HARMONIC AMPLIFICATION

Harmonic amplification is an undesired increase in the magnitude of harmonics beyond the level that is being generated in the system. This in turn amplifies the ill effects of the harmonics. The article briefs how the amplification happens in the network and solutions to avoid this amplification.

Power capacitors are added to the network for improving the power factor. The addition of capacitors results in reduction of system impedance. Capacitive impedance is inversely proportional to frequency (as shown in the figure 1).

Capacitive impedance $X_C = \frac{1}{2\pi fc}$ ---------> Eq 1

Hence the capacitor offers lower impedance for high frequency (250 Hz, 350 Hz, 550 Hz and so on). This results in increase in the magnitude of harmonic currents. This can be practically seen by measuring harmonics at a particular location in the electrical network with and without power factor correction capacitors (APFC panels).

Following are the snapshots of harmonic measurement done at the main incomer, with and without capacitors.

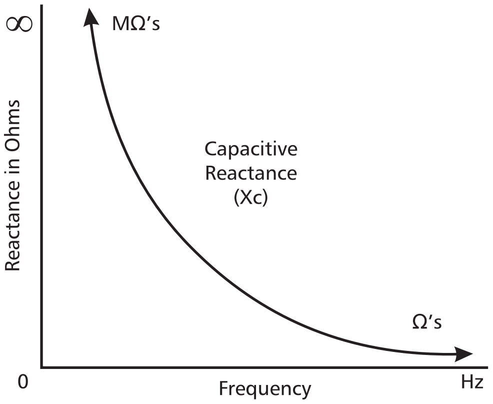
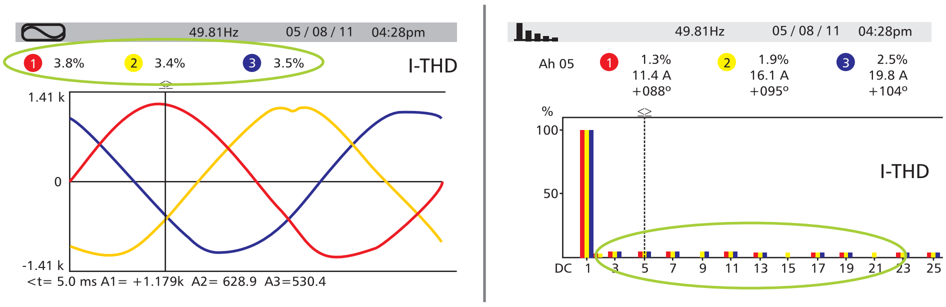


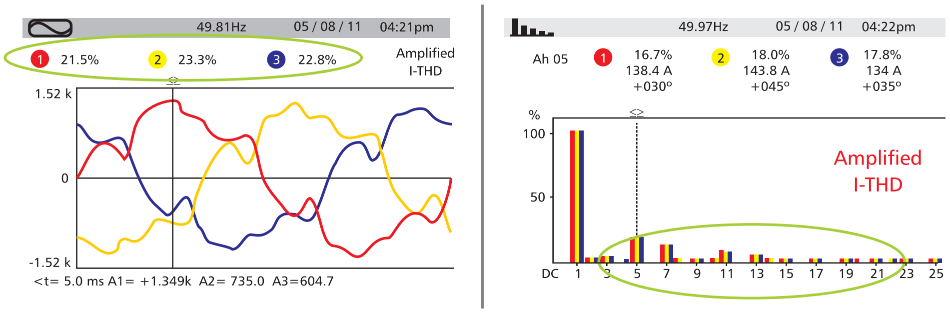
Figure 1

Figure 2: Measurement with APFC Panel OFF



In this case, the power factor, obviously, will be poor. But the harmonic contents are very much within the limit (overall I-THD around 3.5% and 5th harmonic around 2%)

Figure 3: Measurement with APFC Panel ON



As soon as the power factor correction capacitors are connected, the THD value shoots up. The overall I-THD increased from 3.5% to 22% and 5th harmonic increased from 2% to 17%. The absolute magnitude of 5th harmonic amplified from 16 A to 144 A. The distortions in the waveform also indicate the same.

In the above equation (1), for the same set of harmonic frequencies, on adding more capacitors for PF improvement, the capacitive impedance (X_C) will drop further. Again this will result in amplification of the harmonics. If the power factor goes to leading, the amplification will be worse. The unnecessary amplification of harmonics damages power capacitors and over heats switchgear, cables and busbars.

The solutions to prevent harmonic amplification are:

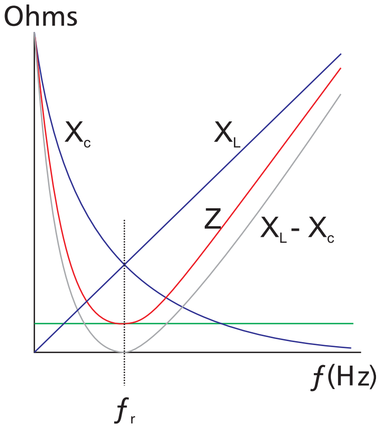
- By connecting a series inductor, so as to form a detuned filter (series LC), the impedance increases, when the frequency increases (as $X_L = 2\pi fL$). The impedance will be high for high frequency harmonics and no amplification will happen. Hence, the THD (with reactor + capacitor) will be less than or equal to the earlier THD levels with no capacitors

- By strictly avoiding leading power factor, the excess addition of capacitors can be prevented and hence the amplification because of this can also be avoided. The optimum power factor of 0.97 to 0.99 should always be maintained always

HARMONIC RESONANCE

Many industries may not generate high harmonics. Sometimes harmonic resonance occurring between power capacitors and transformers causes very high magnification of harmonics. This causes increased rate of failures and over-heating of electrical equipments. This article briefs about the basics of harmonic resonance, a practical case study and solution to avoid resonance.

In a system with inductive (X_L) and capacitive (X_C) impedances, resonance can happen at one particular frequency (resonant frequency, F_R). At this point X_L is equal to X_C and the net impedance is very low. Hence, at resonance point, the magnitude of the current (with frequency F_R) will be maximum and only inherent resistance in the network would limit the current.



In practical network, the resonance is possible because of one of the following reasons:

- Parallel resonance within a given electrical system, involving internally generated harmonics (in the load) and resonance between local capacitors and the predominantly inductive supply (transformers)
- Series resonance involving external harmonics (in the supply system) and resonance between capacitors within electrical system
- Interactive resonance between different harmonics filters within a given electrical network

Typically, the inductance (L, of the transformer)in the system remains almost constant, but the capacitance(C) is varied (in steps) as per the requirement to maintain higher power factor. So, when the capacitance increases the resonant frequency (F_R) drops, as F_R is inversely proportional to square root of capacitance.

$$\text{Resonant frequency } F_R = \frac{1}{2\pi\sqrt{LC}}$$

The lower resonant frequency is dangerous, as it may match with any of the predominant harmonics and cause more damage. Let us see a practical case study of resonance happening between variable PFC capacitors (C) and transformer.

Consider an industry with 1000 kVA transformer of %Z = 5.67% and 750 kVAr APFC panel. The resonant frequency can be calculated from the formula:

$$\text{Resonant frequency} = F_S \times \sqrt{\frac{kVA_{SC}}{kVAr}}$$

Where F_S is the System frequency = 50 Hz

kVA_{SC} is the short circuit power of the transformer $= \frac{kVA}{\%Z/100} = \frac{1000}{0.0567} = 17636\text{kVA}$

kVAr is the power rating of the capacitor connected under the transformer for power factor correction.

Case 1: When 145 kVAr is Connected to the System,

$$\text{Resonant frequency} = 50 \times \sqrt{\frac{17636}{145}} = 550\text{Hz}$$

This frequency exactly matches with 11th harmonic (550 Hz) and results in resonance. Following is the harmonics measurement that depicts the 11th harmonic resonance, where it increases from less than 5% to 25%. This huge amplification will damage the capacitor and other equipments.

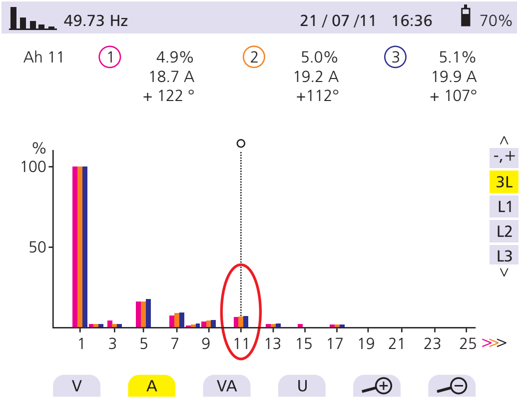


Figure 1: Measurement with APFC Panel OFF

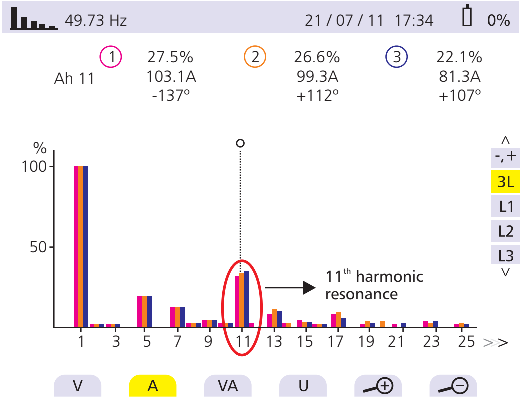


Figure 2: Measurement with APFC PanelON

Case 2: When 250 kVAr of Capacitor is Switched on in the Same Industry,

$$\text{Resonant frequency} = 50 \times \sqrt{\frac{17636}{250}} = 420\text{Hz}$$

In this case, no resonance will happen; hence the amplification level will be less than the case1. If harmonics study is carried at this particular moment, the system would reveal relatively lesser harmonics level (%I-THD)

Case 3: When 700 kVAr is Connected to the System,

$$\text{Resonant frequency} = 50 \times \sqrt{\frac{17636}{700}} = 250\text{Hz}$$

Once again, this frequency perfectly matches with 5th harmonic. Typically 5th harmonic is the least order harmonic with higher magnitude (6 pulse drives). Resonance at this harmonic order would result in even worse damage than the case 1.

From the above cases it is evident that any peculiar problem like frequent failure of capacitors, nuisance tripping of MCCBs, frequent blowing of fuses and over-heating of busbars is, may be because of harmonic resonance. Resonance or worst case THD may not be revealed at the moment of harmonic measurement or troubleshooting. Hence at times, finding the root cause of any such failures is very difficult.

Solution for harmonic resonance is to detune, by using a reactor in series with each capacitor. This detuned filter will forcefully create one resonant frequency, so that the combination offers higher impedance for high frequency harmonics. For example, installation of 7% reactor with each capacitor in APFC panel, will create tuning frequency at 189 Hz. Hence, resonance at harmonic frequencies (5th harmonics and above) can be avoided. Moreover, all the harmonics having frequency above 189 Hz (i.e., from 5th harmonics onwards) will lie in inductive region, where the impedance increases when the frequency increases ($X_L = 2\pi fL$). One important point to note is that all the capacitors in the industry must have similar series inductor; else the overall tuning frequency may not be at 189 Hz.