmonics in the current and voltage waveform cause extra power lose, heating in the system elements and damage in the insulation of system equipment. For these reasons, elimination of harmonics in electrical system has gained more importance. Among many solutions for harmonics, the passive harmonic filtering is the most widely used approach.

## 3. Passive Filters

In the passive filter techniques, the flow of unidirectional harmonic currents may be prevented in the system by diverting the harmonic current flow through a low impedance path, like using tuned filter (Das, 2004). Passive filters are cost effective and can provide an acceptable current harmonic cancellation (Kumar and Zare, 2014). Multi-pulsle rectifier techniques are based on harmonic cancellation principle through phase shifting and are the preferred solution to eliminate harmonics in high power converters like in large motor drive applications and high voltage direct current (HVDC) transmission systems (Aleem e.al, 2012; Rendusara et.al.,1996).

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However, they required bulky and expensive phase shifting transformers and are mostly used in combination with passive filters to eliminate the rest of the harmonics that multi-pulse rectifiers are not able to cancel out (Kamath, et.al, 2001).

## 4. Harmonic Filter Design

A traditional single-tuned passive harmonic filter design adapts a single unit trap tuned at a specific harmonic frequency. These types of filters offer mature technology, reliable operation, and lower installation and maintenance cost. A traditional passive filter design scheme needs the interlocking control when the 5th, 7th, 11th, and 13th harmonic filters are installed in the system. Although the interlocking control provides positive protection, switching off filter traps will leave the system without enough or no harmonic filtering at all, which could result in operation issues such as meters and relays malfunction or nuisance tripping, equipment overheating, and so on (Liang and Ilochonwu, 2011).

The basic principle of passive filters is to connect inductance and capacitance to power system, and calculate the values of them in order to resonance and eliminate of unwanted harmonics. It is necessary to constitute resonance arms separately for each harmonic frequency, and connect them to the power systems. For optimal solution, the most effective method for harmonics is to constitute arms for harmonic frequencies that have high amplitude value. There is only one arm can be connected to the system for eliminating the frequencies have small amplitudes. The biggest risk of using the parallel passive filters is the formation of parallel resonance with power system (Efe, 2015).

Therefore, a detailed analysis of the system is required before the parallel passive filter is applied to the power system. There are four types of parallel passive filters are used in applications. These are;

•Single-tuned (band pass) filters

•Double-tuned filters

•Auto-tuned filters

•High-pass filters

In this study, single-tuned (band pass), double-tuned and high-pass filters are examined and designed under MATLAB / Simulink platform (Efe, 2006). System values are taken from reference. Different types of filter are used to reach system characteristics of various filters.

When filters are applied to the system, capacity elements used in the filters must be met required compensation power. Power factor of the system is 0,75. This is an applicable low level value for approximate network levels and selected to obtain the results for ill-conditioned networks. This value should be increased to 0,95, so required capacitor power is calculated as follows;

$$Q_C = P(\tan\varphi_1 - \tan\varphi_2) \quad (3)$$

$$Q_C = 1500(\tan 41,4^o - \tan 18,2^o) = 829,25kVAr \quad (4)$$

Capacitor power must be taken bigger than the Qc value found in (4) as 1000 kVAr. So;

$$X_C = \frac{U^2}{Q_C} = \frac{500000^2}{1000000} = 250k\Omega \quad (5)$$

Capacitor value is obtained as given in (6),

$$C = \frac{1}{2\pi fX_C} = \frac{1}{2\pi 50(250000)} = 0,0127\mu F \quad (7)$$

Industrial HVDC system with a 6-pulse rectifier unit is given in Fig 1. Also voltage and current waveforms for unfiltered system are given in Fig. 2 respectively.

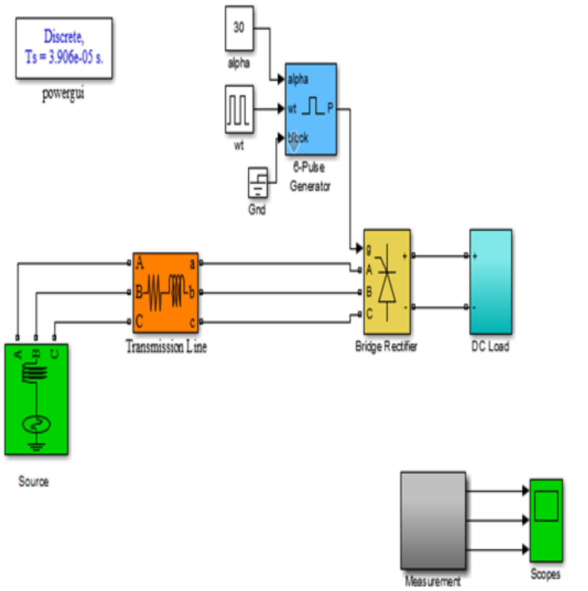


**Figure 1.** Study System

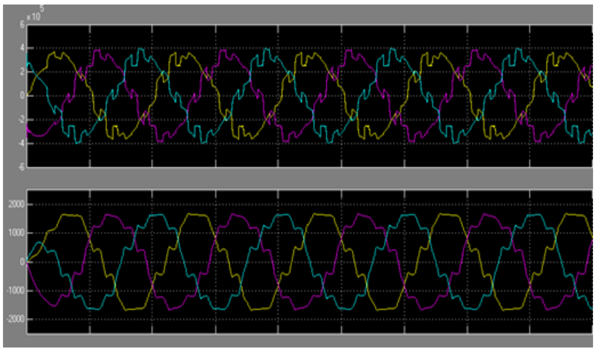

**Figure 2.** Voltage and current waveforms for unfiltered system

It can be seen in Fig. 2, system harmonics have adverse effect on voltage and current waveforms of system. For the unfiltered condition, 3th, 5th, 7th, 9th, 11th and 13th harmonics are effective on system. Values of these harmonics can be determined from Fig. 3 and they are given in Table 1. Also voltage harmonics are given in Fig. 4.

**Table 1.** Values of current harmonics

| Current Harmonic | Amplitude (A) |
|---|---|
| $I_3$ | 325 |
| $I_5$ | 200 |
| $I_7$ | 335 |
| $I_9$ | 275 |
| $I_{11}$ | 200 |
| $I_{13}$ | 125 |

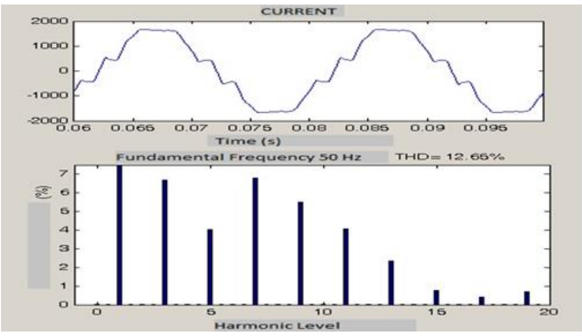


**Figure 3.** Current harmonics for unfiltered system

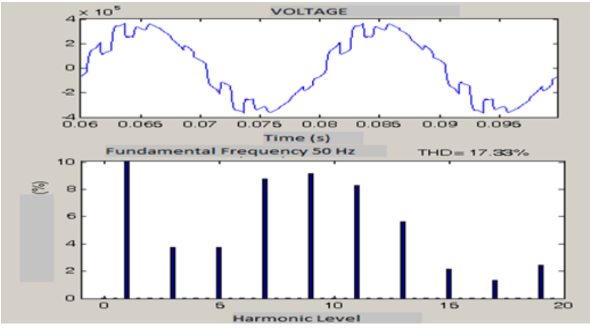


**Figure 4.** Voltage harmonics for unfiltered system

According to the values given in Table 1,

$$I_h = I_3 + I_5 + I_7 + I_9 + I_{11} + I_{13} \quad (7)$$

$$325 + 200 + 335 + 275 + 200 + 125 = 1460 \text{ A} \quad (8)$$

value can be obtained. Capacitor values for each branch is calculated as follows,

$$C_3 = C\frac{I_3}{I_h} = 0,0127\mu F\,\frac{325}{1460} = 0,00282\mu F \quad (9)$$

$$C_5 = C\frac{I_5}{I_h} = 0,0127\mu F\,\frac{200}{1460} = 0,00173\mu F \quad (10)$$

$$C_7 = C\frac{I_7}{I_h} = 0,0127\mu F\,\frac{335}{1460} = 0,00291\mu F \quad (11)$$

$$C_9 = C\frac{I_9}{I_h} = 0,0127\mu F\,\frac{275}{1460} = 0,00239\mu F \quad (12)$$

$$C_{11} = C\frac{I_{11}}{I_h} = 0,0127\mu F\,\frac{200}{1460} = 0,00173\mu F \quad (13)$$

$$C_{13} = C\frac{I_{13}}{I_h} = 0,0127\mu F\,\frac{125}{1460} = 0,00108\mu F \quad (14)$$

According to capacitor values calculated in (9-14), inductance values can be determined as follows,

$$L_3 = \frac{1}{2^2\pi^2 f_3^2 C_3} = \frac{1}{2^2\pi^2 150^2 (0,00282)10^{-6}} = 399,21H \quad (15)$$

$$L_5 = \frac{1}{2^2\pi^2 f_5^2 C_5} = \frac{1}{2^2\pi^2 250^2 (0,00173)10^{-6}} = 234,26H \quad (16)$$

$$L_7 = \frac{1}{2^2\pi^2 f_7^2 C_7} = \frac{1}{2^2\pi^2 350^2 (0,00291)10^{-6}} = 71,05H \quad (17)$$

$$L_9 = \frac{1}{2^2\pi^2 f_9^2 C_9} = \frac{1}{2^2\pi^2 450^2 (0,00239)10^{-6}} = 52,33H \quad (18)$$

$$L_{11} = \frac{1}{2^2\pi^2 f_{11}^2 C_{11}} = \frac{1}{2^2\pi^2 550^2 (0,00173)10^{-6}} = 48,4H \quad (19)$$

$$L_{13} = \frac{1}{2^2\pi^2 f_{13}^2 C_{13}} = \frac{1}{2^2\pi^2 650^2 (0,00108)10^{-6}} = 55,51H \quad (20)$$

Filtered system is given in Fig. 5. After the designed filters applied on system, improvement of current and voltage waveforms can be seen at Fig. 6. Current harmonics are given in Fig. 7 and also voltage harmonics are given in Fig. 8 for filtered system. As the FFT analysis is performed on both filtered and unfiltered system, THD values of voltages and currents are given in Table 2.

**Table 2.** THD Values

| System | Voltage (%) | Current (%) |
|---|---|---|
| Unfiltered | 17,33 | 12,65 |
| Filtered | 0,17 | 0,17 |

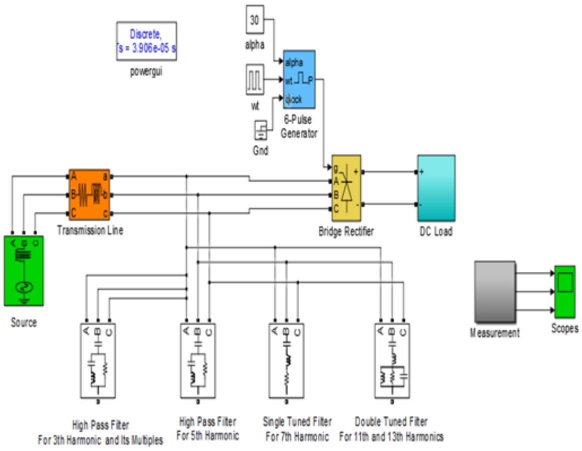


**Figure 5.** Application of filters on system

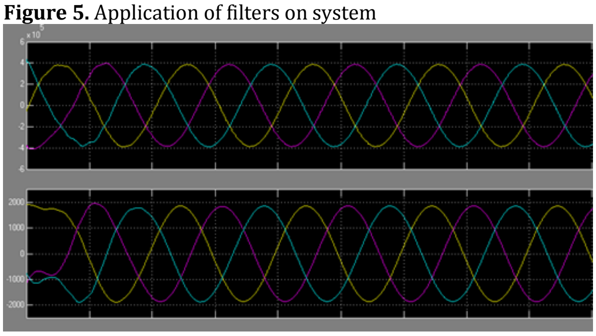

**Figure 6.** Voltage and current waveforms for filtered system

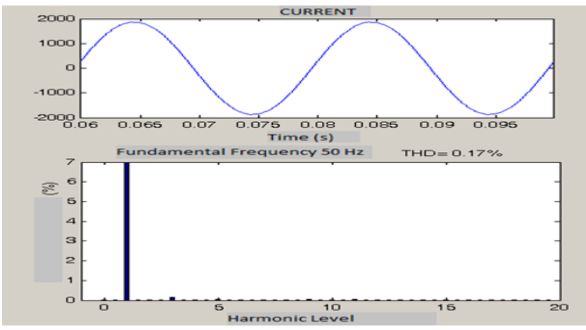


**Figure 7.** Current harmonics for filtered system

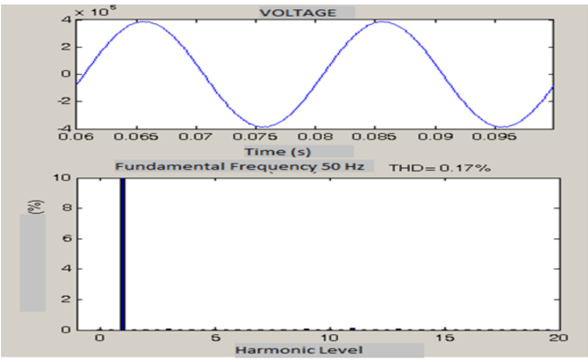


**Figure 8.** Voltage harmonics for filtered system

## 5. Conclusion

Users or customers of the electrical power systems must pay attention to some factors during operation and design of these systems in order to operate safe and in desired format. One of these factors is harmonic caused by non-linear elements determining the quality of the power as a parameter. Some harmful effects of harmonics can be listed as; disruption of control devices, explode of capacitors, overload of transformations and additional losses in rotating machines, motors, and the occurrence of extra noise to motors and other elements, to cause telephone interference, parallel and serial resonance frequency. The most important and useful method of eliminating or reducing of harmonics is using harmonic filters.

This paper has presented the results of the harmonic analysis and harmonic filter design for an HVDC industrial installation. A system is designed under MATLAB/Simulink platform that consist of a DC load with a 6-pulse bridge rectifier. Simulation is performed and system harmonics are carried out. This paper presents an idea to benefit of the harmonic currents and voltages on the load side, its present also a method to reduce harmonics' values by filtering out the harmonic currents in multiple of 50 HZ frequencies According to system components and harmonic values, three types of passive harmonic filters (single-tuned, double-tuned and high-pass filters) are designed for various harmonic levels. Unfiltered and filtered system waveforms for current and voltage are given for comparison. Also THD levels are provided for unfiltered and filtered situations. Results show that filter design is appropriate for eliminating harmonics of the system. It is appropriate to use passive filters for steady loaded installations to take advantage both in cost and easy operating conditions. As it is stated in section IV, the biggest risk of using the parallel passive filters is the formation of parallel resonance with power system. It is necessary to determine filter elements very carefully to avoid this problem. Otherwise, system would be damaged and using of passive filter would cause worst scenarios instead of its advantage.

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