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MITIGATION OF HARMONICS IN POWER SYSTEM USING FILTERS

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ABSTRACT

In the new era, with the increasing use of power electronic devices, power efficiency along with system efficiency is playing an important role in the progress of power supply. The fundamental purpose of the electric utility is to provide a sinusoidal voltage at constant magnitude throughout the system. This objective is convoluted because of the non-linear loads present in the system which produce harmonic currents. Hence, our work aims to mitigate harmonics injected by non-linear load system. The mitigation technique utilized in this project is implementation of Harmonic Filters. According to the recommended IEEE 519 power harmonic standards, the total harmonic distortion must be less than 5%. Hence, to reduce the THD, suitable filter design is implemented in this work. The mitigation of harmonics can report significant benefits for industries in terms of installation cost and protection against equipment faults in the power system. The overall process of Harmonic analysis and mitigation is performed using MATLAB/SIMULINK.

KEYWORDS: *Harmonics, Power electronic devices, Mitigation, non-linear load, Filters, THD, MATLAB.*

I. INTRODUCTION

Power quality problems are manifested in voltage, current, or frequency variations, which can cause sensitive equipment to malfunction [1]. An increase in non-linear and time-varying loads leads to voltage and current distortions in the system with a rapid increase in reactive power. Non-linear loads and switched devices are powered by sinusoidal sources or linear loads, and switched devices with non-sinusoidal sources produce harmonics in the distribution system. Currents flowing over long HVDC and HVAC lines and overloaded distribution transformers can cause line losses. In power electronics, saturated and arcing loads cause harmonics to increase the overall distribution loss. Switching from AC to DC injects lower order harmonics into the system. Harmonics affect energy quality and increase system losses by up to 20%. Smart grids with 1–8% THDV may lose 4.7–42.2% capacity [2]. Harmonics at the instrument and distribution levels can be cut and injected back into the system, resulting in a distorted waveform that leads to lower power quality. Harmonic orders can range from 2 to 100 (even more), although orders 2-25 are generally considered for harmonic analysis. Higher order harmonics are much smaller than lower order harmonics. Inter-harmonics are not integral modules of fundamental ranging from 0 to 600 kHz. The oscillation frequencies of the inter-field large and small signal power system vary from 0.2 to 4 Hz. Voltage fluctuations and sub-synchronous resonance frequencies often range from 20-40 Hz. Simultaneous voltage, current and frequency magnitudes as well as frequency deviation protection and controls affect the signal signals that the filter needs to start signal processing. Satisfactory operation of the system depends on detecting interconnections, new loads, new production stations or their effects before installing new transmission lines. Since system impedance is a major parameter to consider when voltage distortions occur due to harmonic generating loads and the amount of harmonic current injected, harmonic currents can cause further problems such as tripping of circuit breakers, overloading in neutrals and power outages, Factor correction capacitors overloading etc [3]. To reduce the harmonics produced by specific components of the power system, such as non-linear loads, filters are installed.

II. HARMONIC ANALYSIS

The four main characteristics used to define the power quality of any power system are voltage, current, frequency and power imbalance. The distortion or imbalance of these features is called harmonics. In terms of supply voltage and current waveforms, this is a deviation from the ideal sinusoidal waveform. Harmonic analysis plays an important role in understanding and classifying the severity of harmonic problems. Harmonics can be caused by non-linear loads such as variable speed motors, switching mode power supplies and other devices that attract non-sinusoidal outputs. The load that attracts the non-sinusoidal current when excited by a sinusoidal voltage source of the same frequency is called the nonlinear load. The harmonic limit is rated at the common coupling (PCC) point between the power system load and the powerful system utility.

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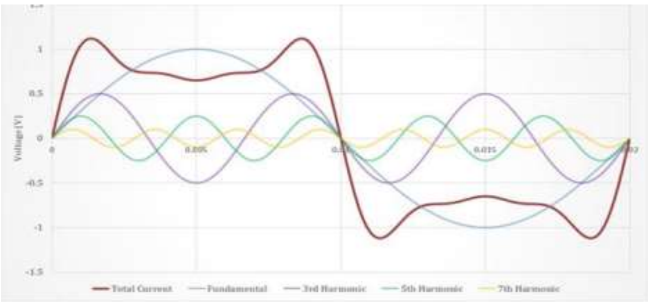
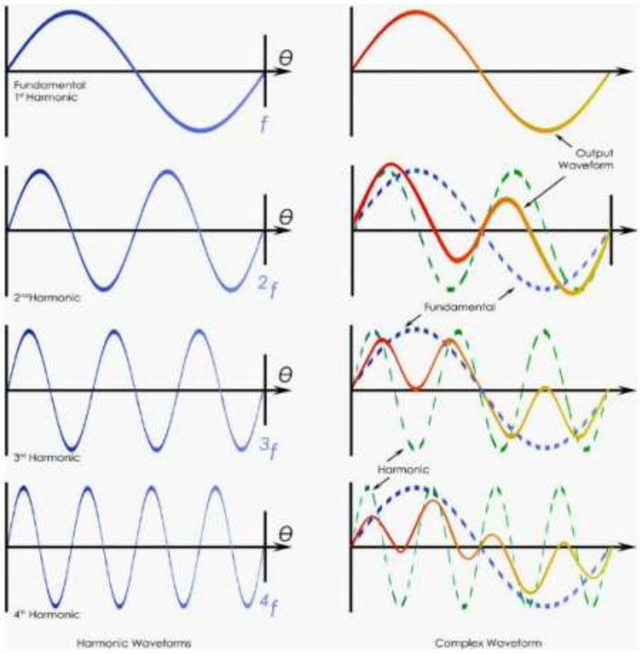


Harmonic analysis takes place while looking for a solution to an existing harmonic problem, such as installing large capacitor banks on power systems or designing harmonic filters. To reduce these harmonic distortions, harmonic mitigation techniques are used [4&5] One such technique is to install harmonic filters in a power system. In this paper, the quenching technique we used to reduce harmonics is to install a single tuned passive filter and a high pass filter. This filter is installed on buses with relatively high personal harmonic distortion factor compared to other buses and exceeds the standard IEEE limit.



III. METHODOLOGY

The process of harmonic analysis depends on whether the system already exists or is completely new. If this is an existing system, the process of calculating the harmonics takes place using the harmonic analyzers in the plant. The whole process of harmonic analysis is performed using MATLAB or Power Quality Analyzer [6].

Step 1: - Establishing the purpose of the harmonic study, in other words, calculating the existing harmonics in the system or determining the source and extent of the problem in the existing system.

Step 2: - Next, we start the process by analyzing the load flow, thus determining the parameters such as active power, reactive power, voltage magnitude and phase angle. This is followed by a harmonic analysis, which determines the level of harmonics in the system and the total harmonic distortion factor, after which we compare the data to the range approved by IEEE 519-2014.

Step 3: - The data of the existing system is analyzed, in particular, its working conditions, problems and causes.

Step 4: - According to the analysis, the filters are applied. It is important to check the sensitivity of the results. To operate the filter, there are four main characteristics: fundamental frequency of operation (H), system voltage (V) in kV, reactive power requirements of the plant (P) and filter quality factor (Q).) The values of resistance (R), inductance (L), capacitance (C) are calculated using the given formula,

$$C = \frac{Q_c}{2\pi f V^2}$$

$$X = \frac{1}{2\pi f h C} = \sqrt{\frac{L}{C}}$$

$$L = X^2 C$$

$$R = \frac{2\pi f h L}{Q}$$

Step 5: - After the implementation of the proposed solution, studies will be conducted to monitor and verify the operation of the system and their harmonic parameters.

IV. CAUSES AND EFFECTS OF HARMONICS

Extensive population growth, energy demand, economic growth and emissions have made renewable energy sources popular. Renewable energy sources connected to the national grid at the distribution level through harmonic rich inverters that increase utility line losses. In power electronics, saturated and arcing loads increase the overall distribution loss of harmonics. For example, an inverter is the heart of a modern renewable energy system, providing DC to AC switching to synchronize renewable energy sources with an existing power grid network; Converting DC to AC introduces lower order harmonic injection into the power system. Is Integrating solar parks, wind farms and DC reserves into the national grid at the distribution level can lead to power quality issues such as harmonics, low power factor and voltage fluctuations. Converter-connected static PV or DC storage and dynamically distributed generation systems minimize traditional line losses but add harmonics losses due to asynchronous THDV. Harmonics are produced by non-linear loads and switched equipment, typically up to 40% of the utility load.

Harmonic currents increase hysteresis, eddy current and core damage in generators, transformers and induction

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motors; Multiplying line losses in conductors and cables due to high frequencies; Due to malfunction of circuit breakers, fuses and protective relays and control systems. Harmonic currents increase the rms value causing joule loss. Distribution system with 10% THDV can experience 2-15% loss in transformer, 6% loss in generator and 15-16% loss in capacitor. Harmonics in wind power conversion systems can damage overall efficiency through torque pulsation, low power factor, overheating and increased stator winding losses. Harmonics affect energy quality and increase system losses by 20%, of which 27% are attributed to harmonics. Recent studies suggest that additional power losses in distribution networks may be in the range of 4-8.5% for different harmonic levels. Distribution system losses vary with non-linear loads and increase to 110% at 100% harmonic loads.

V. SIMULATION AND OBSERVATIONS

In this work, the DC converter from a three-phase AC with and without a passive shunt filter is simulated using the MATLAB / SIMULINK simulation. The system analyzes the total harmonic distortion as an indicator with and without passive filters. The circuit parameters used in the simulation are displayed in the following table:

Supply Voltage	220 V RMS
Source Inductance	1.06mH
Load (Resistive)	100 ohms
Transformer (three winding)	Yg/y/d1, 1200 VA, 220V/100V/100V

The system considered for harmonic analysis here consists of a three phase converter consisting of two 6 pulse bridges modeled to work as an uncontrolled rectifier. The schematic of the system is shown in the figure 5.1.

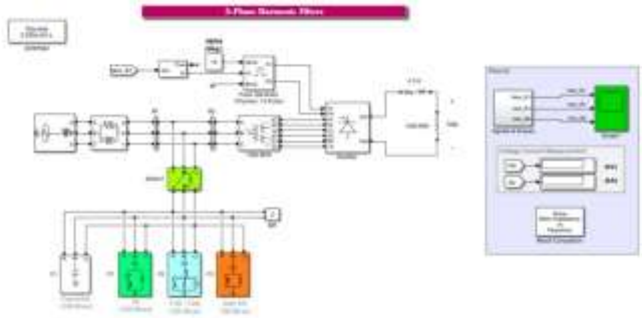

Fig. 5.1 Three Phase 12 Pulse Ac-Dc Converter

The FFT analysis windows of VS and Is are given in figure 5.1.1 and 5.1.2, which shows the percentage harmonics in the spectrum before the filters are incorporated. Since the waveforms are distorted, it implies the presence of harmonics.

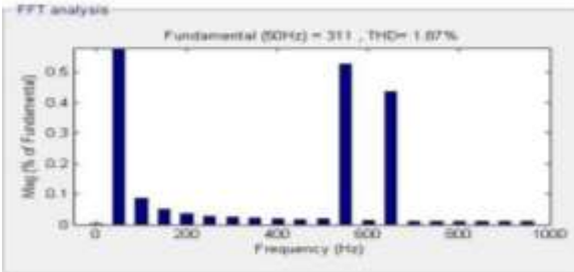

Fig.5.1.1

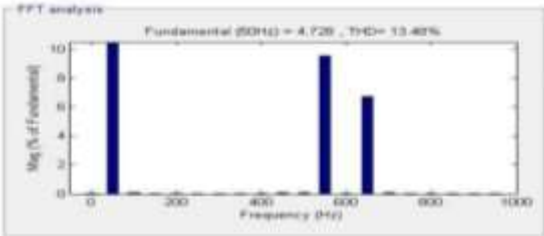

Fig.5.1.2

Without passive filters the total harmonic distortion of the current is above the range specified by the power quality standards. To follow the recommended IEEE 519 power harmonic standards the total harmonic distortion must be less than 5%. This can be obtained by connecting the passive filters to the system. For reducing the THD below 5% passive filters have been designed. There are three filters used, two of which are single tuned at 11th and 13th harmonic and the other is high pass filter for high order harmonics. The filters specifications for each type of filter are shown in the below

Harmonic Order	Capacitance (μF)	Inductance(mH)	Resistance (Ω)
11^{th}	165.1	50.71	0.04375
13^{th}	28.5	2.1036	0.21478
Higher order	39.3	2.1036	7.4775

After connecting the filters the three-phase supply currents become near to sinusoidal and harmonics are decreased below 5%. The FFT analysis windows of the source voltage and current are given in figure 5.2.1 and 5.2.2 respectively which shows the percentage harmonics in the spectrum with the filters incorporated.

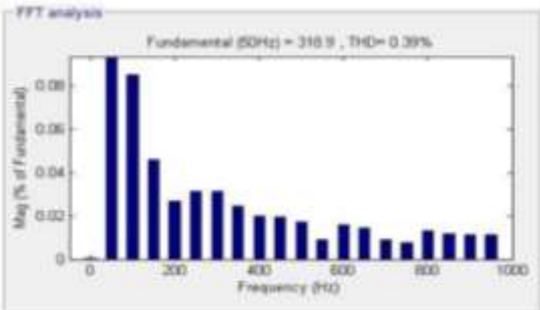

Fig.5.2.1

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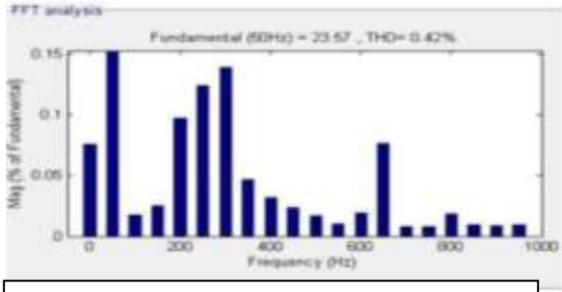


Fig.5.2.2

The resultant output waveform of the current harmonics is given in fig 5.3, Where $I_{abc_{B1}}$ represents the line after the application of filters. The top most graph shows the voltage harmonics, the lower graph shows the current harmonics before filtration and the middle one is the current signal after the application of filters.

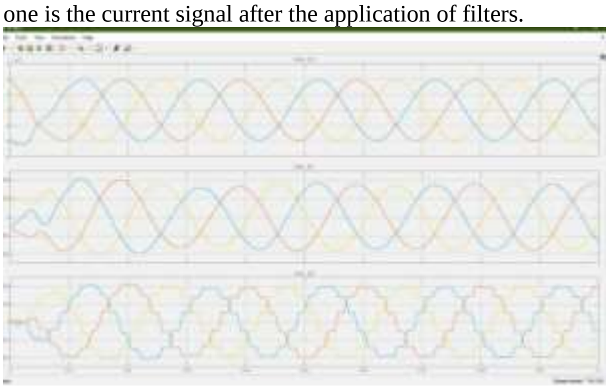


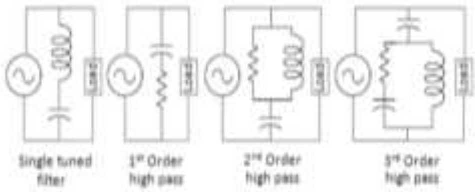
Fig.5.3

As observed from the graph, we can clearly infer that the harmonics present in the current source have been mitigated.

VI. MITIGATION TECHNIQUE

Filters are one of the solutions intended to overcome harmonic problems and keep them within safe limits. They provide a low impedance path or 'trap' for the filtered tuned harmonic, hence the term tuned (resonant) circuit. The purpose of the tuning process is to set the circuit to the maximum or maximum resonance frequency of the reactance. Then the circuit is said to be in resonant state.

Passive filters are arrangements of R, L and C elements that are connected in various combinations to achieve the desired relief of harmonics. This type of filter is used to remove harmonic currents from the line or to block their flow between systems by tuning the elements to create an echo at a selected frequency. . In addition, they provide reactive power compensation to the system and thus improve the overall power quality. Passive filters can be used to reduce the specific harmonic frequency, so the number of passive filters increases as the number of harmonics increases.



Passive harmonic filters.

Passive filters are further classified into two types:

6.1. Passive shunt filter-

These are classified further as single tuned, 1st order high pass, 2nd order high pass, 3rd order high pass.

6.1.1 Single tuned filters

The single tuned filter or the "notch" filter is the most common type of passive filter it can be attributed to the fact that it is also the most economical type of filter. The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter. Notch filters can provide power factor correction in addition to harmonic suppression. At the tuned harmonic, capacitor and reactor have equal reactance and the filter has purely resistive impedance.
The impedance vs frequency curve of this filter is shown in Figure

6.1.2 Double Band Pass Filters

A double Band Pass Filter is a series combination of a main capacitor, a main reactor and a tuning device which consists of a tuning capacitor and a tuning reactor connected in parallel. The impedance of such a filter is low at two tuned frequencies.

6.1.3 Damped Filters

These filters can be of 1st, 2nd, or 3rd order type, among which the most common is the 2nd order. A 2nd order damped filter consists of a capacitor in series with a parallel combination of a reactor and a resistor. It provides low impedance for a moderately wide range of frequencies. When used to eliminate high order harmonics (17th and above), a damped filter is referred to as High Pass Filter, providing a low impedance for high frequencies but stopping low ones.

6.2. Passive series filter

A series passive filter is connected in series with the load of the system whereas the inductance and capacitance are connected in parallel and are tuned to provide high impedance at a selected harmonic frequency. At fundamental frequency, the filter would be designed to yield low impedance, thereby allowing the fundamental current to flow with only minor additional impedance and losses.

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Series filters are used to block a single harmonic current (such as the third harmonic) and are especially useful in a single-phase circuit where it is not possible to take advantage of zero sequence characteristics. The use of the series filters is limited in blocking multiple harmonic currents. Each harmonic current requires a series filter tuned to that harmonic. This arrangement can create significant losses at the fundamental frequency.

VII. DESIGN STEPS OF FILTERS

In design of the filter, the proper selection of the capacitor size is very essential from power factor point of view [11]. A series-tuned filters is a capacitor designed to trap a certain harmonic by adding a reactor such that $X_L=X_c$ at the frequency fn.

To design series-tuned following step are followed:

- Determine the capacitor size Qc in MVAR, say the reactive power requirement of the source.
- The capacitor reactance is

$$X_c = \frac{kV^2}{Q_c}$$

- Capacitance for filters is calculated by

$$C = \frac{1}{2\pi f X_c n}$$

  Where n=number of filters to be designed

- The resonance condition will occur when capacitive reactance is equal to inductive reactance as:

$$X_L = X_C$$

- To trap the harmonics of order h, the reactance should be of size

$$L = \frac{1}{(2\pi h f)^2 * C}$$

- The resistance of filter depends on the quality factor (Q) by which sharpness of the tuning is measured.

$$R = \frac{\sqrt{\frac{L}{C}}}{Q}$$

Where Q is the quality factor and for series tuned is $30<Q\leq100$.

CONCLUSION

The main purpose of electric utilities is to distribute sinusoidal voltage in a constant amount throughout their system. When substantial harmonic production loads are introduced into an industrial system, it is a convenient method to explain their effect on the electrical system by applying mitigation methods. When alternating loads are connected to buses, the source distributes harmonic currents throughout the load. The use of filters reduces these harmonic distortions that trigger compensating components in the system. The filter is designed with the help of a mathematical model of parameters before installation. It is clear from the results and observation in the paper that the harmonic levels are reduced after the filters are installed in a given power system and brought to an acceptable standard range thereby improving the reliability and power quality of the system and reduces damage. Load-ended devices such as adjustable speed drives, power electrical switching elements, synchronous machines, etc. We perform harmonic design analysis of the system at the initial stage of planning before modifying an existing power system or erection of a new power system and obtain simulation results for efficient implementation. Here, the practical and simulation values after the erection of the power system can be compared.

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