Harmonic Issues in industry practical approach to solutions

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Solutions to harmonic problems

- If a harmonic problem is noticed in a power system of utility or industries,
  - Several potential solutions can be tried:

- The level of harmonics does not depend upon the value of the harmonic generating load alone; but depends on:
- The source impedance,
- Reactive impedances connected to the system

Source impendence effect
on harmonic distortion limits

- IEE specifies the current distortion limits permitted at the PCC (Point of Common Coupling) based on the ratio of fault level (source impedance) to the harmonic load currents

Table 10.3
Current Distortion Limits for General Distribution Systems (120 V Through 69 000 V)

	Maximum Harmonic Current Distortion in Percent of I_L					
	Individual Harmonic Order (Odd Harmonics)					
I_{sc}/I_L	<11	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where

I_{sc} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.

HARMONIC ENVIRONMENT

- Increasingly the industries, commercial establishments and homes want to cut down energy consumption bills;
- But, desires to have maximum utilization efficiencies.
- To achieve this,
  - Employ Energy Efficient Equipment
- But, a coin has two sides
- These equipments have their own other side
- They pollute power supply and degrade power quality

HARMONIC ENVIRONMENT

- The main outcome is the distortion of voltage and current waveforms
- Creates problem in their own electrical system and also that of the neighboring consumers
- The utility is also greatly affected
- As seen, a distorted waveform envelops integral multiples of fundamental sine waveforms but may be of lesser magnitude
- Various methods for mitigating this harmonics have been employed

HARMONIC ENVIRONMENT EQUIPMENTS

- The manufacturers of these hi-tech energy efficient equipments trying to find ways and means to limit these effects created by their equipments
- But, harmonics cannot be totally eliminated
- As usual, it is a compromise between the tolerance limits and practicably possible solutions
- Equipment manufacturers also design equipments which can tolerate waveform distortion to certain limits.

ELECTRICAL FAILURES

Mainly due to insulation failure.

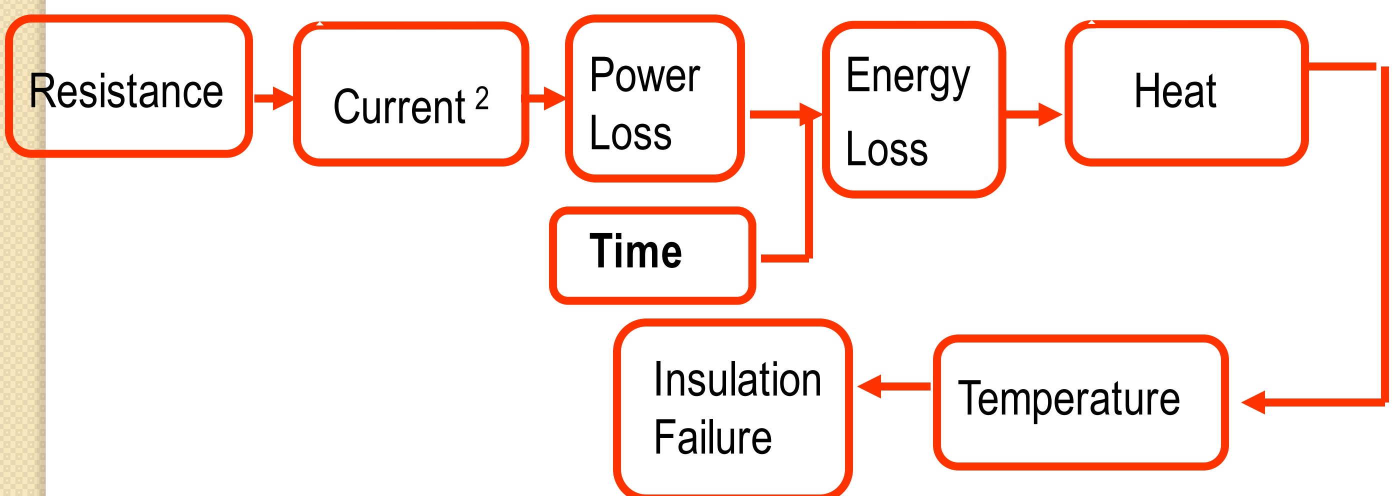
- **Causes:**
- Majority – Due to temperature rise resulting from energy loss
- from heat or thermal effects of current and time duration.
- High current – high power loss
- Higher duration: higher energy loss- higher heat -higher temperature

Heat is proportional to:

- Current^2 X Resistance X Time
- Energy lost - Dissipated as heat.

ELECTRICAL FAILURE MECHANISM

- All protective systems are based on Current^2 & Time
- Rarely – Mechanical Damage.



ELECTRICAL FAILURE

- Power loss is proportional to the square of the current;
- Immaterial, whether the current is in phase with voltage or of fundamental frequency
- Harmonic currents are no exception to this;
- They do not deliver power, but circulate in the system, contributing to energy loss.
- result: higher temperature
- And temperature exceeding the limit for a particular insulation system

THERMAL CLASSIFICATION OF INSULATION

Clas s	Max Temp, ^{o}C	Description of material
A	105	Organic materials such as cotton ,paper, and silk impregnated with varnish. Materials must be proved suitable for this temperature.
B	130	Mica, glass fiber, asbestos with suitable bonding substances and varnishes, or materials proved suitable for this range.
F	155	Materials, organic or inorganic, which have been proved for this temperature.
H	180	Silicone elastomer, mica, glass fibre, asbestos, etc with suitable bonding substances such as appropriate silicone resins.
C	Over 220	Entirely inorganic materials.

ELECTRICAL FAILURE

- Most of the protective schemes are based on this, I.e. I^2t, resistance being almost constant.
- But added disadvantage with harmonics, is they increase the resistance also, by skin and proximity effects.
- Hastens failure, reduce useful life

Mitigating harmonics

- There are several methods practiced to mitigate harmonics
- For major problems, harmonic filters are employed.
- There are two major types:
  - Active filters
  - Passive filters

Disadvantages:

Active filters exceptionally expensive

Passive filters –since the harmonic currents are diverted thro low impedance path, involves high I^2R loss.

Practical solutions

- Harmonics to a certain extent can be mitigated or avoided from proliferation and confined to local circuits.
- by selecting equipments designed to work in harmonic environment to withstand harmful effects of harmonics
- Magnitudes can be moderated by system re-configuration

Practical solutions

CASE STUDIES

CAPTIVE POWER GENERATORS AND HARMONICS

Generators for large lighting installations:

- discharge lamps with inductive chokes etc generate 30% third harmonics
- If generated voltage contains 3% harmonics, with harmonic loads waveform may worsen
- Even in a well balanced three phase lighting system 20% 3rd harmonic may exist in each phase.
- 3rd harmonics are of additive nature; in the neutral it will be 60%..
- will heat up the machines and neutral conductors
- but the fundamental current may be zero

CAPTIVE POWER GENERATORS AND HARMONICS

- Eg: A carefully balanced 250 kVA fluorescent lighting load in a warehouse.
- fed from the public utility - 13% of full load line current observed in the neutral
- fed from 320 kVA stand by generator - current increases to 250 Ampere (72% full load current)
- due to high third harmonic content in the generator output waveform
- The solution was to replace 11/12 pitch of the stator winding by 2/3 pitch
- The neutral current was below than the value when supplied from the utilities

CAPTIVE POWER GENERATORS AND HARMONICS

Sizing generators for non linear loads:

- Simple rules of the thumb is to oversize the standard generators for the load to be catered
- Some allow 50% non linear loads
- But, manufacturers should be given full information of non linear loads while ordering
- The crux of the problem - one of the generating impedance
- Current harmonics of non linear loads are constant – do not depend upon the power supply

CAPTIVE POWER GENERATORS AND HARMONICS

- But voltage distortion is a direct function of generating impedance
- The stator pitch configuration have varying reactance for each harmonics
- Hence evaluating the voltage distortion for all harmonics individually is necessary
- These distorted voltages affect the performance of AVRs affecting their stability
- PMG excitation system has improved this situation
- The power to the AVR is constant irrespective of generated output

CAPTIVE POWER GENERATORS AND HARMONICS

- Designing generators with specific winding pitches and low reactance is not quite commercially viable
- Hence practical solution is to derate the standard industrial generators
- Some reputed manufacturers select a 0.12 p.u. subtransient reactance as a good practical solution
- The basics; 6 pulse VFD motor drive with 26% current distortion

CAPTIVE POWER GENERATORS AND HARMONICS

- The power drawn is a function of the fundamental current only
- Harmonic current increase the total RMS current without increasing the power
- Discrepancy arise between ammeter reading and voltmeter reading
- Standard power factor meter measures displacement power factor only
- They may show a unity power factor while infact the real power factor may be as low as 0.70

POWER FACTR AND HARMONICS

Actual power factor:

- Product of distorted and displacement power factor
- Conventional power factor is Watts/Voltamp – Cosine of the angle between current and voltage
- This is really a displacement power factor
- But in harmonic currents, power factor as Cos ϕ does not hold good
- Because there are many harmonic currents flowing in the circuit
- If the total RMS value of the current is taken into consideration the power factor value may become worse

Harmonics and induction motors Crawling phenomenon

- in induction motors especially the squirrel cage type motors, there is a tendency of the motor to run stably at speeds which are nearly one-seventh of the synchronous speed,
- this phenomenon is known as crawling.
- crawling occurs when actual speed = 1/7 * sync speed
- or in other words when the percentage slip = 85.71%

induction motors Crawling

- why does a motor rotate at 1/7th of the sync speed or why does it crawl?
- Stator windings of the motor produces rotating magnetic flux
- This acts as a driving force to rotate the stator.
- Ideally this flux should be a pure sine wave but in actual practice it is not so.

induction motors
Crawling

- it is a complex wave which consists not only of the fundamental frequency but also contains odd harmonics which either rotate in forward or back direction at a speed which is in proportion to the harmonic. So for example say a 7^{th} harmonic would revolve at a speed of Ns/7 where Ns is the synchronous speed.

induction motors
Crawling

- The main odd harmonics which affect rotor motion are the 3rd, 5th and 7th harmonics.
- The 3rd harmonic is normally not present in a balanced 3 phase system so only 5th and 7th come in the actual picture.
- Out of these two the braking effect produced by the 5th harmonic is insignificant since they have a phase difference of -120 degrees in the three stator windings, and it revolves at Ns/5 speed in opposite direction of main harmonic.

induction motors
Crawling

- Similarly the 7^{th} harmonic phase difference in three stator windings is +120 degrees and there is a forward rotating field whith speed Ns/7 in this case.
- So the overall effect is the combination of the main harmonic and this 7^{th} harmonic.
- the 7^{th} harmonic reaches its maximum positive value just before the $1/7^{th}$ synchronous speed and becomes negative after that. Hence the resultant torque shows a dip

induction motors
Crawling

- So if the motor is loaded at constant torque due to external mechanical engagement, it is quite possible that motor torque is lower than that applied torque. In this case the motor will not accelerate to its normal speed but continue to rotate at 1/7 speed which is exactly what crawling means.

CAPACITORS AND HARMONICS

- Capacitors are the worst affected by harmonics
- They fall prey to the harmonics since the reactance is indirectly proportional to the frequency
- Capacitive reactance = $1/2\pi fc$
- I.e. the reactance decreases with the increase in frequency
- Higher harmonics means higher current, higher heating and failure
- By design capacitors are capable of withstanding 1.3 times the nominal RMS current

CAPACITORS AND HARMONICS

- Capable of **1.3 times the nominal current,** at nominal voltage and frequency.
- The excess is to take care of harmonics to certain degree and excess voltage
- But capacitors are designated for harmonic environments
- The criteria is the ratio of harmonic creating source (Non linear loads, SH) to that of the power source, I.e. transformer kVA (ST) etc.
- The network can be defined by SH/ST
- The table below gives the type of capacitors to be selected

SELECTION OF CAPACITORS
BASED ON NON LINEAR LOADS

Type of supply	Pollution criterion	Type of capacitor to be used
Low level of interference	if $\frac{SH}{ST} \leq 15\%$	Standard type
Moderate level of interference	if $15\% < \frac{SH}{ST} \leq 25\%$	H type
High level of interference	if $\frac{SH}{ST} > 25\%$	*SAH type anti-harmonic reactors *FH type harmonic filters

CAPACITORS AND RESONANCE

- The impedance of any power distribution system is inductive in nature because of the elements being transformers, motors etc.
- Inductive reactance forms major portion of the total impedance
- Adding a capacitance in a circuit changes its impedance, because capacitive reactance is in direct opposition to the inductive reactance
- It reduces the total impedance of the circuit, since it is of subtractive in nature

CAPACITORS AND RESONANCE

- Both the inductive reactance and capacitive reactance are frequency dependent
- While the former increases, the later decreases according to the frequency increment
- At certain typical frequency the reactance of both may become equal
- At this point the total circuit impedance becomes zero
- This is called resonance
- This is a dangerous situation, very large currents will flow and create havoc in the system

CAPACITORS AND RESONANCE

While adding capacitors to a system careful attention should be paid to avoid resonance

- The capacitor may resonate with the transformer of the distribution section and also with the source impedance
- By deliberately adding inductors, popularly know as reactors the resonate frequency can be shifted away from the harmonic frequencies present in the distribution system
- Certain thumb rules are available for selecting the reactors but for bigger systems a detailed examination has to be done

Transformers with special connections

- Different transformer connections can eliminate certain harmonic orders, as shown below:
- A Dyd connection suppresses 5th and 7th harmonics
- A Dy connection suppresses the 3rd harmonic
- A DZ 5 connection suppresses the 5th harmonic

K-Factor

The amount of harmonic disturbance caused by a device is known as the K-Factor.

- The higher the K-Factor, the greater the harmonics.
- The devices that have the highest K-Factors are personal computers,
  - computer terminals,
  - mainframe computers and
  - AC variable drives.

K-Factor

- weighting of the harmonic load currents according to their effects on transformer heating, as
- The higher the K-factor, the greater the harmonic heating effects.
- it is sometimes necessary to de-rate the transformer capacity to avoid overheating and subsequent insulation failure.
- increased eddy currents caused by the harmonics increase transformer losses

K-Factor

- the RMS load current could be much higher than the kVA rating of the load would indicate. Hence, a transformer rated for the expected load will have insufficient capacity.
- The K-Factor is used by transformer manufacturers and their customers to adjust the load rating as a function

K-factor transformers

A value used to determine how much harmonic current a transformer can handle without exceeding it's maximum temperature rise level.

K-factor values range from 1 to 50. K-factor of 1 is used for linear loads only, and

A K-factor of 50 is used for the harshest harmonic environment possible.

Capacitors and harmonics

- Harmonics can damage power-factor correction capacitors, so a successful capacitor installation may require harmonic filtering—either active harmonic filters, passive harmonic filters, flux shifting transformers or other mitigating tactics. Without such protection, a tuned resonant circuit could cause the capacitor to fail, or even explode. However, the added expense can drive overall costs up significantly.

Capacitors and harmonics

- Capacitor failure can, in many cases, be directly linked to harmonic content in the electrical-distribution system. Capacitors are low-impedance devices susceptible to harmonics, and large harmonic currents in the electrical system can over heat the units, causing untimely failure.

Capacitors and harmonics

- A capacitor bank, itself, can contribute to harmonics problems.
- Parallel resonance between the capacitor bank and the source impedance can cause electrical-system resonance, resulting in higher-than-typical voltages and currents within the overall distribution system. Inductive and capacitive reactance vary directly, and in an opposite manners, with changing frequency:

Capacitors and harmonics

- At higher frequencies, inductive reactance increases and capacitive reactance is reduced.
- Formulas for inductive and capacitive reactance:
- XL (inductive reactance) = 2 π f L
- XC (capacitive reactance) = 1/ 2 π f C
- [Note: f= frequency]

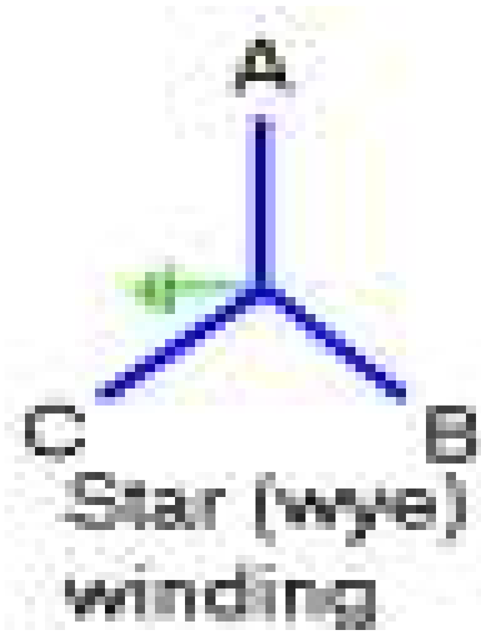
Capacitors and harmonics

- Most problems in industrial facilities with large motors and variable-frequency drives occur when the resonant frequency approaches the 5th or 7th harmonic.
- These harmonics are common distribution systems incorporating 6-pulse IGBT adjustable speed drives.
- In these cases, capacitor banks should be resized to shift the resonant point to another frequency.

Capacitors and harmonics

- Examining the distribution system's harmonic content and sizing the capacitor so
- the resonant point is not at common harmonic levels
- will ensure that the correct capacitor system will be specified and installed.
- However, determining the power system's resonant frequency requires analysis and modeling based on equivalent electrical circuits.

Zigzag transformer



Zigzag transformer

- special purpose transformer with
- a zigzag or 'interconnected star' winding connection.
- Its applications are
- derivation of a neutral connection from an ungrounded 3-phase system and the grounding of that neutral to an earth reference point
- and harmonics mitigation.

Zigzag transformer

- It can cancel triplet (3rd, 9th, 15th, 21st, etc.) harmonic currents to supply 3-phase power as an autotransformer (serving as the primary and secondary with no isolated circuits),
- and to supply non-standard phase-shifted 3-phase power

Conclusion

- It may not always be necessary that filterf are to be employed to suppress the harmonics in a power distribution system
- All possible simper and practical methods may be resorted to before embarking on an expensive filtering g system as discussed