HARMONICS

Presentation By

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Harmonics in Electrical Power Systems
A Major Power Quality Issue

The Scenario Today

- The quality of power has always been a concern for the users as well as utilities.
- There has been increased awareness and concern about the power quality over the last few years.
- The proportion of nonlinear loads has risen over the years. Some estimates indicate the reversal of this proportion from 30% to 70 %.

The two major factors that have changed the scenario completely are

1. Use of Variable Speed Drives

- In order to achieve higher operating efficiencies of electrical loads use of variable speed drives has become a norm.
- The VFDs inject harmonics in the power system and cause deterioration of power quality and at the same time they being sensitive to the quality of power also bear the impact of poor power quality.

2. Use of Power Factor improvement Capacitors

- There is increased use of PF improvement Capacitors to reduce losses and to optimize the use of installed Generation and distribution infrastructure.
- Utilities encourage this practice by way of incentives. The capacitors lead to amplification of harmonics which are present in the system due to non linear loads. The parallel resonance between PF capacitors and system inductance at harmonic frequencies causes this amplification of Harmonics.

How the Harmonics spread in the system

- The utilities do not generate any harmonics; these are **generated by loads at user end**.
- All the users who experience harmonics in their system may not necessarily be generating these harmonics themselves. **Users having non linear loads generate harmonics**.
- If the measures to eliminate these harmonics are not in place at the user end then these harmonics are pumped into the utility network and in turn they find their way to all the other users on the same system.
- The **nonlinear loads act as Harmonic Current generators**. These harmonic currents are **injected into the power system and produce voltage drops** for corresponding harmonics across the series impedance of the power distribution system.

Where to apply Harmonic Mitigation Solution

- The ideal place to mitigate current harmonics is at **the point where they are generated by non linear loads**.

- This practice is very cost effective and an optimum solution normally consist a combination of filter units at Load DBs, Main DB and MV side of transformer.

Harmonics – a continuous power quality issue as compared to other power quality problems which are transient in nature

- Transient phenomena such as sags, swells, Flicker, Surge, Notch etc. are undesirable momentary events and the power system returns to normal steady state after they disappear.
- **Harmonics** on the other hand are induced in the power system **by non linear loads and become a permanent steady state feature of the system and need solutions** such as **Active Filters** or **Passive filters** to treat them on continuous basis.
- **Harmonics appear with continuous loads** and **transients** occur due to **temporary system** changes such as **capacitor switching** etc.
- Transients and Harmonics are two different phenomena which are to be independently analyzed and treated.

Phase Sequence of Harmonics

- The unbalanced set of phase currents or voltages can be assumed to be made of three sets of symmetrical components
  - **Positive Sequence** Components 7, 13, --- displaced by 120 Degrees from one another having same phase sequence as that of fundamental component
  - **Negative Sequence** Components 5, 11, 17 ----displaced by 120 Degrees from one another having phase sequence opposite to that of fundamental component
  - **Zero Sequence** Components 3, 9, 15, ---- Zero Sequence Harmonics which are odd multiples of three are also termed as Triplen Harmonics.
- All these types of Harmonics cause heating losses.
- **Positive Sequence Harmonics** add to the electromotive force of moving machines and result in **increased speed** whereas **Negative Sequence Harmonics** oppose the electromotive force of fundamental component and result in **decreased speed**.
- Triplen Harmonics have distinct character and need special treatment. **Triplen Harmonic phase components add together and flow through the neutral thus overloading the neutral.**
- **The neutral loading increases further with unbalanced and single phase loads** where the unbalance part of the current flows also through the neutral. The strengthening of neutral is required to increase the current carrying capacity of neutral network. It is a common practice now for certain power systems such as IT installations to have five core power cables with two cores for neutral connection.

Measurement of Harmonics THD and TDD

- Harmonic current distortion **THD is a measure of current distortion with respect to fundamental component of current** flowing through the load during the measurement.

- The current THD value does not give a true picture of the potential threat to the installation. A non linear load such as a VFD may be generating a very heavy distortion at a light loading condition with respect to fundamental but the distortion may not be significant enough as the magnitude of the harmonic current is low despite the relative distortion being high.

- **The true measure of severity of Harmonics** to the installations is represented by **TDD** i.e. Total Demand Distortion. **TDD is the current distortion with respect to the fundamental component of the peak demand current**.

- IEEE592-1992 standards are based on TDD values.

How Harmonics affect Power System

- All power system parameters are defined with respect to fundamental frequency under ideal sinusoidal conditions. Under influence of harmonics the system no longer operates in sinusoidal conditions. All system parameters RMS Voltage, RMS Current, Power Factor need to be applied with correction factors to get true values.
- Harmonic distortion causes harmonic current components in addition to fundamental current to flow through the system. **These harmonic currents** do not produce any useful work but instead **cause losses in the power system components.**

Harmonic Generating Loads

Some of the Harmonic Generating loads are

- Variable Frequency Drives
- DC Drives
- Electronic Ballasts for Lighting
- Arc Furnaces – Harmonics are produced due to non linear voltage current characteristics of the arc.
- Saturable Devices – Nonlinear magnetizing characteristics of core generates harmonics. Harmonics are nominal and minimum at rated current and increase at light load conditions.

Direction of Harmonic Flow

- **Harmonics flow from the harmonic generating loads to the power source.**
- This occurs as the power system impedance encountered by harmonics is very low.
- Connection of power factor correction capacitors alters this flow as the capacitors provide low impedance to harmonic frequencies and act as sink for the harmonic currents.

Impact of Harmonics

Capacitors

- **A Capacitor is the first item that fails or deteriorates in a harmonic environment.**
- This is **due to** the fact that capacitors offer **very low impedance to harmonic frequencies.**
- Frequent failure of capacitors should be taken as a **warning sign of harmonic pollution.**
- To withstand harmonic environment **IEEE standards** specify continuous ratings of capacitors to be **135 % of nameplate KVAR**, **110 % of rated RMS voltage**, **180 % of rated RMS current** and **120 % of peak voltage**.
- Self protecting MPP Capacitors with features like Overpressure interrupter mechanism and Segmented Film are preferable. Use of extra low ESR Capacitors having very high, about four times the rated current handling capabilities and almost no heating/temperature rise is ideal in harmonic environment.

Impact of Harmonics Contd.

Transformers

- **Harmonic** distortion causes additional **heating of transformers.**
- The RMS current in presence of harmonics is higher than the rated value and causes increased heating of conductors.
- **Eddy currents** in winding, core and other conducting parts **caused by harmonic currents add to eddy current losses**.
- The core losses which are a function of applied voltage also increase due to voltage distortion. **ANSI /IEEE standards specify guidelines for sizing of Transformers to work in harmonic environment.**

Impact of Harmonics Contd.

Motors

- **Magnetic fluxes caused by Harmonics in the motor body do not significantly affect the motor torque but induce high frequency currents in the rotor.**
- This causes **increased heating**, **decreased efficiency**, **vibration and abnormal noise**.
- If the distortion is within **IEEE 519 norms** no derating is needed.
- Higher voltage distortion levels of say 8 percent or more should be corrected by suitable measures to avoid excessive heating.

Impact of Harmonics Contd.

Communication circuits

- Inductive coupling of electrical and communication circuits can often lead to induced voltages at frequencies which are within voice communication bandwidth thus disturbing the communication quality.

Impact of Harmonics Contd.

Metering

- Utilities charge customers for **unit consumption** and **maximum recorded demand**.
- **Harmonics affect the accuracy** of **both these metered quantities**.
- Present day digital meters are capable of measuring harmonic components; however they may be set to measure only fundamental component.
- The user needs to ensure that the setting is appropriate and there is no excess billing due to harmonic losses. The Demand Meters may have higher errors if the current distortion is high. It is necessary to ascertain that the harmonics are accounted for in the meter design and setting.
- Conventional magnetic disc meters record both fundamental and harmonic power. Ideally the harmonic power which is fed back to the grid should be subtracted from the total recorded power but it is not done.

Impact of Harmonics Contd.

- **Performance Characteristics of Electrical and Electronic Equipments**
  - All Electrical and Electronic equipments and systems are designed to operate at fundamental frequency
  - and Harmonics adversely affect their performance characteristics resulting in their erratic operation and reduced efficiency.

Impact of Harmonics Contd.

Neutral Overloading

- Triplen Harmonics produced mainly by single phase non linear loads flow through neutral connections.
- Neutral current values can be as high as twice the phase current values.
- Strengthening of Neutral system is required in installations. In commercial buildings and IT installations use of five core power cables having two neutral cores as against standard three and a half core cables is normal practice.

Harmonic Mitigation solutions at user facility

- Non linear loads, the source of Harmonic generation are located at the user facilities.
- The problems encountered due to Harmonics are more pronounced at the user facilities.
- This is not to say that utilities are immune to the ill effects of harmonics.
- When unchecked harmonic currents find their path to utility distribution system they lead to higher losses in the system, overloading and even failures of distribution transformers.
- The measures commonly used for Harmonic Mitigation at the load installations are Passive Filters, Active Filters and Special Purpose Transformers.

Harmonic Mitigation solutions at user facility—Contd.

There are also simple and inexpensive measures such as:

- Altering Capacitive KVAR injection in either direction
- Adding a line reactor
- Foregoing PF improvement and associated consequences of incentives and penalties by reducing Capacitors in the system. This can sometimes be employed as an ideal temporary solution till a better solution is installed.
- Distributing linear and non linear loads on individual transformers instead of loading them exclusively with linear or nonlinear loads

Harmonic Mitigation solutions at user facility--Contd.

- All the above measures change the frequency response of the system and eliminate a resonance occurrence which is most often the cause of unacceptable harmonic levels.

- The harmonic solutions can be employed at the point of harmonic generation i.e. across loads at LT mains or on HV side of the transformer.

- The ideal place is the load itself to get maximum benefits by way of more reduction in losses but this option is not preferred due to larger capacity requirements of scattered solution units. The solutions at main LT bus are easier, economical, practical, offer reduced transformer losses and are thus more prevalent.

- The solutions on HT side of the transformers are least expensive but do not offer loss reduction and are used in combination with LT solutions to have an optimum mix.

Harmonic Mitigation solutions at user facility--Contd.

- To minimize harmonic mitigation requirements it is advisable to specify allowable harmonics while ordering non linear loads like VFDs, DC Drives, UPS, and Induction Furnaces etc. When simple measures elaborated above are exhausted more serious, complex and dedicated solutions are employed.

- Here again Passive Filter solutions should be exhausted first before attempting to employ Active Filter solutions which are more expensive, do not offer economical reactive compensation and have large number of components which go into their production reducing their relative reliability compared to passive filters.

- Passive Filter solutions use fewer components, mainly Reactors and Capacitors; are more robust and simultaneously provide economical Harmonic mitigation and reactive compensation.

- Lastly fine correction of left over Harmonics by Active Filters gives an optimum combination of Passive and Active filters.

Shunt Connected Tuned Passive Filters

- A single tuned combination of a Reactor connected in series with a PF improvement Capacitor is the simplest filter circuit and is most commonly used.
- This configuration connected in parallel to the loads is very economical and is mostly sufficient for majority of applications. A 7% detuned Reactor Capacitor combination is most widely used.
- The tuning frequency here is 189 Hz. It effectively avoids resonance at a critical harmonic frequency thus preventing harmonic amplification but it hardly provides any significant harmonic filtration.
- A shunt connected Passive Filter tuned closer to the targeted harmonic frequency say 230 Hz for fifth Harmonic frequency of 250 Hz performs both functions that of avoiding harmonic amplification and of filtering significant harmonic content

Shunt Connected Tuned Passive Filters—Contd.

- A tuned filter takes upon itself the burden of absorbing a large Harmonic content in addition to fundamental current and thus it is required to be sufficiently oversized.

- This filter design creates a parallel system resonance below the frequency which is being targeted for filtration.

- This necessitates that the tuning frequency is kept below the targeted frequency and this margin should be adequate to take care of tolerances / degradation / changes in value with temperature of Capacitors and Reactors. If this precaution is not taken during design stage and the tuning frequency is made same as the frequency being filtered than the minor changes in component parameters described above may shift the parallel resonance condition at the frequency being filtered.

- This will present a dangerous situation and the purpose of putting filter will not only get defeated but it will magnify the problems.

Shunt Connected Tuned Passive Filters—Contd.

- The detuned / tuned passive filters are designed normally having tuning frequency below 5th harmonic frequency which in most cases is the most dominant harmonic frequency present in the loads.

- In this case the parallel system resonance occurs between third and fourth harmonic frequencies.

- This entire range between third and fourth harmonic frequencies is considered safe as only third harmonic frequency is likely to be present in this range and this being a zero sequence frequency requires neutral to flow which is not available in Delta connected LT Capacitors.

Shunt Connected Tuned Passive Filters—Contd.

- If the passive filter design is done for seventh harmonic than the parallel resonance frequency most likely falls near fifth frequency.
- This is most undesirable place for parallel resonance to occur as the fifth harmonic frequencies are largely available in the system.
- Thus seventh harmonic filters are not provided as independent units.
- Wherever it becomes necessary to provide seventh harmonic filter it is normally accompanied by a fifth harmonic filter also.

Shunt Connected Tuned Passive Filters—Contd.

- The filters need to be adequately oversized if they have to work on own generation supply as against Grid supply.
- The system impedance for small generators is higher than that of a Grid system which amplifies even insignificant harmonics and leads to higher voltage distortion at the bus.
- The higher levels of bus voltage distortion puts extra burden on the filters. It is often advisable not to use filters for small generator connected loads.

Series connected Tuned Passive Filters

- As against shunt connected tuned filters these are not commonly used and have limited applications.
- A series connected filter is tuned to a particular frequency to be filtered out and is connected in series with the load. The filter offers maximum impedance to the tuned frequency which is thus blocked.
- The Reactor Capacitor combination is connected in parallel and the tuning is done at the desired frequency.
- As the filter is in series with the load it has to carry the full load current. The load current has to overcome series impedance of filter at fundamental frequency and a voltage drop occurs across filter.
- The series impedance of a series filter at fundamental frequency is designed to be low to allow the fundamental current to flow easily and also to limit voltage drop and losses across it.

Active Harmonic Filters

- As against passive filters which divert the path of harmonics through them and do not allow them to flow back to the power system the Active Filters kill the harmonics by cancelling them with 180 degrees out of phase currents.

- There is no scope of an adverse parallel resonance occurrence with the system while using Active Filters.Their working is independent of system impedance values.

- As Active Filters are highly priced they can be used as hybrid combination with passive filters to optimize the cost.

- It is possible to easily achieve up to 80% filtration with passive tuned filters and balance 20% fine correction with Active Filters.

- The advantages of Active Filters as compared to Passive Tuned Filters are that they can handle multiple harmonics, can address Power Quality issues like flicker and unbalance.

- They are also useful in cases where the existing PF values are good and no further reactive power injection is possible.

- They can also be programmed to inject capacitive or inductive power for unused filtration capacity. One of the major problems being faced with Active Filters is their derating and failures at higher temperatures.

Role of Utilities

Though the aspects of Power quality and power reliability are interconnected but the power quality should not be confused with power reliability. The emphasis by utilities is mainly on maintaining continuity of power. The users of harmonic generating loads dump these harmonics in the power system which in turn find their path to all loads on the utility. The pollution of power system goes unchecked in the absence of any effective measures by the utilities that remain more focused on maintaining continuity of power. Utilities need to take up the responsibility of maintaining power quality in line with IEEE519 norms. The end users who suffer due to poor quality of power being fed by utilities need to build up pressure on the utilities and hold them accountable for their losses, equipment failures, spurious trippings etc. The utilities in turn need regulatory norms to discipline consumers who pollute the power system. The regulations today favor maintaining good power factor by way of PF incentives or KVAH billing. This practice leads to indiscriminate use of PF improvement Capacitors thus increasing Harmonic pollution in the power systems. In the absence of penal provision for excessive harmonics, KVAH based billing encourages Harmonic pollution. Utility tariff structures play a very important role in maintaining good power quality and thus tariff structures need to be rationalized to discourage power utilization practices that cause poor power quality.

Some Case Studies

The table below gives three typical case studies.

In the first case of TAAL hybrid solution is provided to get ATHD harmonic reduction from 24.11% to 3.8% and Power Factor improvement from 0.94 to 0.993.

Maximum reactive power that could be injected with tuned filter alone was not adequate to bring down the ATHD to desired level of less than 5%. Total filtration with Active Filter would have needed Active Filter capacity of 200 Amps without any improvement of power Factor. The ideal combination of Active Filter and Passive filter ratings was selected to get optimum performance at minimum cost.

Some Case Studies—Contd.

- **In the second case of Mylan Laboratories** the initial Power Factor of load on UPS was 0.99. The total filtration was achieved by Active Filter as no reactive power could be further injected into the system with passive filter.

Some Case Studies– Contd.

- **In the third case of Laxmi Rolling and Strips Pvt Ltd** the complete filtration was possible with passive tuned filters. Fixed passive tuned filter at HT and a combination of Automatic and fixed compensation on LT was employed to increase Power Factor from 0.93 to 0.98 and ATHD reduction from 45.9% to 6.6%.

Taneja Aerospace & Aviation Limited (TAAL), Hosur (TN) (Aircraft Manufacturing)	Before Installation			After Installation		
	VTHD	ATHD	PF	VTHD	ATHD	PF
	1.1	24.11	0.94	0.8	3.8	0.993
Solution provided (Hybrid)	300KVAr @ 525V AHPFC + 100A Active Harmonic Filter					

Mylan Laboratory Limited, Taloja (MH) (Pharmaceutical Company)	Before Installation			After Installation		
	VTHD	ATHD	PF	VTHD	ATHD	PF
	1.3	42.5	0.99	1.2	7.9	0.99
Solution provided (Active)	100A Active Harmonic Filter					

Laxmi Rolling & Strips Pvt. Ltd. Hosur (TN) (Steel Manufacturing)	Before Installation			After Installation		
	VTHD	ATHD	PF	VTHD	ATHD	PF
	2.1	45.9	0.93	1.9	6.6	0.98
Solution provided (Passive)	1500KVAr@42.5KV HT HF + 750KVAr@525V RTPFC + 2*300KVAr@525V Localized Tuned Filter					

About the author

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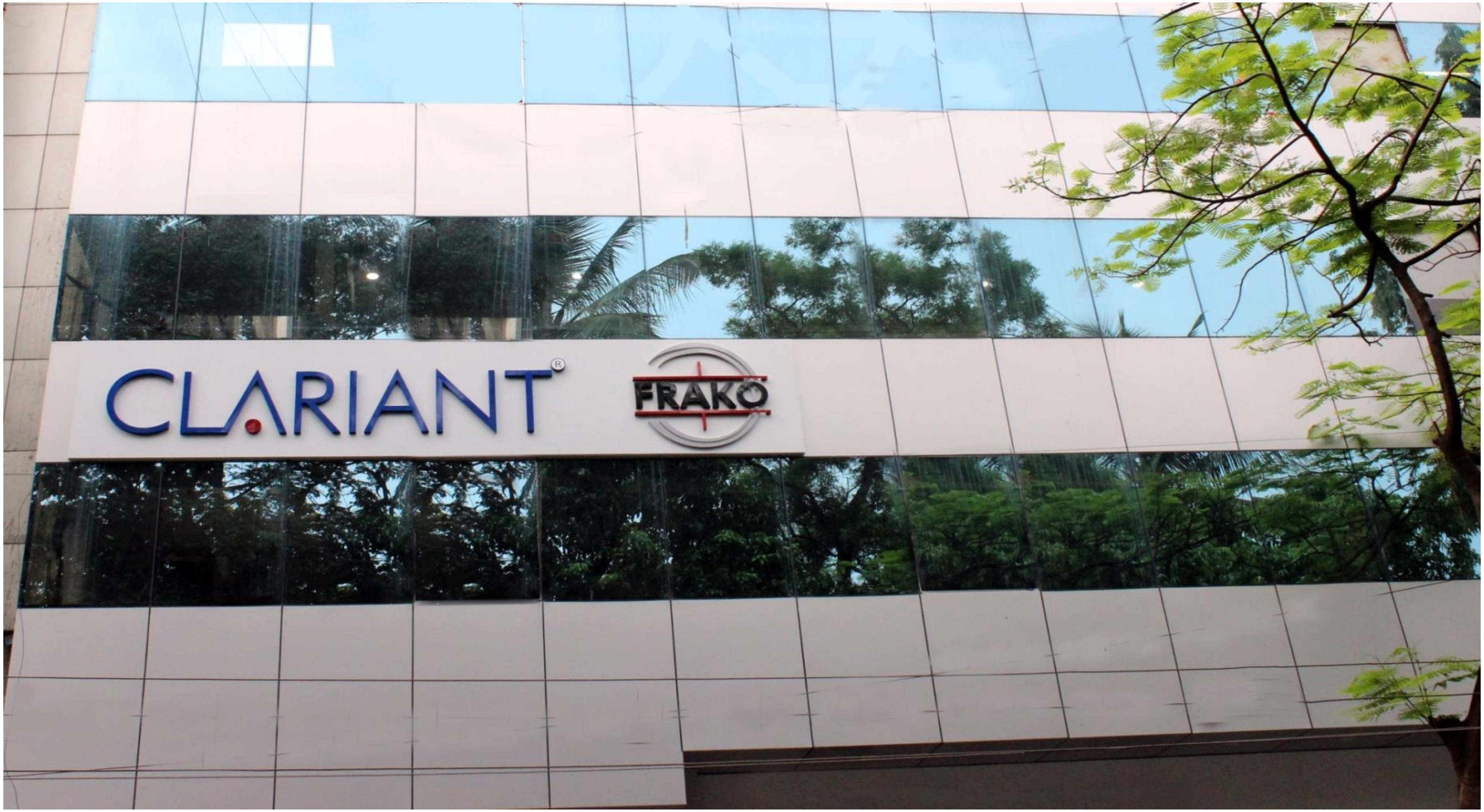

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