RESEARCH ARTICLE OPEN ACCESS

Power System Harmonics

Fuhaid BasheerAldousari

I. INTRODUCTION

The objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. This objective is complicated by the fact that there are loads on the system that produce harmonic currents. These currents result in distorted voltages and currents that can adversely impact the system performance in different ways. As the number of harmonic producing loads has increased over the years, it has become increasingly necessary to address their influence when making any additions or changes to an Installation. To fully appreciate the impact of this phenomena, there are two important concepts to bear in mind with regard to power system harmonics. The first is the nature of harmonic-current producing loads (non-linear loads) and the second is the way in which harmonic currents flow and how the resulting harmonic voltages develop.

II. LINEAR AND NON-LINEAR LOADS

A linear element in a power system is a component in which the current is proportional to the voltage. In general, this means that the current wave shape will be the same as the voltage (See Figure 1). Typical examples of linear loads include motors, heaters and incandescent lamps.

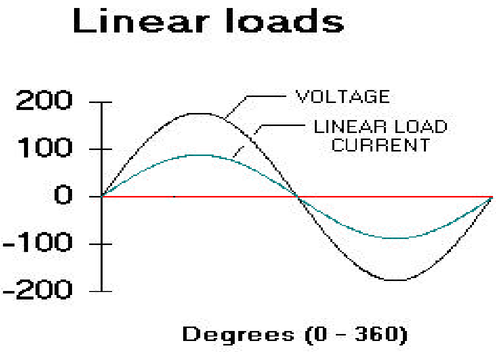

Figure 1 – Voltage and current waveforms for linear

On the other hand, the current wave shape on a non-linear load is not the same as the voltage (See Figure 2). Typical examples of non-linear loads include rectifiers (power supplies, UPS units, discharge lighting), adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment.

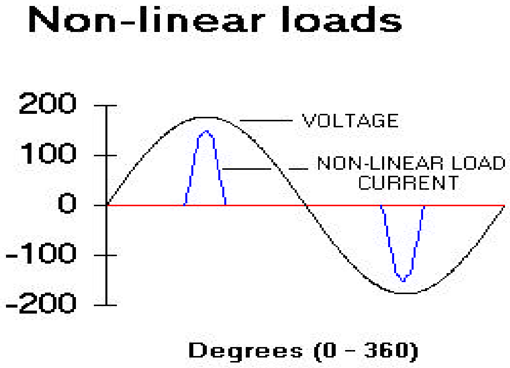

Figure 2 – Voltage and current waveforms for non-linear loads

The current drawn by non-linear loads is not sinusoidal but it is periodic, meaning that the current wave looks the same from cycle to cycle. Periodic waveforms can be described mathematically as a series of sinusoidal waveforms that have been summed together (See Figure 3).

The sinusoidal components are integer multiples of the fundamental where the fundamental, in the United States, is 60 Hz. The only way to measure a voltage or current that contains harmonics is to use a true-RMS reading meter. If an averaging meter is used, which is the most common type, the error can be Significant.

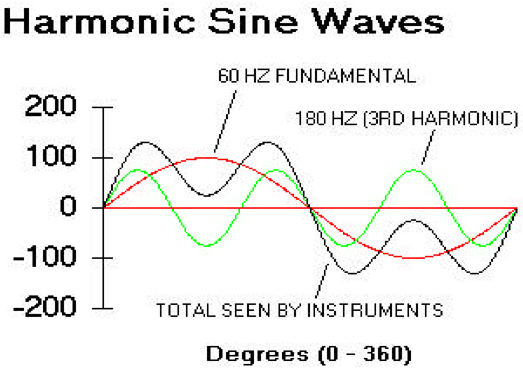

Figure 3. Waveform with symmetrical harmonic components

Each term in the series is referred to as a harmonic of the fundamental. The third harmonic would have a frequency of three times 60 Hz or 180 Hz. Symmetrical waves contain only odd harmonics and un-symmetrical waves contain even and odd harmonics.

A symmetrical wave is one in which the positive portion of the wave is identical to the negative portion of the wave. An un-symmetrical wave contains a DC component (or offset) or the load is such that the positive portion of the wave is different than the negative portion. An example of un-symmetrical wave would be a half wave rectifier.

III. MOST POWER SYSTEM ELEMENTS ARE SYMMETRICAL

When a non-linear load draws current, that current passes through all of the impedance that is between the load and the system source (See Figure 4). As a result of the current flow, harmonic voltages are produced by impedance in the system for each harmonic.

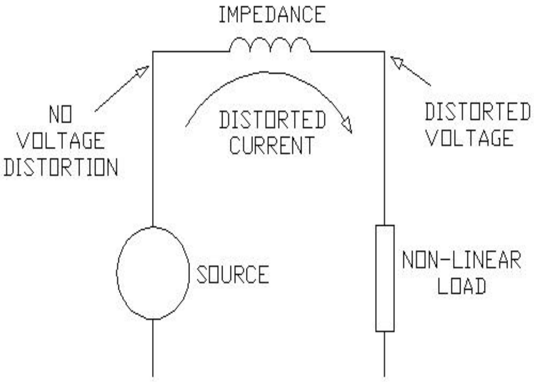

Figure 4 – Distorted-current induced voltage distortion

These voltages sum and when added to the nominal voltage produce voltage distortion. The magnitude of the voltage distortion depends on the source impedance and the harmonic voltages produced.

If the source impedance is low then the voltage distortion will be low. If a significant portion of the load becomes non-linear (harmonic currents increase) and/or when a resonant condition prevails (system impedance increases), the voltage can increase dramatically. When problems arise, they are usually associated with resonant conditions.

Harmonic currents can produce a number of problems, namely:

Equipment heating
Equipment malfunction
Equipment failure
Communications interference
Fuse and breaker mis-operation
Process problems
Conductor heating

Because of the number and variety of available methods, the selection of the best-suited technique for a particular application is not always an easy or straightforward process. Many options are available, including active and passive methods. Some of the most technically advanced solutions offer guaranteed results and have little or no adverse effect on the isolated power system, while the performance of other simple methods may be largely dependent on system conditions. This study, presents a comprehensive survey on harmonic mitigation techniques in which a large number of technical publications have been reviewed and used to classify harmonic mitigation techniques in some categories: passive techniques and active techniques. A brief description of the electrical characteristics of each method is presented with the aim of providing the designer and site engineer with a more informed choice regarding their available options when dealing with the effects and consequences of the presence of these harmonics in the distribution network.

IV. PASSIVE HARMONIC MITIGATION TECHNIQUES

Many passive techniques are available to reduce the level of harmonic pollution in an electrical network, including the connection of series line reactors, tuned harmonic filters, and the use of higher pulse number converter circuits such as 12-pulse, 18-pulse, and 24-pulse rectifiers. In these methods, the undesirable harmonic currents may be prevented from flowing into the system by either installing a high series impedance to block their flow or diverting the flow of harmonic currents by means of a low-impedance parallel path.

Harmonic mitigation techniques used for supply power factor correction and harmonics mitigation in two ways to qualify the products performance. One is to put a limit on the PF for loads above a specified minimum power. Utility companies often place limits on acceptable power factors for loads (e.g., <0.8 leading and >0.75 lagging). A second way to measure or specify a product is to define absolute maximum limits for current harmonic distortion. This is usually expressed as limits for odd harmonics (e.g., 1st, 3rd, 5th, 7th, etc.). This approach does not need any qualifying minimum percentage load and is more relevant to the electric utility.

Harmonic regulations or guidelines are currently applied to keep current and voltage harmonic levels in check. As an example, the current distortion limits in Japan illustrated in Tables 1 and 2 represent the maximum and minimum values of total harmonic distortion (THD) in voltage and the most dominant fifth harmonic voltage in a typical power system.

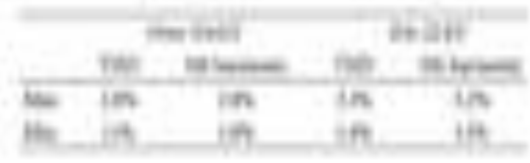

Table 1: Voltage THD and fifth harmonic voltage in a high-voltage power transmission system.

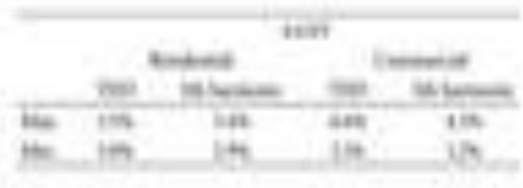

Table 2: Voltage THD and fifth harmonic voltage in a 6.6 kV power distribution system.

Certain techniques, such as the use of tuned filters, require extensive system analysis to prevent resonance problems and capacitor failures, while others, such as the use of 12-pulse or 24-pulse converters, can be applied with virtually no system analysis.

4.1. Effect of Source Reactance

Typical AC current waveforms in single-phase and three-phase rectifiers are far from a sinusoid. The power factor is also very poor because of the high harmonic contents of the line current waveform. In rectifier with a small source reactance, the input current is highly discontinuous, and, as a consequence, the power is drawn from the utility source at a very poor power factor.

The magnitude of harmonic currents in some nonlinear loads depends greatly on the total effective input reactance, comprised of the source reactance plus any added line reactance. For example, given a 6-pulse diode rectifier feeding a DC bus capacitor and operating with discontinuous DC current, the level of the resultant input current harmonic spectrum is largely dependent on the value of AC source reactance and an added series line reactance; the lower the reactance, the higher the harmonic content

Other nonlinear loads, such as a 6-pulse diode rectifier feeding a highly inductive DC load and operating with continuous DC current, act as harmonic current sources. In such cases, the amount of voltage distortion at the PCC is dependant on the total supply impedance, including the effects of any power factor correction capacitors, with higher impedances producing higher distortion levels].

4.2. Series Line Reactors

The use of series AC line reactors is a common and economical means of increasing the source impedance relative to an individual load, for example, the input rectifier used as part of a motor drive system. The harmonic mitigation performance of series reactors is a function of the load; however, their effective impedance reduces proportionality as the current through them is decreased.

4.3. Tuned Harmonic Filters

Passive harmonic filters (PHF) involve the series or parallel connection of a tuned LC and high-pass filter circuit to form a low-impedance path for a specific harmonic frequency. The filter is connected in parallel or series with the nonlinear load to divert the tuned frequency harmonic current away from the power supply. Unlike series line reactors, harmonic filters do not attenuate all harmonic frequencies but eliminate a single harmonic frequency from the supply current waveform. Eliminating harmonics at their source has been shown to be the most effective method to reduce harmonic losses in the isolated power system.. Many types of harmonic filters are commonly employed, including the following:

4.3.1. Series Induction Filters

Harmonic currents produced by switched-mode power supplies and other DC-to-DC converter circuits can be significantly lowered by the connection of a series inductor that can be added on either the AC or DC power circuit ,as shown in Figure 1. So many improvements on these filters have been made.

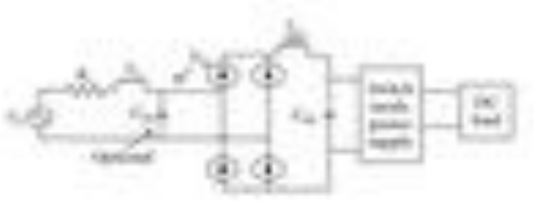

Figure 1: (a) The Series inductor filters for current shaping, (b) The Ziogas inductor capacitor filter, (c) The Yanchao improvement on Ziogas filter, and (d) The Hussein improvement on Yanchao filter.

Ziogas passive filter for single-phase rectifiers has some reduction in Total Harmonics Distortion THD and improvement in PF in comparison with conventional rectifier. Also, Yanchoawaveshaping filter used to reduce THD and increase power factor. Connecting author filter at the output terminal of the rectifier will improve power factor and reduce input current THD of the supply.

4.3.2. DC-DC Converter Current Shaping

Like the series induction filter, this circuit (Figure 2) can greatly reduce current distortion produced by switched-mode power supplies and other DC converter circuits by modulating the duty cycle of switch Sb to control the shape of input supply current to track a desired sine waveshapeSo many improvements on these filters have been made.

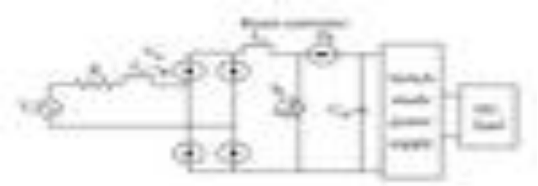

Figure 2: (a) Boost converter current shaping circuit, (b) buck converter current shaping circuit, (c) improve boost converter current shaping circuit, and (d) improve buck converter current shaping circuit.

4.3.3. Parallel-Connected Resonant Filter

Passive LC filters tuned to eliminate a particular harmonic are often used to reduce the level of low-frequency harmonic components like the 5th and 7th produced by three-phase rectifier and inverter circuits. The filter is usually connected across the line as shown in Figure 3. If more than one harmonic is to be eliminated, then a shunt filter must be installed for each harmonic. Care must be taken to ensure that the peak impedances of such an arrangement are tuned to frequencies between the required harmonic frequencies to avoid causing high levels of voltage distortion at the supply’s PCC because of the presence of an LC resonance circuit.

Figure 3: A parallel-connected resonant filter.

4.3.4. Series-Connected Resonant Filter

This work on a similar in principle to the parallel version, but with the tuned LC circuits connected in series with the supply. The series filter can be tuned to a single harmonic frequency, or it may be multituned to a number of harmonic frequencies. The multituned arrangement connects multiple tuned filters in series as shown in Figure 4 showing a third harmonic tuned LC circuit,Lr3 and Cr3 , and a high-frequency tuned LC circuit,Lrh and Crh , to eliminate high-order harmonics.

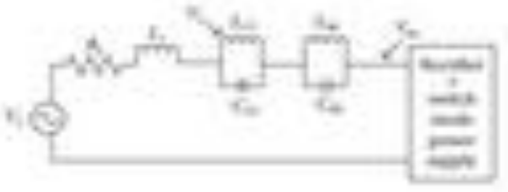

Figure 4: Double-tuned series-connected resonant filter.

4.3.5. Neutral Current Filter

This filter is connected in the neutral conductor between the site transformer and the three-phase load to block all triple frequency harmonics, as shown in Figure 5. Because these triple zero-sequence harmonics are in phase with each other, they all flow through the neutral conductor, and it is more economical to block them in the neutral instead of individual phases.

Figure 5: A neutral current blocking filters.

4.3.6. Zigzag Grounding Filter

By integrating phase shifting into a single or multiphase transformer with an extremely low zero-sequence impedance, substantial reduction of triple, 5th, and 7th harmonics can be achieved. This method provides an alternative to protect the transformer neutral conductor from triple harmonics by canceling these harmonics near the load. In this method, an autotransformer connected in parallel with the supply can provide a zero-sequence current path to trap and cancel triple harmonics as shown in Figure 6

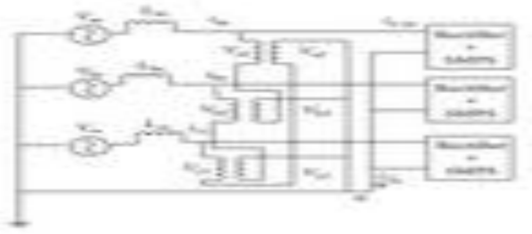

Figure 6: Zigzag autotransformer connected to three-phase nonlinear loads.

4.4. Higher Pulse Converters

Three phases, 6-pulse static power converters, such as those found in VSD, generate low-frequency current harmonics. Predominantly, these are the 5th, 7th, 11th, and 13th with other higher orders harmonics also present but at lower levels. With a 6-pulse converter circuit, harmonics of the order , where = 1, 2, 3, 4, and so forth, will be present in the supply current waveform. In high-power applications, AC-DC converters based on the concept of multipulse, namely, 12, 18, or 24 pulses, are used to reduce the harmonics in AC supply currents. They are referred to as a multipulse converters. They use either a diode bridge or thyristor bridge and a special arrangement of phase-shifting magnetic circuit such as transformers and inductors to produce the required supply current waveforms.

4.4.1. 12-Pulse Rectification

In large converter installations, where harmonics generated by a three-phase converter can reach unacceptable levels, it is possible to connect two 6-pulse converters in series with star/delta phase-shifting transformers to generate a 12-pulse waveform and reduce the harmonics on the supply and load sides, as shown in Figure 7. This could be beneficial despite the considerable extra cost of the transformers. Twelve-pulse rectifier is frequently specified by consulting engineers for heating, ventilating, and air-conditioning applications because of their theoretical ability to reduce harmonic current distortion.

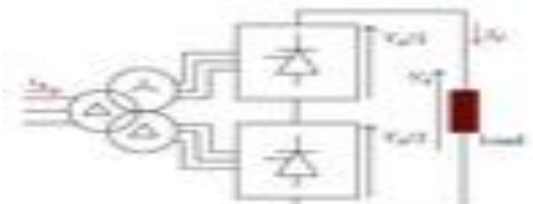

Figure 7: Series 12-pulse rectifier connection.

Instead of connecting the two converter bridges in series, they could also be connected in parallel to give 12-pulse operation. A parallel 12-pulse arrangement is shown in Figure 8. Parallel connections require special care to ensure adequate balance between the currents drawn by each bridge. Secondary leakage reactance must be carefully matched, and extra reactors are needed on the DC side to absorb the instantaneous differences between the two DC voltage waveforms.

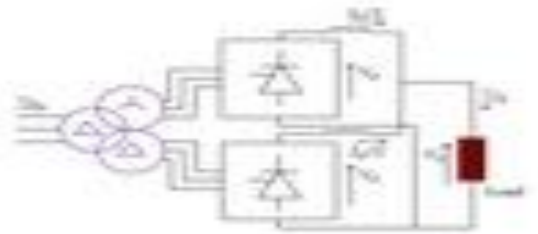

Figure 8: Parallel twelve-pulse rectifier connection.

When using a 12-pulse system, the 5th and 7th harmonics disappear from line current waveforms leaving the 11th as the first to appear. Only harmonics of the order 12K+-1 , where = 1, 2, 3, 4, and so forth, will be present in the supply current waveform, thus resulting in a high power factor, low THD at input AC mains, and ripple-free DC output of high quality.

4.4.2. 18-Pulse Rectification

Eighteen-pulse converter circuits, shown in Figure 9, use a transformer with three sets of secondary windings that are phase-shifted by 20 degrees with respect to each other. Only harmonics of the order , where = 1, 2, 3, 4, and so forth, will be present in the supply current waveform .

Figure 9: 18-pulse rectifier connection.

4.4.3. 24-Pulse Rectification

Connecting two 12-pulse circuits with a 15° phase shift produces a 24-pulse system. Figure 10 shows one such system in which the two 12-pulse circuits are connected in parallel to produce the required 24-pulse system. The 11th and 13th harmonics now disappear from the supply current waveform leaving the 23rd as the first to appear. Only harmonics of the order24K+-1 , where = 1, 2, 3, 4, and so forth, will be present in a 24-pulse system.

Figure 10: 24-pulse rectifier connection.

V. ACTIVE HARMONIC MITIGATION TECHNIQUES

When using active harmonic reduction techniques, the improving in the power quality came from injecting equal-but-opposite current or voltage distortion into the network, thereby canceling the original distortion. Active harmonic filters (AHFs) utilize fast-switching insulated gate bipolar transistors (IGBTs) to produce an output current of the required shape such that when injected into the AC lines, it cancels the original load-generated harmonics. The heart of the AHF is the controller part. The control strategies applied to the AHF play a very important role on the improvement of the performance and stability of the filter.

5.1. Parallel Active Filters

This is the most widely used type of AHF (more preferable than series AHF in terms of form and function). As the name implies, it is connected in parallel to the main power circuit as shown in Figure 11. The filter is operated to cancel out the load harmonic currents leaving the supply current free from any harmonic distortion. Parallel filters have the advantage of carrying the load harmonic current components only and not the full load current of the circuit.

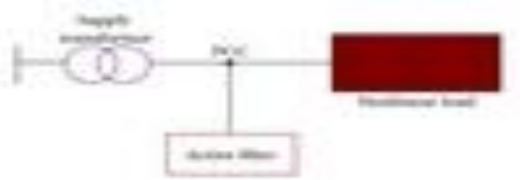

Figure 11: Parallel active filter.

AHF can be controlled on the basis of the following methods:

(i) the controller detects the instantaneous load currentiL,
(ii) the AHF extracts the harmonic currentiLh from the detected load current by means of digital signal processing,
(iii) the AHF draws the compensating currentiAF (= -iLh) from the utility supply voltage vs so as to cancel out the harmonic currentiLh .

5.2. Series Active Filters

The main circuit configuration for this type of AHF is shown in Figure 12. The idea here is to eliminate voltage harmonic distortions and improve the quality of the voltage applied to the load. This is achieved by producing a sinusoidal pulse width modulated (PWM) voltage waveform across the connection transformer, which is added to the supply voltage to counter the distortion across the supply impedance and present a sinusoidal voltage across the load.

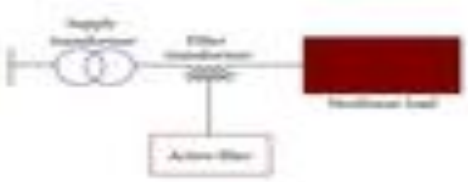

Figure 12: Series active filter.

Unlike the shunt AHF, the series AHF is controlled on the basis of the following methods:

(i) the controller detects the instantaneous supply currentis,
(ii) the AHF extracts the harmonic current is from the detected supply current by means of digital signal processing
(iii) the active filter applies the compensating voltage AF(= - Kish) across the primary of the transformer. This will result in a significant reduction in the supply harmonic current (ish), when the feedback gain K is set to be high enough.

An AHF with both series and parallel (shunt) connected sections, as shown in Figures 11 and 12, respectively, can be used to compensate for both voltage and current harmonics simultaneously. In all cases, the critical requirement of any AHF circuit is to calculate the required compensation current accurately and in real time.

VI. CONCLUSION

Harmonic currents can have a significant impact on electrical distribution systems and the facilities that they feed. It is important to consider their impact when contemplating additions or changes to a system. In addition, identifying the size and location of non-linear loads should be an important part of any maintenance.

Electrical system reliability and normal operation of electrical equipment rely heavily upon a clean distortion free power supply. Designers and engineers wishing to reduce the level of harmonic pollution on a power distribution network where nonlinear harmonic generating loads are connected have several harmonic mitigation techniques available. Because of the number and variety of available methods, selection of the best-suited technique for a particular application is not always an easy or straightforward process. A broad categorization of different harmonic mitigation techniques (passive, active) has been carried out to give a general viewpoint on this wide-ranging and rapidly developing topic. PHF is traditionally used to absorb harmonic currents because of low cost and simple robust structure. However, they provide fixed compensation and create system resonance. AHF provides multiple functions such as harmonic reduction, isolation, damping and termination, load balancing, PF correction, and voltage regulation. The HHF is more attractive in harmonic filtering than the pure filters from both viability and economical points of view, particularly for high-power applications. It is hoped that the discussion and classification of harmonic mitigation techniques presented in this paper will provide some useful information to help make the selection of an appropriate harmonic reduction method for a given application on an easier task.

REFERENCES

[1]. R.C. Dugan, D.T. Rizy, "Harmonic Considerations For Electrical Distribution Feeders", National Technical Information Service, Report No. Ornl/Sub/81-95011/4 (Cooper Power Systems As Bulletin 87011, "Electrical Power System Harmonics, Design Guide")
[2]. J. Arillaga, Et Al, "Power System Harmonics" Isbn 0-471-90640-9
[3]. 4. P519a Task Force, Harmonics Working Group (Ieee Pes T&D Committee) And Scc22 – Power Quality, "Guide For Applying Harmonic Limits On Power Systems" (Un-Approved Draft)
[4]. Ieee Standard 519-1992, Ieee Recommended Practices And Requirements For Harmonic Control In Electrical Power Systems.