Harmonics: Effects, Power Quality Problems and Solutions

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Introduction

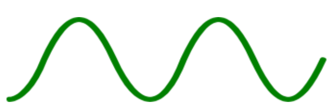
In today's world, almost every business depends on relatively fragile micro-electronics to run everything from computers, through electronic circuitry and devices, which are especially vulnerable to fluctuations in the power, they consume and pollute the power and makes the power "dirty". Dirty power as described is electronic rust, surge, spike, transient, fluctuation, interruption or noise, harmonics, etc. Several organizations are suffering from these types of critical problems but are unable to identify the root cause, mainly due to lack of awareness and thus incurring heavy losses in their business. The paper intends to help stakeholders understand about harmonics and how it can be resolved by simple methods.

Importance of Power Quality:

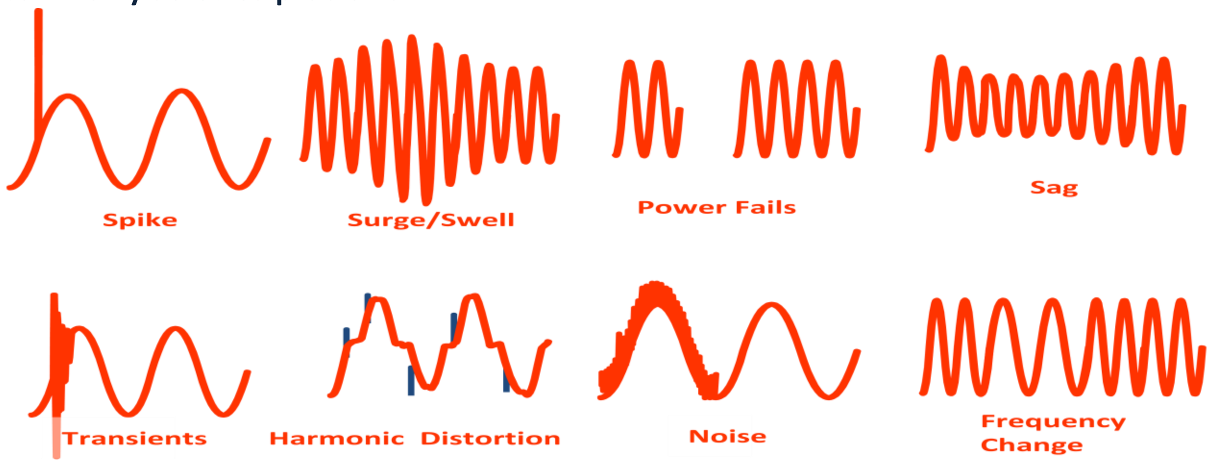
- **Increasing Sensitive Loads**
- **Increasing use of power electronics in equipments**
- **Increasing emphasis on power system efficiency and maximum utilisation**
- **Process Accuracy and Product Quality Issues**
- **Down Time of the Costly Equipments and the Man Power**
- **Uneven Specific Power Consumption (KWh/Product Unit)**

Power Quality Problem:

Equipment Demands: a uniform sinosudial AC supply



But the supplied power : has several issues in the waveform, leading the folowing most commonly detected problems



Harmonics Sequence and Effect

Rotating Sequence according to Harmonic Number

+	**1st**	**7th**	**13th**	**19th**	**Rotates with Fundamental**
0	**3rd**	**9th**	**15th**	**21th**	**Does Not Rotate**
-	**5th**	**11th**	**17th**	**23rd**	**Rotates Against Fundamental**

Power quality used to be the ability of the electric utilities to provide electric power without interruption. Today, power quality encompasses any deviation from a perfect sinusoidal waveform including a reliable supply without interruption. This includes EMI and RFI noise, transients, surges, sags, brown outs, black outs, and any other distortions to the sinusoidal waveform. **One distortion to the sinusoidal waveform which has dangerous consequences is harmonics.**

According to the studies, 3/4th of all power disturbances are caused by equipments inside the factory, buildings. We can not control how power is generated or distributed but we can manage power quality inside our premises. It is the dirty power components which results in frequent failure of electronic devices, CTPT, Metering Errors, Process and PLC malfunctions, cable faults, transformer failures, and HT side faults results in the very high maintenance cost and down time.

The term “Harmonics” is a popular buzz word in the power quality industry and the layman needs some information to understand the term and realize that it can be a serious problem if not treated properly. The treatment and the details of harmonics is better left to the expert with the proper diagnostic tools and professional training. Understanding “Harmonics” is simple, just relate “human body” and the **“hormones”. No matter the word “Harmonics” is also derived from the Medical Science to Electrical field**. Imbalance of hormones causes many health related problems in the human body. Even the root cause of all the diseases is the imbalance of hormones, it is proved that imbalance of hormones, if left untreated can result in serious medical conditions like diabetes, etc. It is possible that the imbalance could also cause an overproduction of growth hormones and cause medical conditions such as permanent disabilities and even death. There are approximately 6,000 endocrine disorders that result because of imbalance of hormones. Control of hormones is totally dependent on our Food Quality, Quantity, and Frequency of intake and time schedule. If we imagine, our old age peoples were having average life more than 100, 120 Years, but today our average life has reduced significantly.

For simple understanding, Harmonics can be simply defined as **“Multi Frequency Supply Travelling through a single conductor”.** Harmonics can be present in voltage, current or both. <u>It is forecasted that before the end of the year 2020, half of all electrical devices will operate with nonlinear current draw</u>. These nonlinear loads are the cause of current harmonics. This harmonic current is drawn from the power distribution transformer and there will be additional magnetic field generation in the transformer (Source) which will generate Voltage Harmonics having equal frequencies to the current harmonics. These distorted wave forms will be supplied to all the equipments downstream, which were pure sinusoidal previously. For better understanding, I have tried to explain the effects in the below diagram.

<u>Harmonics</u>: A sinusoidal waveform with a frequency that is an integral multiple of the fundamental 50/60 Hz frequency

- **a)** 50/60 Hz fundamental
- **b)** 100/120 Hz 2nd harmonic
- **c)** 150/180 Hz 3rd harmonic
- **d)** 250/300 Hz 5th harmonic, etc.

<u>Triplen Harmonics:</u> Odd multiple of the 3rd harmonic (3rd, 9th, 15th, 21st, etc.)

<u>Harmonic Distortion</u>: Non-linear distortion of a system characterized by the appearance in the output of harmonic currents (voltages) when the input is sinusoidal

<u>Voltage Harmonic Distortion (VHD):</u> Voltage harmonic distortion is distortion caused by harmonic currents flowing through the system impedance. The utility power system has relatively low system impedance, and the VHD is very low. VHD on the distribution power system can be significant due to its relatively high system impedance. $E + I^2R$ Ohm's Law

<u>Total Harmonic Distortion (THD):</u> The square root of the sum of the square of all harmonic currents present in the load excluding the 50/60 Hz fundamental. It is usually expressed as a percent of the fundamental

Current waveforms from non-linear loads appear distorted because the non-linear waveform is the result of adding harmonic components to the fundamental current.
Non-linear loads generate high levels of harmonic currents and when supplying power to these loads, a special transformer design is necessary.

Of these non-linear loads, the major source of harmonic currents is the switch mode power supply found in most desktop computers, terminals, data processors and other office and industrial machines and equipment.

Harmonics are produced by the diode-capacitor input section of power supplies. The diode-capacitor section rectifies the AC input power into the DC voltage used by the internal circuits. The personal computer uses DC voltage internally to power the various circuits and boards that make up the computer. The circuit of the power supply only draws current from the AC line during the peaks of the voltage waveform, thereby charging a capacitor to the Peak of the line voltage. The DC equipment requirements are fed from this capacitor and, as a result, the current waveform becomes distorted.

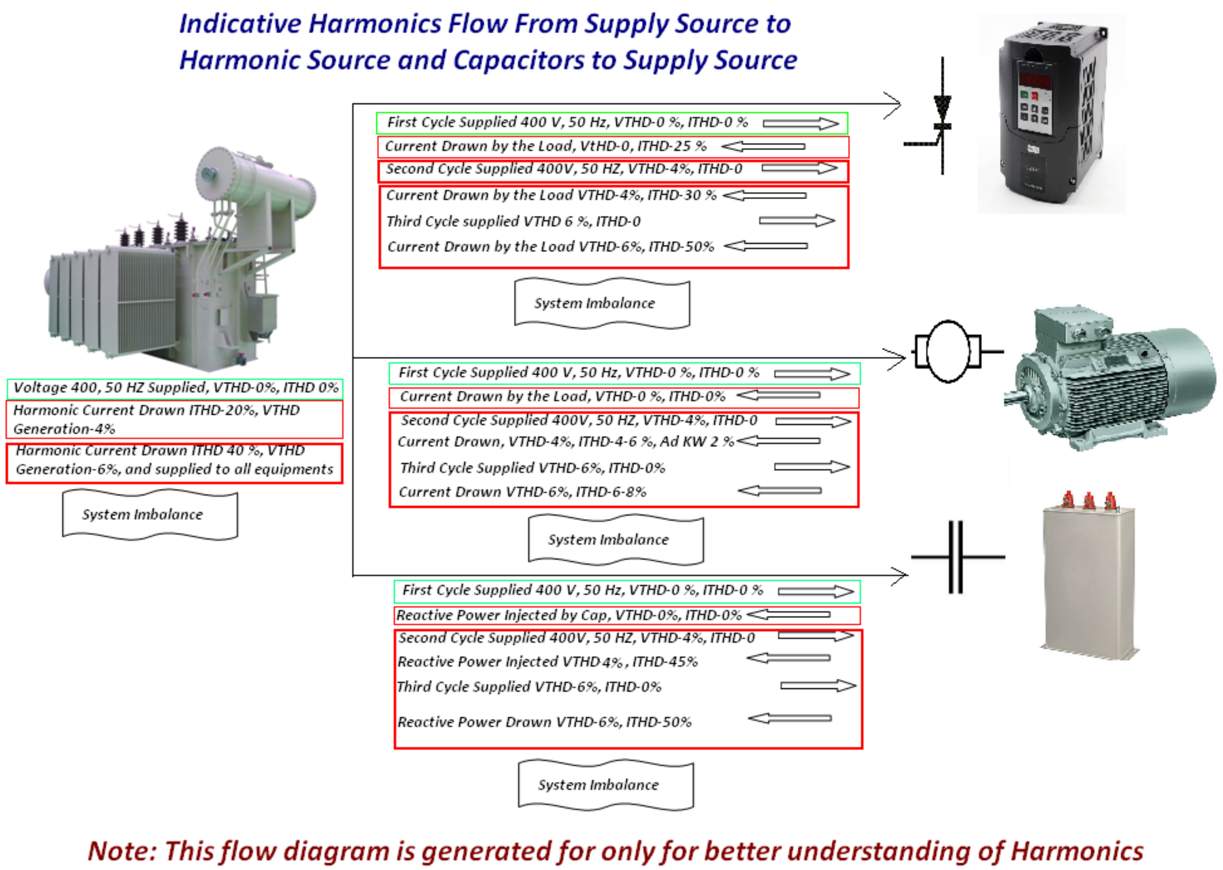
"Harmonics are not a problem unless they create a problem!"

Utilities invest Lakhs of Rupees annually to ensure the power supplies their customers receive are as close as possible to a sinusoidal waveform. Resistive linear loads such as the incandescent light bulb result in sinusoidal waveforms, but switching loads do not. The power supply in a modern personal computer is a good example of a non-linear load. The switching action of the computer power supply results in distortion of the current waveform. There are many other switching loads and a few are listed in the below:

Electronic Ballasts, Variable Speed Drives, Computers, Welding Machines, Process Controllers, UPS Systems, Induction and Arc Furnaces, SSR's, DC Motors, Medical equipments, Heater banks controlled by SSR's. Etc.

The problem faced by one of the fuel tank manufacturing industry was very serious and the same industry was suffering heavy losses from last 5 years. The industry was unable to produce the quality product, the percentage of in-process rejection and rework was recorded @ 30 %. the industry was paying heavy penalty on power factor from last 5 years and was unable to connect any capacitors in the circuit. Many consultants and experts tried to improve the power factor by use of various gadgets like APFC Panels, Detuned Reactors, Single phase PF correction equipments, Phase shifting and Isolation transformers etc. but everything failed. Basically, no expert was able to understand the root cause of the problem. Another expert's team did deep study and came to know that, the Harmonics are injected from the neighbored industry and VTHD was @ 12 %. Whatever equipments were connected, were not capable to control the voltage harmonics injected by this industry having the load 6.5 MVA, whereas the load of the sufferer industry was 400 KVA only. Finally, Electricity Supply Company fed the supply to the sufferer industry from another feeder by providing a 15 KM separate feeder line. The problem was thus resolved permanently. The industry recovered from the high financial losses during the period of last 5 years. Apart from power factor improvement, the rejection percentage also reduced to 3 %, and now is able to produce good quality components. It is thus necessary to understand the importance of Root Cause analysis and then only plan the corrective actions to be effective.

Flow of Harmonics from Load to Source, from Source to Load, Source to Capacitors and Capacitors to Source.



Effects of Harmonics:
Harmonic currents cause false circuit breaker tripping. Peak sensing circuit breakers often will trip even though the amperage value has not been exceeded. Harmonic current Peak values can be many times higher than sinusoidal waveforms. In electronic equipment that relies on the zero crossing of the sinusoidal waveform, such as clock timing devices, heavy harmonic content can cause a zero crossing point offset.

Odd number harmonics (3rd, 5th, 7th, etc.) are of the greatest concern in the electrical distribution system. Even number harmonics are usually mitigated because the harmonics swing equally in both the positive and negative direction.

The heating effect causes the greatest problem in electrical distribution systems and equipment. Electrical equipment often overheats and fails even when operating well below the design ratings. The increase in temperature is directly related to the increase in RMS current.

Harmonic frequencies are always higher than the 50 Hz fundamental frequency so “skin effect” also becomes a factor. Skin effect is a phenomenon where the higher frequency causes the electrons to flow toward the outer sides of a conductor. This reduces the ability of the conductor to carry current by reducing the cross-sectional diameter of the conductor and thereby reduces the ampere capacity rating of the conductor. Skin effect increases as the frequency and the amplitude increase and this is the reason higher harmonic frequencies cause a greater degree of heating in conductors.

The effect on transformer operation when multiple loads are connected is that each load generates triplen harmonic currents on the neutral conductor. These are sent on to the transformer secondary and reflected into the delta primary and these currents circulate within the delta primary causing overheating, shortened service life, catastrophic failure or worse.

When there is distortion in any one of the phase currents, the harmonic currents increase and the cancellation effect is lessened. The usual result is the neutral current THD is significantly higher than planned. The triple harmonics (odd multiples of three) are additive in the neutral and can quickly cause dangerous overheating. whereas once balanced, three phase systems with no harmonic content, the line currents are 120° out of phase, cancel each other and result in very little neutral current

In general, and the standard practice, the maximum current that the neutral will carry is 1.73 times the phase current and if not sized correctly, overheating will result. Higher than normal neutral current will cause voltage drops between neutral and ground which are well above normal. Readings above 4 volts indicate high neutral current

Power factor correction capacitor failure can be directly attributed to harmonics. Inductive reactance varies directly with frequency (XL=2x3.14 fl), because of the Parallel resonance between the capacitor bank and the source impedance can cause system resonance resulting in higher than normal currents and voltages. Capacitors appear as extremely low impedance values and are more susceptible to harmonics. High Harmonic currents have been known to overheat correction capacitors, causing premature failure and **sometimes resulting in explosion**. In many cases, power factor correction capacitor failure can be directly attributed to harmonic content

Peak sensing circuit breakers often will trip even though the amperage value has not been exceeded. Harmonic current Peak values can be many times higher than sinusoidal waveforms. In electronic equipment that relies on the zero crossing of the sinusoidal waveform, such as clock timing devices, heavy harmonic content can cause a zero crossing point offset. Harmonic currents cause false circuit breaker tripping

Electrical fires resulting from distribution system wiring and transformer overheating were rare occurrences until harmonic currents became a problem. The frequency of such fires is now becoming more common. The life safety issues of electrical fires are not part of this discussion, but should be considered. Harmonic currents cause overheating of electrical distribution system wiring, transformer overheating and shortened transformer service life

The majority of problems result when the resonant frequency is close to the 5th or 7th harmonic. These happen to be the largest harmonic amplitude numbers that most adjustable speed drives create. When this situation arises, capacitor banks should be re-sized to shift the resonant point to another frequency

The harmonic distortion limit of 5% is proven to be the point where harmonics begin to have a detrimental effect on the electrical distribution system. IEEE standard 519-1992 is a guidance document for utilities and electric power users which specifies both the maximum distortion levels and recommends correction levels

Influence of Voltage and Current Harmonics on Behavior of Electric Devices

It is the objective of the electric utility to supply its customers with a sinusoidal voltage of fairly constant magnitude. The generators that produce the electric power generate a very close approximation to a sinusoidal signal

1) **Harmonic Generating Loads :** Electronic devices such as rectifiers, inverters, and cycloconverters which are sensitive to the zero-crossing point of the voltage waveform can obviously be affected by harmonic distortion. The effect on converters is to displace the natural commutation point- decreases the performance of the equipment, providing a larger reserve in order to avoid the commutation errors which could carry an internal short-circuit, Possibility of failure in zero crossing of the voltage as a point of reference,
2) **Transformers and Reactors : Increase in the winding stray losses, Hysteresis losses,** Possible resonance may occur between the transformer inductance and the line capacitance
3) **Capacitors :** Reactive power increases due to harmonic voltages, Dielectric losses increase thus additional heating occurs, Capacitor bank failure from dielectric breakdown or reactive power overload, Life expectancy decreases, Resonance may occur resulting in harmonic magnification, Overvoltage can occur and system may go to fault in worst condition.
4) **Cables :** Additional heating occurs due to no sinusoidal current and because of skin and proximity effects which are a function of frequency, Dielectric breakdown of insulated cables resulting from harmonic overvoltage on the system, Increase in the I^2R Losses,
5) **Switchgears :** Medium-voltage, single-bar switchgear current carrying parts will behave similar to cables, with regard to skin and proximity effect, Changes the rate of rise of the transient recovery voltage, Affects the operation of the blow out coil.
6) **Protective Relays :** Affects the time delay characteristics, Signal interference and relay malfunction, particularly in solid-state and microprocessor-control systems, False tripping may occur (in general their sensitivity to currents of higher order discrete frequencies decreases).
7) **Generators :** Rotor heating, Production of pulsating or oscillating torques which involve torsional oscillations of the rotor elements and flexing of turbine buckets.

8) **Motors:** Stator and rotor I_2R losses will increase due to the flow of harmonic currents, Leakage fields set up by harmonic currents in the stator and rotor end windings produce extra losses (losses in the stator and rotor conductors are greater that those associated with the DC resistance because of eddy currents and skin effect), If VTHD is more than 2%, power loss will rise due to negative sequence harmonics present in the circuit, In the case of induction motors with skewed rotors, the flux changes in both the stator and rotor and high frequency can produce substantial iron losses, Core losses increases due to harmonic voltage, Positive sequence harmonics develop shaft torques that aid shaft rotation; negative sequence harmonics have the opposite effect, Excessive losses in -and heating of- induction and synchronous machines,
9) **Electricity meters:** The meters are frequency sensitive, with negative error increasing with the frequency, Decreasing the accuracy.
10) **Computers and Processors:** Possibility of disc errors, Failure and errors on the magnetic tapes medias, Hanging of processors.
11) **Radios and TV Receivers :** Possibility of light variation in the picture and its luminosity

The biggest culprit of the problems: Voltage Harmonics

Voltage harmonics may cause havoc within the electrical distribution system. Motors are typically considered to be linear loads; however, when the source voltage supply is rich in harmonics, the motor will draw harmonic current. The result is typically a higher than normal operation temperature and shortened service life

The noise is inductively or capacitive coupled into the communications and data lines. Noise can be picked up in computer networks, communications equipment and telephone systems when harmonics are at audio or radio frequencies. With the increase in speed of computer networks, the future will bring these systems into the frequencies where they will be more affected by harmonic generated noise.

When induction-disc watt-hour meters, Electronic meters are monitoring non linear loads, depending on the content of the harmonics, the disk may run slower or faster, samples collected by the electronic meters may be of peak and resulting in erroneous readings.

When the waveforms are rich in harmonics, shortened service or complete failure is sure to result. The majority of generators and transformers base their operating characteristics on non disturbed 50 Hz waveforms.

Solution of Harmonic problem

The most important parts of the solution include employing an expert with wide experience and good understanding of the power quality issues and cross linkages and is also equipped with proper diagnostic equipment and analytical softwares. The second part is consideration of quality and reliable solution products, like harmonic filter.

Harmonic Filtering is currently the most common method used to limit the effects that harmonics present to supply and distribution and the rest of the system. Generally there are two types of filters, Active Harmonic Filters and Passive Filters. Active Harmonic Filters are only the best solutions and can nullify all the harmonics present in the system and can be programmed for multiple intensity. Passive Filters typically consist of tuned series L-C circuits. Filter impedance is negligible with respect to the rest of the distribution system. These filter products are commercially available under different trade names. Most Passive filter products are not more than 50% effective. The best solution is to install Active Harmonic Filters, transformers, with the appropriate K rating and wiring that is sized to meet the equipment and systems needs

De-rating K factors can be applied specifically to transformers to ensure dangerous heating will not result when supplying load currents which are rich in harmonic content. One option in distribution system if harmonics are present is to de-rate the transformer supplying the system