Harmonics in Electrical Power Systems

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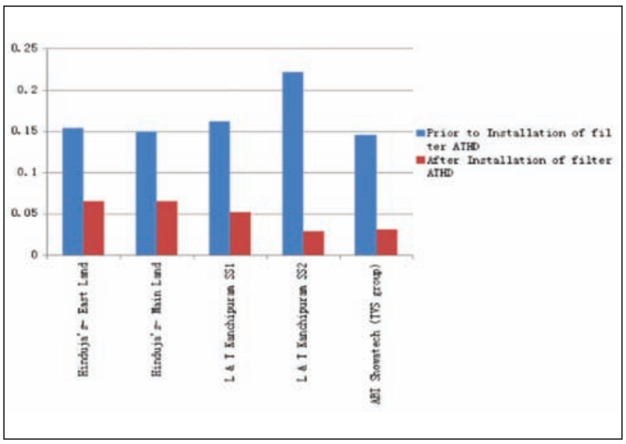
Electrical circuits carry currents of undesirable frequencies besides fundamental current of 50Hz or 60Hz. Fundamental current performs the intended work of catering to power needs of the loads whereas currents of frequencies which are multiples of fundamental frequency create various undesirable effects in the Electrical network. When a sinusoidal voltage is applied to a linear load it causes a sinusoidal current while for non linear loads the current is not sinusoidal. The distorted current waveform can be assumed to be made up of sinusoidal waveforms of frequencies which are multiples of fundamental frequency. Harmonics are classified as positive sequence (1,4,7,10,13,---), negative sequence (2,5,8,11,1---)and zero sequence (3,6,9,12,1---).

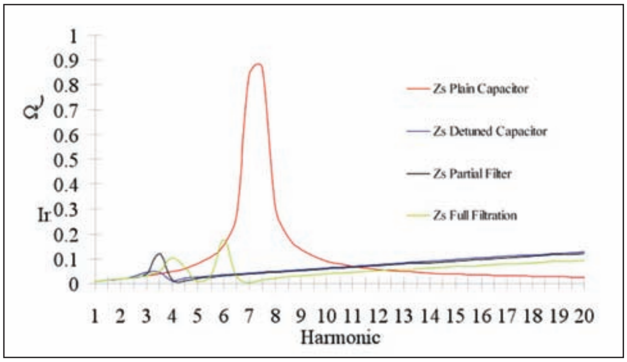
How they are generated: Harmonics are generated by non linear loads which use a part of controlled sine wave and the load current does not vary linearly with voltage. As against this linear loads use complete sine wave and the load current varies linearly with the applied voltage.

What they do: Zero sequence harmonics cause currents in neutral conductors and develop neutral voltage with respect to earth. Negative Sequence Harmonics cause reverse electromotive forces in motors and affect the motor performance. Heating is caused by all three types of harmonics. Harmonics set up high frequency magnetic fields and induce eddy currents in conductors.

Capacitors bear the maximum burden of harmonic currents due to their low impedance values at higher frequencies. Capacitors also set up parallel resonance condition by interacting with system impedance. If the resonance condition occurs near any of the prevailing harmonic frequencies these harmonics are amplified. Some consequences of harmonics are capacitor failures, spurious tripping of thermal relays, measurement errors, higher losses, overstressing and shortening life of transformers, cables and other electrical equipments, erratic operation of controls, change in performance characteristics of electrical and electronic equipments, interference with communication systems etc.



A major cause of concern: Parallel resonance between power factor improvement capacitors and system reactance amplifies the harmonics to alarming levels and the adverse effects of harmonics are magnified. Resonance is a condition with potential for heavy damage and it occurs when the combined impedance of inductive reactance of the system and the capacitive reactance of the system attains maximum value. Indiscriminate use of capacitors leads to resonance at undesirable frequencies and it is the major cause of failures and problems associated with harmonics.

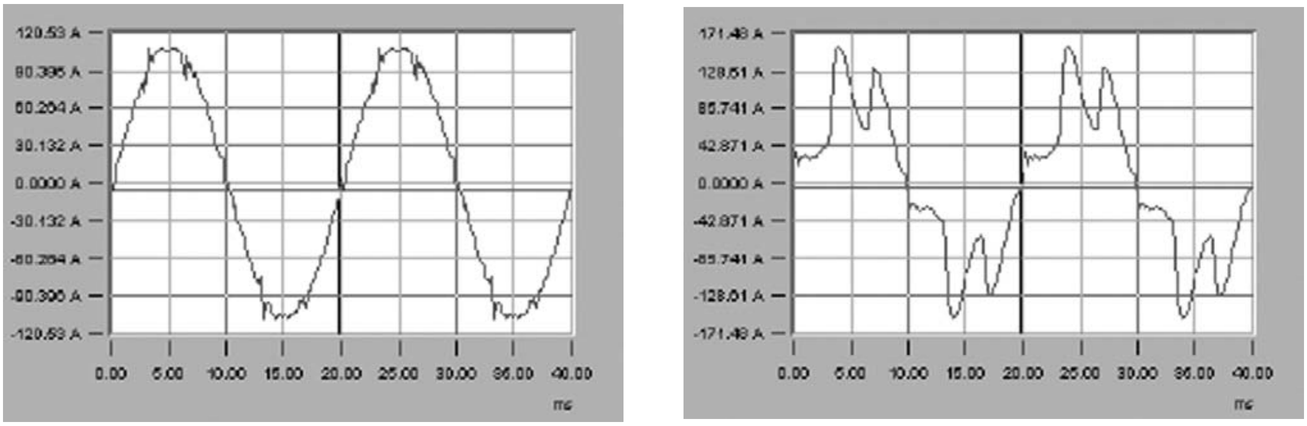


Comparison of Harmonic Resonance Solutions

Objectives of harmonic mitigation: The objectives of mitigating harmonics are: to have all electrical equipments functioning properly with a high probability of meeting normal life expectations; to have operational efficiency and energy efficiency; to maintain power quality; and to meet the harmonic current and voltage distortion limits prescribed by international standards or by utility supply companies.

Methods of mitigating harmonics: Increasing effective source impedance: Harmonic current distortion can be reduced by increasing the effective source impedance relative to individual loads. This is commonly accomplished by adding a series line reactor at the input to various loads such as VFDs.

Harmonic cancellation: A 12-pulse converter uses two 6-pulse bridge rectifiers that are supplied from two different power sources. These power sources are phase shifted by 30 electrical degrees, resulting in cancellation of the 5th and 7th harmonics. Similarly, the 18-pulse converter uses three sets of 6-pulse bridge rectifiers that are supplied from three different power sources, each of which are phase shifted by 20 electrical degrees. This arrangement results in cancellation of the 5th, 7th, 11th, and 13th harmonics.



current waveforms with and without filter

Active Harmonic Filter using IGBTs: AHF analyses the current harmonics in the load side and generates exactly these harmonics in 180-degree phase opposition to cancel out the harmonics. As a result, harmonic currents are supplied from the AHF and fundamental current is supplied from the mains. If the total harmonic current requirement is higher than the capacity of the AHF then it merely limits the harmonics by doing partial correction and leaves out some of the harmonic currents to be drawn from the supply.

Diverting harmonics to an alternate path: Detuned and tuned filters when used in parallel with the loads allow a partial to almost full magnitude of harmonic frequencies to be diverted to them instead of flowing through supply system. This is by far the most effective and most economical and commonly used method of harmonic mitigation.

Detuned Filter: A detuned filter avoids harmonic amplification with normal filtration. A suitably designed reactor connected in series with the power factor correction capacitor is designed to have a series resonance frequency lower than the most significant lowest order harmonic present in the system. This is usually the fifth harmonic order harmonic having frequency of 250 Hz for 50 Hz systems. The net combined impedance of LC combination and system impedance above selected resonance frequency is always inductive and there is no chance of resonance occurrence above this point. However, there is a chance of resonance occurrence at a lower frequency and it may be close to third harmonic but it does not cause any problem as third harmonic being a zero sequence harmonic needs neutral to flow and the capacitors are normally connected in delta.

The LC filter combination serves the dual purpose of shifting resonance to a safe point thus avoiding harmonic amplification and provides an inductive path to higher level frequencies to flow through it. A 7 per cent reactor is the most commonly used Reactor. Its impedance is 7 per cent of the impedance of the series connected Capacitor at fundamental frequency. The tuning frequency of LC series combination is 189 Hz. This LC series combination avoids amplification of harmonics and provides a nominal filtration too. The purpose of this detuned bank is not to significantly reduce harmonic distortion but rather to ensure that the capacitor bank does not resonate with the network impedance. If compliance with harmonic quality regulations is required, alternative measures offering higher filtration capacity are necessary.

Single Tuned Filter: Single tuned filter avoids harmonic amplification with partial filtration. The tuning frequency is 210 Hz or higher. Besides avoiding harmonic amplification it is designed to absorb a significant portion of harmonics. This design usually allows harmonic levels to be brought within IEEE 519 prescribed limits.

Multi Tuned Filter: Multi-tuned filter avoids harmonic amplification with near total filtration. When more than one type of harmonics are significant in the system say 5th and 7th then for each such harmonic an LC series filter combination arm tuned for individual harmonic frequency, here 5th and 7th harmonic, is connected in parallel with the load. This allows a larger portion of harmonics to be absorbed by filters. The resultant harmonic level in the system can be brought down to more stringently designed values. Special care in designing has to be taken here to account for any amplification of 5th harmonic caused by the filter arm designed for filtering 7th harmonic.

Tapped Reactors: It is advisable to use multi tapped reactors instead of single tap construction. This allows fine tuning at site as per actual working conditions and parameters, it also allows retuning under changed load configuration or changed system configuration.

Selection of Capacitors and Reactors: The LC series capacitor-reactor combination provides an inductive path to harmonic frequencies through them thus diverting these harmonics away from the utility distribution system. This requires the capacitors and reactors to be capable of withstanding increased current loadings without deterioration or failure.

Reactors: Reactors dampen effect of transients during capacitor switching, avoid resonance and harmonic amplification and are main constituents of harmonic filtration circuit. A hitherto common practice of using 7 per cent light duty reactors which were mainly meant to provide some protection to capacitors may have to be done away with in favor of appropriately tuned heavy duty reactors which can provide filtration to achieve desired harmonic levels.

The most critical components: Reliability and safety under hostile harmonic environment is the most important requirement for capacitors today. The IEC standards require capacitors to be capable of continuously handling 130 per cent of rated current but in harmonic environment this value can be exceeded and values higher than 200 per cent can only be considered safe. This is now becoming possible with the advent of segmented MPP type low ESR capacitors which have excellent over current handling capabilities. ESR value assumes higher significance in view of high frequency harmonics being handled by capacitors. ESR value had a limited significance when fundamental frequency current was the only consideration. In a harmonic environment higher ESR values lead to significantly higher levels of heating.

Reliability of capacitors in stressful harmonic environment, overload conditions and high operating temperatures is of prime importance for uninterrupted operation of harmonic filtration and power factor correction systems. The segmented film MPP type construction provides enhanced safety and increases service life of capacitor by clearing multiple faults occurring in close proximity within the segment before the heat and pressure developed can cause total isolation through overpressure interrupter. The hostile conditions call for capacitors to have built in over pressure interruption mechanism for safely isolating them during overloads and during end of their service life without destroying them in an unsafe way to save the installation and surroundings from any damages. Here MPP capacitors with continuous technological innovations and developments perfectly fit the bill. MPP capacitors with working life of 200,000 hours are available today.

Problems with APP Capacitors: There are typical problems associated with APP capacitors—absence of inherent safety features; high dissipation factor; high manufacturing tolerances; poor quality of bimetallic end connections; abnormally high operating temperatures; loose winding with trapped moisture and impurities; low power density leading to higher space requirements; and higher CO_2 emission requirements due to higher losses.

The absence of any inbuilt safety mechanism to clear internal faults leads to continued operation under abnormal conditions of over temperature, over pressure and degradation of oil, thus leading ultimately to complete failure under unsafe conditions. The undesirable mode of failure under heavy loads, or at the end of service life has made APP capacitors unusable worldwide for LT applications. The ongoing research for development of HT capacitors with a superior and safer technology may soon phase out APP capacitors for HT applications too.

Harmonic mitigation scheme: The technical benefits of applying harmonic solutions are available upwards of the point of application. Most solutions today are applied by users close to the point of utility company's supply to meet mainly statutory requirements. The harmonic solutions need to be shifted downwards closer to the harmonic generating loads in order to pass on the benefits to both the utility company and the user.

Conclusion: There is increasing presence of non linear loads leading to harmonic generation and their further amplification due to resonance conditions induced by capacitors. To safeguard their installations utility companies are rightly coming out with penal tariff structures to limit harmonics being fed to the grid. Reactive power management systems today need to focus attention not only on power factor correction but also on the power quality aspects. Tariff structures which promote power factor correction aspect alone and lead to indiscriminate use of plain capacitors causing large amounts of harmonics in power systems need to be discontinued in favor of more rational tariff structures.

ABOUT THE AUTHOR

Baldev Raj Narang is an Electrical Engineering Graduate from Delhi College of Engineering, University of Delhi and is currently CEO of Pune-based Clariant Power System Ltd, a company which in association with FRAKO Germany, is engaged in providing solutions in reactive power systems and power quality management to Indian and overseas industrial customers in diverse fields. Narang has previously worked for Indian Oil Corporation and Century Enka Ltd, among others. He can be reached at baldevrajnarang@clariantindidia.co.in

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