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Understanding Harmonic Reduction And Power Quality Improvemnet

Amit Bhardwaj, Dr AA Mujumdar, Prabahan Baruah, Dr P R Dongarwar

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I. Introduction

Electric power quality is the degree to which the voltage, frequency, and waveform of a power supply system conform to established specifications. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value, and smooth voltage curve waveform (which resembles a sine wave). In general, it is useful to consider power quality as the compatibility between what comes out of an electric outlet and the load that is plugged into it.

The electric power industry comprises electricity generation (AC power), electric power transmission and ultimately electric power distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

II. Power Quality

The quality of electrical power may be described as a set of values of parameters, such as:

(a) Continuity of service (Whether the electrical power is subject to voltage drops or overages below or above a threshold level thereby causing blackouts or brownouts).
(b) Variation in voltage magnitude.
(c) Transient voltages and currents.
(d) Harmonic content in the waveforms for AC power.

Common power quality challenges are grouped into two broad areas: voltage anomalies and harmonic distortion issues. Voltage anomalies can cause several problems, many easily corrected. The key is to spot the symptoms are as follows:

(a) Voltage dips or sags.
(b) Voltage swells or surges.
(c) Voltage transients.
(d) Voltage interruptions.
(e) Voltage unbalance.

III. Harmonics

The term harmonics referred to Power quality in ideal world would mean how pure the voltage is, how pure the current waveform is in its sinusoidal form. A harmonic is a wave with a frequency that is a positive integer multiple of the fundamental frequency, the frequency of the original periodic signal, such as a sinusoidal wave. The original signal is also called the 1st harmonic, the other harmonics are known as higher harmonics. As all harmonics are periodic at the fundamental frequency, the sum of harmonics is also periodic at that frequency. The set of harmonics forms a harmonic series.

Harmonics are one of the major concerns in a power system. Harmonics cause distortion in current and voltage waveforms resulting into deterioration of the power system. The first step for harmonic analysis is the harmonics from non-linear loads. The results of such analysis are complex. Over many years, much importance is given to the methods of analysis and control of harmonics.

First category of loads are described as linear loads. The linear time-invariant loads are characterized such that application of sinusoidal voltage results in sinusoidal flow of current. A constant steady-impedance is displayed from these loads during the applied sinusoidal voltage. As the voltage and current are directly proportional to each other, if voltage is increased it will also result into increase in the current. An example of such a load is incandescent lighting. Even if the flux wave in air gap of rotating machine is not sinusoidal, under normal loading conditions transformers and rotation machines pretty much meet this definition. Also, in a transformer the current contains odd and even harmonics including a dc component. More and more use of magnetic circuits over a period of time may get saturated and result into generation of harmonics. In power systems, synchronous generators produce sinusoidal voltages and the loads draw sinusoidal currents. In this case, the harmonic distortion is produced because of the linear load types for sinusoidal voltage is small.

Non-linear loads are considered as the second category of loads. The application of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for non-linear devices. The non-linear loads draw a current that may be discontinuous. Harmonic current is isolated by using harmonic filters in order to protect the electrical equipment from getting damaged due to harmonic voltage distortion. They can also be used to improve the power factor. The harmful and damaging effects of harmonic distortion can be evident in many different ways such as electronics miss-timings, increased heating effect in electrical equipments, capacitor overloads, etc. There can be two types of filters that are used in order to reduce the harmonic distortion i.e. the active filters and the passive filters. Active harmonic filters are electronic devices that eliminate the undesirable harmonics on the network by inserting negative harmonics into the network. The active filters are normally available for low voltage networks. The active filters consist of active components such as IGBT-transistors and eliminate many different harmonic frequencies. The signal types can be single phase AC, three phase AC. On the other hand, passive harmonic filters consist of passive components such as resistors, inductors and capacitors. Unlike the active filters which are used only for low voltages, the passive filters are commonly used and are available for different voltage levels.

IV. Problems caused by harmonics:

Transformers:

Harmonics in transformers cause an increase in the iron and copper losses. Voltage distortion increase losses due to hysteresis and eddy currents and causes overstressing of the insulation material used. The primary effect of power line harmonics in transformer is, thus the additional heat generated. Other problems include possible resonance between the transformer inductance and the system capacitance, thermal fatigue due to temperature cycling and possible core vibration.

Motor and generators:

Harmonic voltage and current cause increased heating in rotating machines due to additional iron and copper losses at harmonic frequencies. This lowers the machine efficiency and affects the torque developed.

Thyrister drives:

AC variable frequency drives with thyrister converter when operated at slow speed, generally result in poor power factor.

Power cable:

Normal level of harmonics currents cause heating in cables. However, cables involved under system resonance condition may be subjected to voltage stress and corona, which can lead to insulation failure.

Metering equipments:

In general, harmonics flowing in induction type metering equipment will generate additional coupling paths thereby increasing the speed of the disc and hence an apparent increase of costs.

Switchgear and relay:

Harmonics current increases heating and losses in switchgear there by lowering its normal current capacity and shortening the life due to voltage stress fuses require derating due to the heat generated by harmonics.

Earthing system and computer performance:

In a 3 phase and neutral system- when 3rd harmonics and multiples are expected, the neutral conductor size should be the same size as the phase conductor size. Computer hanging up, loosing instructions, data or misbehaving can be as much attributed to poor quality of power.

Communication network:

The induction coupling between the AC power transmission lines containing harmonics and the neighbouring communication network causing high noise levels.

Common sources of harmonics:

The main source of the harmonics is any non-linear loads that produce the voltage harmonics and current harmonics. This occurs because the resistance of the device is not a constant. The resistance in fact, changes during each sine wave. So, non linear device is one in which the current is not proportional to the applied voltage. Various common sources of harmonics are as follows:

(a) Transformers.
(b) Rotating machines.
(c) Power converters
(d) Fluorescent lamps
(e) Arcing devices.

V. MITIGATION TECHNIQUES:

A growing number of harmonic mitigation techniques are now available including active and passive methods, and the selection of the best-suited technique for a particular case can be a complicated decision-making process. The performance of some of these techniques is largely dependent on system conditions, while others require extensive system analysis to prevent resonance problems and capacitor failure. A classification of the various available harmonic mitigation techniques is presented in this paper aimed at presenting a review of harmonic mitigation methods to researchers, designers, and engineers dealing with power distribution systems.

The nonlinear characteristics of many industrial and commercial loads such as power converters, fluorescent lamps, computers, light dimmers, and variable speed motor drives (VSDs) used in conjunction with industrial pumps, fans, and compressors and also in air-conditioning equipment have made the harmonic distortion a common occurrence in electrical power networks. Harmonic currents injected by some of these loads are usually too small to cause a significant distortion in distribution networks. However, when operating in large numbers, the cumulative effect has the capability of causing serious harmonic distortion levels. These do not usually upset the end-user electronic equipment as much as they overload neutral conductors and transformers and, in general, cause additional losses and reduced power factor. Large industrial converters and variable speed drives on the other hand are capable of generating significant levels of distortion at the point of common coupling (PCC), where other users are connected to the network. To comply with the harmonic standards, installations utilizing power electronic and nonlinear loads often use one of the growing numbers of harmonic mitigation techniques. 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.

VI. 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.

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. However, the increased first cost entailed presents a barrier to this approach. If the parallel-connected filter is connected further upstream in the power network, higher day-to-day costs will accumulate due to losses in the conductors and other plant items that carry the harmonic currents. Conversely, for series-connected filter at the load, there are increased losses in the filter itself. These losses are simply the result of the higher series impedance, which blocks the flow of harmonics but increases the line loss as a result of the flow of the remaining components of the load current. The quality factor of the filter inductor affects the actual value of the low-impedance path for each filter. Many types of harmonic filters are commonly employed, including the following:

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.

DC-DC Converter Current Shaping

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

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. If more than one harmonic is to be eliminated, then a shunt filter must be installed for each harmonic.

Series-Connected Resonant Filter

This work on a similar in principle to the parallel version, but with the tuned 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 to eliminate high-order harmonics.

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.

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. 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.

18-Pulse Rectification

Eighteen-pulse converter circuits 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.

24-Pulse Rectification

Connecting two 12-pulse circuits with a 15° phase shift produces a 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 order, where = 1, 2, 3, 4, and so forth, will be present in a 24-pulse system.

VII. 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. AHF is designed with two types of control scheme. The first performs fast Fourier transforms to calculate the amplitude and phase angle of each harmonic order. The power devices are directed to produce a current of equal amplitude but opposite phase angle for specific harmonic orders. The second method of control is often referred to as full spectrum cancellation in which the full current waveform is used by the controller of the filter, which removes the fundamental frequency component and directs the filter to inject the inverse of the remaining waveform.Typically, these filters are sized based on how much harmonic current the filter can produce, normally in amperage increments of 50 Amps. The proper amperage of AHF can be chosen after determining the amount of harmonic cancellation current.Essentially, the filter consists of a VSD with a special electronic controller which injects the harmonic current onto the system 180 out of phase to the system or drive harmonics. This results in harmonics cancellation. For example, if the VSD created 50 A of 5th harmonic current, and the AHF produced 40 A of 5th harmonic current, the amount of 5th harmonic current exported to the utility grid would be 10 A. The AHF may be classified as single-phase or three-phase filters.Also, it could be classified as parallel or series AHF according to the circuit configuration.

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. 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.

Series Active Filters

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. Series AHF has to carry the full load current increasing their current ratings and losses compared with parallel filters, especially across the secondary side of the coupling transformer.

Hybrid Harmonic Mitigation Techniques

Hybrid connections of AHF and PHF are also employed to reduce harmonics distortion levels in the network. The PHF with fixed compensation characteristics is ineffective to filter the current harmonics. AHF overcomes the drawbacks of the PHF by using the switching-mode power converter to perform the harmonic current elimination. However, the AHF construction cost in an industry is too high. The AHF power rating of power converter is very large. These bound the applications of AHF used in the power system. Hybrid harmonic filter (HHF) topologies have been developed to solve the problems of reactive power and harmonic currents effectively. Using low cost PHF in the HHF, the power rating of active converter is reduced compared with that of AHF. HHF retains the advantages of AHF and does not have the drawbacks of PHF and AHF.

Direct Testing and Calculating Method (DTC)

Separation of the harmonic and reactive components from the load current is the aim of current reference generator. The main characteristic of this method is the direct derivation of the compensating component from the load current, without the use of any reference frame transformation. In fact, this method presents a low-frequency oscillation problem in the AHF DC bus voltage.

Synchronous Reference Fame Method (SRF)

Real currents are transformed into a synchronous reference frame in this method. The reference frame is synchronized with the AC mains voltage and is rotating at the same frequency. In this method, the reference currents are derived directly from the real load currents without considering the source voltages, which represent the most important characteristics of this method. The generation of the reference signals is not affected by distortion or voltage unbalance, therefore increasing the compensation robustness and performance.

Current Hysteresis Control

The basic principle of this control method is that the switching signals are derived from the comparison of the current error signal with a fixed width hysteresis band. This current control technique exhibits some unsatisfactory features due to simple, extreme robustness, fast dynamic, good stability, and automatic current limited characteristics.

Triangle-Comparison PWM Control

This control method is also called linear current control. The conventional triangle-comparison PWM control principle is that the modulation signal achieved by a current regulator from the current error signal is intersected with the triangle wave. After that, ulse signals obtained are to control the switches of the converters. With analog PWM circuit, this control method has simple implementation with fast speed of response. Because the modulation frequency equals the triangle frequency, the current loop gain crossover frequency must be kept below the modulation frequency.

Space Vector Modulation (SVM)

The aim of this method is to find the appropriate switching combinations and their duty ratios according to certain modulation scheme. The SVM operates in a complex plane divided in the six sectors separated by a combination of conducting or non-conducting switchesin the power circuit. The reference vector is used to locate two adjacent switching-state vectors and compute the time for which each one is active. SVM is of low speed of response caused by the inherent calculation delay, due to the strong anti-jamming and the good reliability of digital control technique. In order to solve the drawback, the improvement of adopting deadbeat control and a certain oversize of the system reactive components is advised.

Distribution Static Compensator (D-STATCOM)

A D-STATCOM (Distribution Static Compensator) consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

(a) Voltage regulation and compensation of reactive power.
(b) Correction of power factor.
(c) Elimination of current harmonics.

VIII. CONCLUSION:

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, and hybrid) 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.

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