International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 09 Series. I || September 2019 || PP 01-08

Harmonics Mitigation Using Active Power Filter

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Abstract~*this paper discussed the method of filtering technology by using active power filter. Sometimes studying the problem is much important than starting solving the problem. Firstly, the paper started by studying the power quality importance and how to improve this power and naturally the power factor as well. Recently, wide applications of non-linear devices in an electrical grid, which it use has become urgent. Elimination of harmonics and solving this problem are not new. Since more methods are planned to decrease harmonics, improving power quality and reactive power losses. One of the best methods employing the filtering is the active filter. Presently, many of countries using this type of filtering depending on its capacity to eliminate the harmonics up to 25th level. MATLAB/SIMULINK power system toolbox is used to simulate the planned system.*
Keywords~ *Hormanic, Power, Migitation, Filter, Sinusoidal, Transients*

Date of Submission: 02-09-2019 Date of acceptance: 19-09-2019

I. Introduction

Power quality is an issue of distinct concerned for electrical power industry utility, manufacturer and consumer as the power quality determines the fitness of electrical power to devices' consumer and the efficiency of consumer devices. Power quality was widely used years back which; it includes all ways of events in the system that deviates from normal operations [1]. In the power system, Power quality issues have different types includes voltage variations, power outage, sags, transient, and interruptions. The electrical system will be considered effective if the power factor is between 85% to 100%, however, is difficult to maintain the desired power factor. The low power factor will lead to increasing in transmission and generation cost. All electrical power is distributed as sinusoidal voltage. When we look at the basics of how the generator works, we will understand the electrical power distributed as a sinusoidal wave [2].

A generator is a rotating magnet in a stationary coil of wire. The rotating magnetic (rotor) is called the field winding. The stationary coil is called the stator winding. The field is excited by direct current by mean of carbon brushes and slip rings. The field winding is twisted at a constant speed by a mechanical power source which connected to the motor shaft. The field winding turns the magnetic flux sweeps by the stationary stator windings which induced voltage in the stator winding and in a two-pole generator the induced voltage makes a complete cycle of values for each complete mechanical revolution which it has a sine wave. The frequency of the two-pole generation of the induced voltage in Hertz is the equivalent of the speed of the rotor or field winding in revolutions per one second [3]. The frequency is synchronized with the mechanical speed and for that reason, this type of equipment is called synchronous generator. A two-pole synchronous generator turned at 50 revolutions per second (3000 per minute) will produce a 50-hertz voltage sine wave [4]. Electricity generation to the consumers is the main function of the power system. Also, related to power system generation is the term power quality. There are many reasons for the importance given to the power quality. Protective devices become sensitive near power quality variation than were the past generation protective devices. There are some of the troubles which are common in affecting the power system such as transients, sagging, variations in voltage and harmonics [5].

II. Harmonics

Non-sinusoidal waveforms can be produced in four fundamentally different sets of circuit conditions. In the first case, a voltage or current sources generate a non-sinusoidal emf or current, while other circuits elements (R, L, and C) are linear i.e. independent of the magnitude of current. Hormonics are introduced in the output voltage of an alternator due to many reasons such as irregular distribution of flux in it. In the second case, a voltage or current sources generate a sinusoidal voltge or current in a circuit with one or more non-linear elements. In the third case, the source generates a non-sonusoidal voltage or current and the circuit incoporates one or more non-linear impedances. In the fourth case, the source generates a non-sinusoidal voltage while one or more circuit elements vary periodically.

Harmonic frequencies are the multiples of the full number of base frequency provided, i.e. for 50 Hz as fundamental, the third and fifth harmonic will be 150 Hz and 250 respectively; these are referred to as third order and fifth order harmonics. Harmonics are one of the major concerns in a power system. Harmonics cause malformation in voltage and current waveforms resulting into damage of the power system. The first step for harmonic analysis is the harmonics from non-linear loads [6]. The results of such analysis are convoluted. For many years, methods of analyzing and controlling harmonics are very important.

Practically, most of the distorted waveforms will be more convoluted than this example, containing many more harmonics with a more convoluted phase relationship. This waveform is clearly not a sinewave and that means that some everyday measurement equipment, such as average-reading RMS-calibrated multi-meters, will give imprecise readings. There are six zero-crossing points per cycle instead of two, so any equipment that uses zero-crossing as a reference may fault [6].

2.1 Harmonics distortion

2.1.1 Linear and nonlinear loads

When an electrical load is connected to the voltage source, it draws current to perform work. If the current follows in the same sinusoidal pattern as the voltage, then the load is said to linearly flow the voltage and in short is called a linear load, however if the connected load does not follow the sinusoidal wave shape of the voltage then the load is called nonlinear load.

Nonlinear loads cause stress on the transformers and generators that make up the power system also known as the power grid [7]. This stress has been found to be primarily thermal in nature. In other words, equipment gets hot and even though the load that is doing the work can be very efficient, the overall energy used to perform the work of nonlinear is higher than linear load. Power system carrying nonlinear loads are less efficient so it is important to find them and take corrective action to reduce their negative impact on the power grid. Now in the real world, the grid is filled with all types of devices that create nonlinear loads like power supplies, electronics and variable speed drives [1]. A great many things consume current intermittently in blocks or bursts causing the sine wave of the power grid to become distorted. In an electrical power utility, distorted current wave is a problem.The hazards of degraded power are including line losses, equipment damage, increased power costs and wasted energy [3].

Figure 1: Distortion in current waveforms due to harmonics

2.1.2 Harmonics sources

Non-linear loads cause the harmonic problems such as power supplies, adjustable speed drives, electronic ballasts for fluorescent lamp, and arcing devices such as welders. These devices can cause nearby equipment, such as sensitive computer controls or digital clocks, to malfunction. They can cause nearby transformers to overheat as well. It is possible for non-linear devices to make voltage distortion or trigger a resonance for the system with the utility's, equipment of power system and thus cause more widespread problems [8].

2.2 Effects of Harmonics

We are interested in the subject of harmonics because of the harmful effects they have on power system devices. Harmonics can result to power system inefficiency. What makes harmonics so sneaky is that usually harmonics effects are not known until failure occurs. Perception into how harmonics can interact within a power system and how they can affect power system components are important for avoiding failures. The following points are undesirable ways of harmonics affect on equipment [9].

Current harmonics are produced by important nonlinear circuits. Harmonic current does not affect electrical equipment supplies the harmonic current of the device (transformer and conductors). Current harmonics can cause problems with distribution equipment with the current of the transformer tool must be handled all the way down to the device, but generally do not affect the other equipment related to the electrical system. Harmonic currents can cause high heating of transformers. For single phase electric load systems, the third compatibility has gained attention in the design of the consideration and the selection of the transformer to cause a neutral conductor to draw the excess current [10].

Voltage harmonics can affect sensitive equipment through your facility. Voltage harmonics arise when current harmonics can create swings in the supply voltage.When any current device is drawn; it creates the desired voltage dip for the current flow. This voltage retracts visible with larger loads when turning on the hair dryer or saw the table and see the lights dimmed down. The amount of slack depends on many factors such as resistors of wire size resistance. Current harmonics create voltage harmonics, but the size of the voltage harmonics depends on the "hardening" of your electrical distribution "system impedance" [11].

In addition to running the transformers on the sinusoidal supply, harmonic behaviour becomes important as the size and classification of the transformer increases. One of the effects of harmonic currents is, it increases electromagnetic interference with communication circuits and on the other hand, the harmonic voltages of the transformer can also increase insulation pressure on insulation, fixed electrical interference with communication circuits and resonance between reactive reaction and feeding amplitude [12].

2.2.1 Power factor

The power factor is the ratio between active power (P) and apparent power (S) is:

$$\mathrm{PF} = \frac{\mathrm{P}}{\mathrm{S}} \qquad (1)$$

2.2.2 Transformers

Harmonics can affect transformers in the first place in two ways. Voltage harmonics produce additional losses at the core of the transformers as the higher harmonic voltages set up the deceleration rings, which are based on the fundamental loop. Each loop offers higher magnetization requirements and higher base losses.

A more serious and second effect of harmonics is due to harmonic frequency currents in the winding transformer. Harmonic currents increase the current net code flowing into the transformer coils resulting in additional (I^2R) losses. As current losses are further swirled, the winding eddy current is currents in conductors by magnetic. Eddy current concentrations are higher at the ends of the coils due to the dense effect of the magnetic field leaking in the coil of the coils. The turbulent current turbulence losses increase as the square of the harmonic current and current frequency square. Thus, the eddy current losses (EC) are proportional to (Ih2 x h2), where Ih is the RMS value of the harmonic congruence of order h, and h is the order of the harmonic frequencies [4].

2.2.3 Motors

Nowadays, Variable frequency drives (VFDs) are increasing daily which it operates with electric motors. The voltages and currents of the VFD that go to the motors are rich in components of harmonic frequency. The engine-saving voltage puts the magnetic fields in the heart, which creates iron losses in the magnetic frame of the motor. Current vortex losses and deceleration are part of the iron losses that are produced in the core due to the rotating magnetic field. The decompression losses correspond to frequency, and the eddy current losses vary as the square of frequency. As a result, high voltage components generate additional losses at the core of the AC motors, which in turn, increase the operating temperature of the core and flux surrounding at the core [1].

Application of non-sinusoidal voltages to the result motors in the current harmonic rotation of the winding motors. Net current code is:

$$\mathrm{I}_{\mathrm{rms}} = \sqrt{\mathrm{I}_1^2 + \mathrm{I}_2^2 + \mathrm{I}_3^2 + \cdots} \qquad (2)$$

Where the subscripts 1, 2, 3, etc. represent the different harmonic currents.

2.2.4 Generators, Drives/Power Suppliesand Skin Effect

Generators have problems such as transformer problems. Coordination and sizing is critical to the orderly operation of voltage and controls. Deformation of excessive harmonic voltage will cause multiple zero crossing of the current waveform. Multiple zero-effect transitions on timing regulator, causing interference and operating instability which can be affected by disoperation as a result of multiple zero crossings. Harmonics can cause circuit attenuation failure of the communication circuits, found in DC and AC drives with silicon-controlled rectifiers (SCRs) [8].

The alternating current inclines to flow on the outer surface of the conductor. This is known as the skin effect and is more pronounced at high frequencies. The effect of the skin is usually ignored because it has only very little effect on the power supply frequencies but above about 350 Hz, i.e. the seventh harmony and above, the skin effect becomes important, causing additional losses and heating. In the case of coordinated currents, designers must take the skin effect into account and cancel the rate cables accordingly. Multiple busbar or covered bus-bars can be used to overcome this problem. It is also noted that the installation systems for bus-bar should be designed to avoid mechanical resonance at the harmonic frequencies [11].

III. Control and limits of Harmonics

The Harmonic standards and Norms: Standard IEE 519-1992 is a useful document for understanding harmonics and applying harmonic limits in power systems. After many years of good use there is still some confusion about how to apply certain aspects of the standard.

Table 1. IEEE-519 Maximum odd harmonic current limits for general distributions systems, 120 V through 69 kV

Isc/IL	n <11	11≤ n <17	17≤ n <23	23≤ n <35	35 ≤ n	THD
<20	4.0%	2.0%	1.5%	0.6%	0.3%	5.0%
20-50	7.0%	3.5%	2.5%	1.0%	0.5%	8.0%
50-100	10.0%	4.5%	4.0%	1.5%	0.7%	12.0%
100-1000	12.0%	5.5%	5.0%	2.0%	1.0%	15.0%
>1000	15.0%	7.0%	6.0%	2.5%	1.4%	20.0%

3.1 Total harmonic distortion THD

We can apply this measurement to a current, voltage and power waveform which is the ratio between the RMS summations of harmonics to fundamental's RMS value.THD used to describe current or voltage malformations [9].

$$\mathrm{THD} = \sqrt{\frac{\text{Sum of squares of amplitudes of all harmonics}}{\text{square of amplitude of fundamental}}} \times 100$$

The THD is very useful quantity for many applications, but its curb or limitation must be realized. It can furnish a good idea of how much extra heat will be realized when distorted.

Table 2. Consistency levels of harmonic voltage (in percent fundamental) for winding systems

Odd harmonics				Even harmonics	
Not multiple of 3		Multiple of 3			
Order h	Harmonics voltage (%)	Order h	Harmonics voltage (%)	Order h	Harmonics voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2	>21	0.2	10	0.5
19	1.5			12	0.2
23	1.5			>12	0.2
25	1.5				
>25	0.2+1.3*25h				
*Limit for total harmonic distortion (THD) is 8 percent.					

3.1 Total demand distortion (TDD) and Distortion factor (DF)

We can distinguish the levels of the current distortion value of the arc, as shown, but this is often misleading. For example, many adjustable speed drives will display high THD values to input the current when running at very light loads. This is not unavoidably a major concern because the size of the harmonic current is low, although its current relative distortion is high [6]. This difficulty by attaching a THD to the fundamental of the load current peak demand rather than the current sample fundamental. This is called total distortion and serves as the basis for the guidelines in Standard 519-1992, recommended practices and requirements for coordinated control of electrical power systems [5]. They are defined as:

$$\mathrm{TDD} = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h^2}}{I_L} \qquad (3)$$

The distortion Factor (DF) is clarified as follows:

$$\mathrm{DF} = \frac{1}{\sqrt{1+\mathrm{THD}^2}} \qquad (4)$$

Total Power Factor (PF) = Product of the Input Displacement Factor and the Distortion Factor as follows:

$$\mathrm{PF} = \mathrm{IDF} \times \mathrm{DF} \qquad (5)$$

3.2.1 Point of common coupling (PCC) and Pulse number (q)
The point on the power utility system, electrically near a certain load, which other loads are, or can be connected. In the correction circuit, the number of pulses (lobes) seen in the DC output in the input cycle

IV. Harmonics Analysis

The Fourier series are used in the analysis of periodic functions. Many phenomena studied in engineering and science is cyclical in nature for example. Voltage and current circuit instead. These periodic components can be analyzed periodically (criteria and alignment) through a process called Fourier analysis task [12].

We aimed to find an approximation using the trigonometric functions of a different square, tooth of saw, etc. that occurs in electronics. We do this by adding more and more trigonometric functions together. The sum of these three functions is called Fourier series.

4.1 Harmonics Filtering Techniques

Active filters or active harmonic conditioners are the newest technology available for reduction of harmonics. Active filtering techniques can be applied either as a standard filter or by integrating technology at the tuner stage of a drive, UPS or other energy electronics equipment. The solutions listed so far have been suitable only for special harmonics, since the torque converter is useful only for the three-phase harmonics and passive filters only for harmonic frequency design. Some of an installation, the content of harmonics is less predictable [7].

For example, the combination of equipment and the stir in IT installation is also constantly changing. The right solution is an active filter or an active conditioner. The active filter is an extruder. The harmonic content of the load current can be measured and controlled the current generator to produce an exact replica that is fed back on the display in the next cycle. Since the harmonic current is the source of an active state, only the primary stream is extracted from the display. In practice, the current harmonic sizes are reduced by 90%, and because the source impedance at the harmonic frequencies of the voltage distortion is reduced [2].

4.1.2 Active harmonic filter control

Control strategies are important for injecting harmonic currents/voltages that need to be compensated. It is divided into 3 stages. In the first signal, one is obtained using specific equipment for it, such as the current transformer.

The second phase is responsible for compensating voltages or currents based on control methodologies (power generation/voltage generation techniques). In the third phase pulse signals (current control techniques) are created. Signal generation techniques are harmonizing techniques for detection and compatibility and are divided into time methods and frequency methods.The static response of the negative harmonic filter and other problems has resulted in the electronic power solution of harmonic distortion of any active filters (AHF). A modern solution to ancient harmonic problems. At present, negative filters are used to cancel the switching frequency of active filters and high frequency. Filters that are mapped together use active filters to cancel selected frequencies and reduce the capacity of active filters. Active filters have been designed, improved, and marketed in the past 30 years. They are applicable to offset current-based distortions such as current harmonics, interactive power, and neutral current. It is also used for voltage-based deformities such as voltage harmonics, flickering voltage, swinging voltage, amplification, voltage imbalances, unbalance load and neutral conversion. Moreover, unlike negative filters, they do not cause harmful resonance with power distribution systems. Thus, the AHF performance independent of the characteristics of the power distribution system.

4.2.2 Operation principle of active filter

Active filters are systems that use electrical and electronics equipment, installed in a series or parallel to nonlinear load, to provide harmonic currents of nonlinear loads and thus, avoiding distortion on the power system.

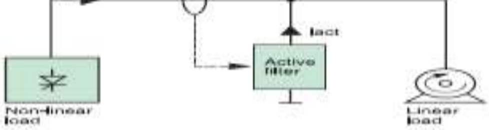

Figure 3. Operating principle of an active filter.

Active filter injection, in the opposition phase, harmonics drawn by the load, such that the current line is still sinusoidal.The typical applications are: Commercial enterprises consisting of a range of harmonic devices with a total power rating of less than 200 kVA (variable speed motors, UPS, office equipment, etc.) and cases where the current distortion should be reduced to avoid overcharging.

4.1.4 Hybrid filters

Operating Principle: Two types of filters provided above can be combined into one machine, thus forming a hybrid filter. This new filtering solution combines the advantages of the existing systems and provides a high-performance solution covering a wide power range.

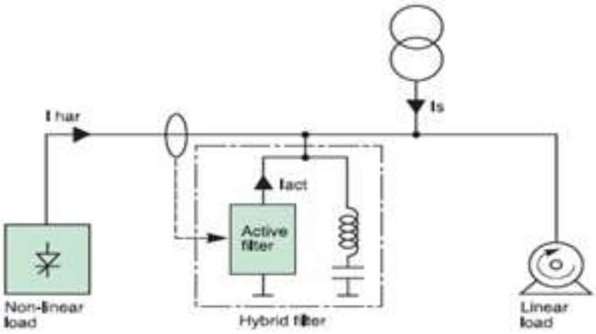

Figure4. Hybrid filter circuit

The typical applications:

1. Industrial installations with a range of devices cause compatibility with a total power rating of approximately 200 kVA (variable speed motors, UPSs, rectifiers, etc.) Connections where power factor correction is essential.
2. Cases where voltage deformation should be reduced to avoid disturbing sensitive loads.
3. Cases where the current distortion should be reduced to avoid over loads.
4. Case where strict limits on coordinated emissions are required.

V. Simulation and Results

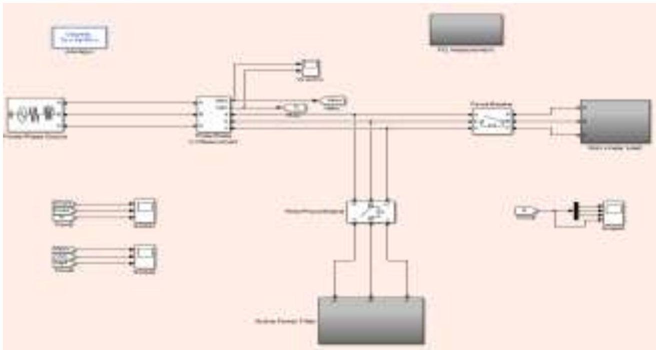

Figure 5. MATLAB simulation of shunt active filter

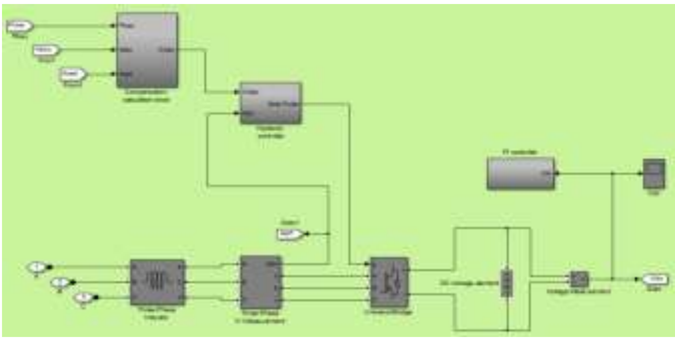

Figure 6. Shunt Active Power Filter block

The following figures show the THD using Fast Fourier transform in MATLAB from toolbox once with active filter and another without filtering.

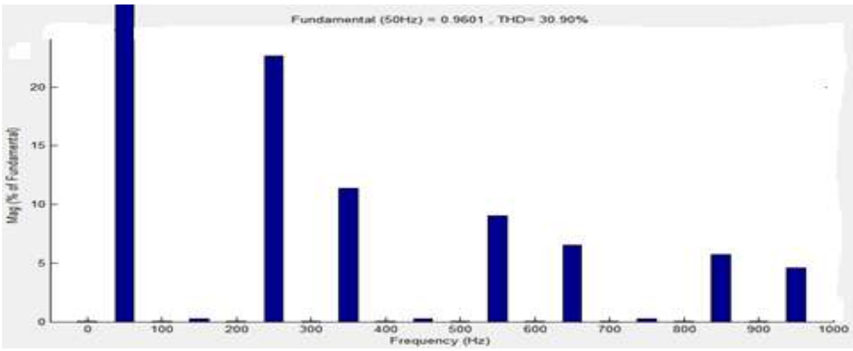

Figure 7.THD calculated using the currents on Load side. THD is around30.90%

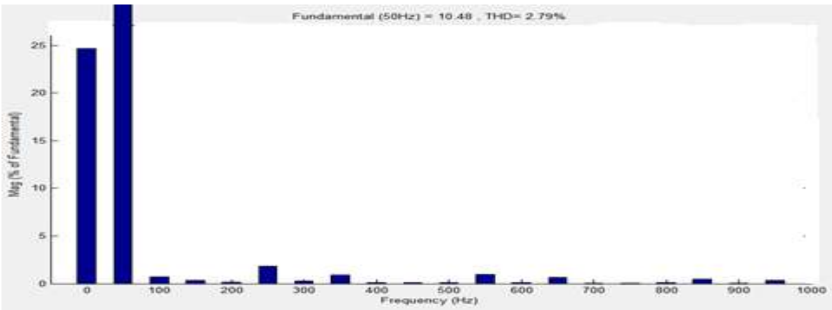

Figure 8. THD calculated Using the currents on Source side. THD is approximately S2.79%.

The maximum allowable total harmonic deformation in accordance with IEE 519_1992 regulations is less than 5% for bus voltages less than 69 kV using our active power extender. Using our Shunt Active Power Filter, we have reduced the THD remarkably from 30% to 2.79% on the simulated power systems circuit.

VI. Conclusion

The use of electronic devices have significantly increased power in industrial and domestic applications. Nonlinear devices or electronic components are powered by the extraction of nonlinear currents only from the source leaving the harmonic components in the source currents. When other loads are connected to power common coupling, the source of harmonic imports to loads. The use of APF can reduce harmonic pollution in a system that induces compensation components to the system. The active power filter is used as a transformer in this paper to compensate for the harmonic components in the source streams.The operation of APF was validated by considering two different cases of fixed connected load and variable connected load. Models of the system were developed without APF and its results discussed in detail. System models with APF have been developed with the presence of static and variable loads using MATLAB/Simulink and discussed the results of these cases in detail showing voltage source, load current and current source. THD values for source currents were scheduled for different situations and compensation for currents produced by APF is discussed, attaching the voltage link from the VSI transformer combined with the power factor.

It was found that the density is within nominal values when it is connected to the system with nonlinear loads. Results corroborate the application of APF transducer for different load conditions. The maximum allowable total harmonic deformation in accordance with IEE 519_1992 regulations is less than 5% for bus voltages less than 69 kV using our active power extender.Using our Shunt Active Power Filter, we have reduced the THD remarkably from 30% to 2.79% on the simulated power systems circuit.

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Edache-Abah" Effect of Youtube on Performance of Secondary School Students in Biology Concepts in Ikwerre Local Government Area of Rivers State" International Journal of Engineering Science Invention (IJESI), Vol. 08, No., 2019, PP 01-08