Traditional and Familiar to everyone. Nevertheless, unpleasant or even dangerous sometime

CASE STUDY

Power Capacitors may be meant to enhance Power Factor, but they will make your system as a curse instead of a boon if incorrectly specified.

Let us see the possibilities of bad impacts with power capacitors and the importance of short circuit current and parallel resonance.

As any Industrial system requires Reactive Power to compensate for the lagging characteristics of inductive power application of Capacitors are common everywhere and also installation of Power Capacitors can reduce the penalties imposed by the utility companies due to low Power Factor resulting into increased Demand in kVA and help pay for the capacitors in a relatively short amount of time.

However, it is not possible to add the power capacitors indiscriminately to a system without understanding how their presence will affect the system.

As any capacitor bank can be a source of parallel resonance with the system inductance before installation of any capacitors calculation of resonance frequency will avoid most of the dangerous incidents due to the parallel resonance, which these also can be considered as harmonic frequency and self-created by the electrical system. To calculate this self-generated harmonic frequency by the system, no need of any load end parameters and even no need to worry about either linear or nonlinear.

However as variable frequency drives (VFDs) for motors, DC power supplies for computers, electronic ballasts for fluorescent lighting, Furnaces, UPS and various non-linear loads are common everywhere even at very small commercial establishment , we well aware that those nonlinear load can create harmonics. Hence, if you don't consider the existence of these harmonic sources and the inductive reactance of the existing system, you'll create the potential for harmonic resonance.

Hence, before connecting any load only with the supply source, Engineers has to calculate and know the exact resonance point and accordingly capacitors has to be installed in the system tp perform this exercise no need to worry about the characteristics of load like linear or non-linear.

However, this first step will considerably helpful when the load is predominant with non-linear load and sometimes with linear load also too and also mainly scientific method of installation of capacitors will ensure the failure free operation and protect from accidents.

A capacitor or group of capacitors and the source impedance have the same reactance (impedance) at a frequency equal to one of the characteristic frequencies created by the loads.

In other words, the system is parallel resonant at a frequency equal to one of the harmonics flowing on the power system.

Generally, harmonic resonance is a steady-state phenomenon triggered by an event in which the harmonic source changes or the source impedance or capacitor size changes, such as if capacitors are switched on or off in steps. When installing power capacitors, you can estimate the resulting parallel resonant frequency, or harmonic order, by using the following equation:

System Resonance Frequency or Harmonic Resonance Frequency or Parallel Resonance

Frequency (Rfreq) = (√MVAsc/MVAR) * Ffund

Where

Rfreq - is the parallel resonant freq. harmonic order

MVAsc- is the fault level of the bus where at the voltage level of all capacitors are connected

MVARcap - is the 3-phase rating of the total capacitor bank installed in the system.

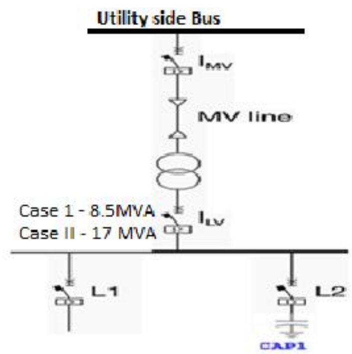

Fig 1 - Identical for the following Case I and Case II

I - CASE – 1

I – 1 - CALCULATED RESULT

One of the system at the Fault level at LV side of the transformer of 8.5 MVA (Calculated from Source @ utility side SS) and Installed capacitors at LV side Total (Including APFC and Fixed – 350 kVAR)

Let's find the resonance frequency

$$(\sqrt{8.5/0.350})*50 = 239\text{hZ}$$

Result from the above -too close to 250 hz - 5thorder

I – 2 - FIELD MEASUREMENT

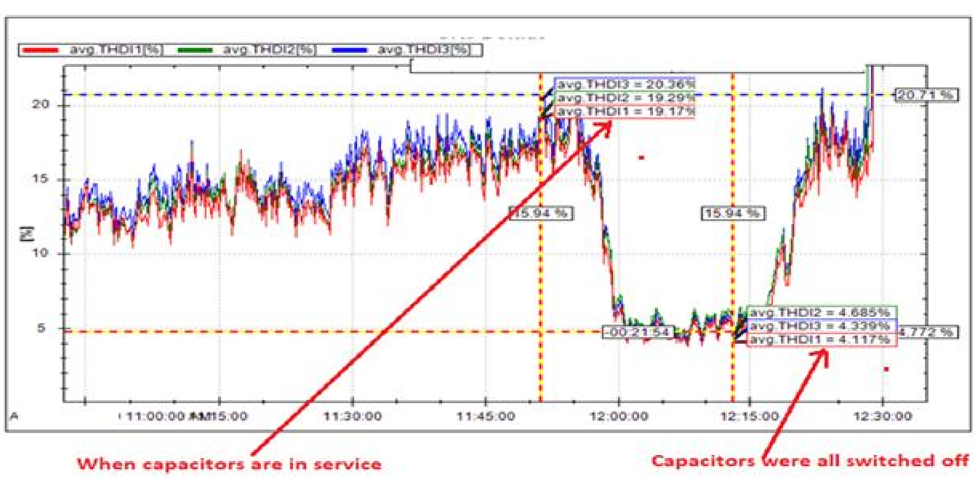

Fig 2 – Total Harmonic Distortion - Current (THD –I)

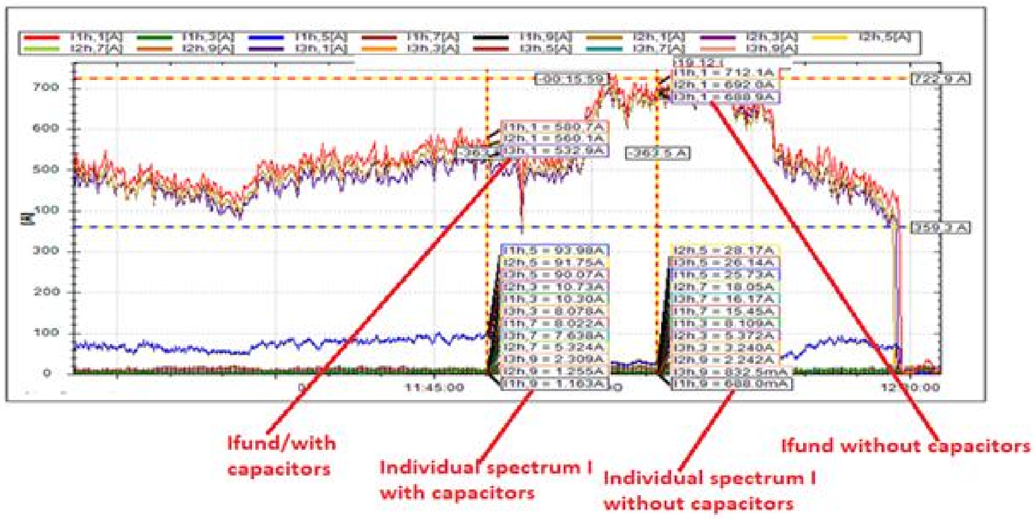

Fig – 3 – RMS and Individual spectrum of current – 5th order current is High

Fig 4 – Total Harmonic Distortion –V (THD-V) With and Without Capacitors

From the above field measurement we can understand

a. THD – I Amplified due to parallel resonance
b. Individual spectrum of current and increased contribution of 5th order confirming the parallel resonance at calculated results, which is without
c. capacitors 5th order current alone was 28.17A, which is 4.0% but with capacitors 99 Amperes – 17% of the RMS current
d. Due to capacitive resonance resulting in to the increase in distortion of voltage also from 2 to 3.6%

II - CASE – II

II - 1 CALCULATED RESULT

Another location there is a Fault level of the at Trafo's LV side of the consumer side bus is 17mVA and the same capacitor rating, which the FL calculated from utility side (source) and considering all conductors in between PCC to Source

$(\sqrt{17/0.36})*50 = 345$ hZ.

From the above calculation Resonance @ 348 hZ – 7th order

II - 2 - FIELD MEASUREMENT

Fig 5 – Total Harmonic Distortion – Current

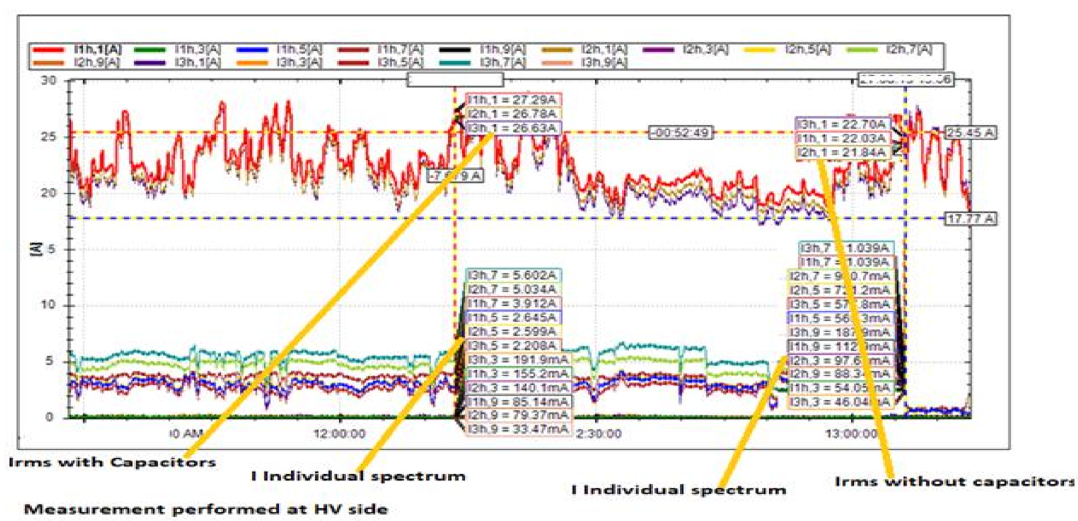

Fig – 6 RMS and Individual spectrum of current

From the above field measurement data,

a. THD – I Amplified due to parallel resonance, which is L1 29, L2 37 and L3 41% with all capacitors are in operation and without any capacitors less than 5.5%. Also unbalance in current during capacitors is in service noticing that some of the capacitors are either defective or any one or two phases of supply is missing.
b. Individual spectrum of current increased contribution of 7th order confirming the parallel resonance as per the calculated results, which is 7th order current alone was 5.6A, - 20% of the RMS current. But without capacitors 1.03 Amperes – 4.5% of the RMS current

III – BACKGROUND

At a given harmonic frequency in any system where a capacitor exists, there will be a crossover point where the inductive and capacitive reactance are equal. This crossover point, called the parallel resonant point, where the power system has coincidental similarity of system impedances. Every system with a capacitor has a parallel resonant point.

Parallel resonance causes problems only if a source of harmonics exists at the frequency where the impedances match. This is typically called harmonic resonance. Harmonic resonance results in very high harmonic currents and voltages at the resonant frequency. It's extremely unlikely that these two impedances are exactly identical, but near resonance can be very damaging as well. If, for example, the parallel resonant point is at the 5thharmonic and a resonance point of source (Calculated) is 5thharmonic current exists on the system, problems are likely to occur and dangerous to the system and operator too.

A capacitor or group of capacitors and the source impedance have the same reactance (impedance) at a frequency equal to one of the characteristic frequencies created by the loads. In other words, the system is parallel resonant at a frequency equal to one of the harmonics flowing on the power system.

Generally, harmonic resonance is a steady-state phenomenon triggered by an event in which the harmonic source changes or the source impedance or capacitor size changes, such as if capacitors are switched on or off in steps.

III - 1 - HARMONIC SEQUENCE

Positive (+)	Negative (-)	Zero (0)
		0
1	2	3
4	5	6
7	8	9
10	11	12
13	14	15

IV - ANALYSIS

IV – 1 - CASE – I

Harmonic order – 5th – 250 Hz

HARMONIC SEQUENCE – (-) Negative

<u>Effects</u> – As any electrical system dominated by 6 Pulse convertors and can be considered as 95% - 5th order will be rich and next will be 7th. As source generated own harmonics due to installed capacitors also at 5th whenever impedance of exact 5th order due to change in load impedance and the capacitive reactance and inductive reactance parallel one to one with each other dangerous effects are prone. Until such any bad effects amplified level of harmonics and particularly on 5th can be seen in these type of locations.

Hence user has to be cautious if 5th is predominant and if they are not interesting to replace their capacitors with tuned system with the resonance frequency of 189hz they can at least shift the resonance frequency by uninstalling or adding few capacitors in the system, through which we can shift the frequency to safe point.

However, losses due to Negative sequence is

a. Negative torque character of this harmonic will over load all the motors, which will increase the thermal loading of all motors in the system even the motors are linear and anywhere in the network as the motor virtually getting the thrust backwards.
b. Overheating of all cables, Transformers, Switchgears and protective relays
c. Transformer cannot be utilized its full efficiency. Overloaded Transformer
d. Overloading of all capacitors
e. Resultant outcome is worst performance in energy efficiency, premature ageing and failure

IV – 2 - CASE – II

Harmonic Order – 7th – 350Hz

HARMONIC SEQUENCE – (+) Positive

Even the load in this location is linear 7th will be dominant

Effects – As the order is Positive sequence all motors will get the acceleration effect in to positive direction, which will generate High temperature.

Under loaded Motors if presence in this location inters harmonics will follow with 7th order due to the high magnetizing current of those Motors, which will result in to more vibration and noise on voltage.

High frequency harmonics tendency is to increase the Skin effect. Due to Skin effect losses on cables will be high.

Skin effect will disturb the communication system and Telephone Interference Factor (TIF) will be high in this type of location.

Power cables carrying harmonic loads act to introduce EMI (electromagnetic interference) in adjacent signal or control cables via conducted and radiated emissions. This “EMI noise” has a detrimental effect on telephones, televisions, radios, computers, control systems and other types of equipment. Correct procedures with regard to grounding and segregation within enclosures and in external wiring, systems must be adopted to minimize EMI.

V - SOLUTION

To avoid the resonance and best practice has to be the installation of capacitors with reactors connected in series. In this L and C combination of Reactive Power compensation an inductive reactance XL of a Reactor is directly proportional to the frequency. The magnitude of inductive reactance will increase with high frequency harmonics thus blocking the harmonic current entering in to the Capacitors. Hence, use of properly designed reactor in series with capacitor will offer higher impedance for harmonics, thus eliminating risk of over load in capacitors.

Though the generic name called as Detuned Filter for the frequencies of 190, 210 and 133, technically speaking these are all also Tuned Filter as these combination of reactor and capacitor tuned to the specific requirement of said frequency.

Also these type of filters with the these standard frequencies (190/210/133) also needs more attention on design and some of the cases either amplification or no reduction on harmonic amplification due to resonance can be seen even after complete replacement of bare capacitors with this L and C combined filters with the said percentage of filters.

Unless understanding the depth and strength of individual spectrum of harmonics and accordingly chosen the linearity of the reactors no standard reactors will perform well and also installing these standard reactors will resulting in to amplification of voltage due to Ferro resonance effect of the reactors due to its insufficient linearity. Hence, Power Quality Analyst and Designer have to be serious and cautious when choosing the right product.

Parallel Resonance – Is it a self-debugging Problem?

Generally, Harmonic resonance is said to be a self-correcting problem. But Most of the times capacitor fuses will open, capacitor cans will fail, or the source transformer fails.

Any of these events will lead to the removal of a component from the system, eliminating the resonance condition. However, they are all undesirable results and often turnout in to serious accident.

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