Harmonics Distortion in Distribution Systems: A Review of Non–Linear Load Effects and Solutions

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ABSTRACT

Alinear load shows current corresponding to the applied voltage, while a "non-linear" load has varying impedance with voltage, prompting non-sinusoidal current in any event when associated with sinusoidal voltage. Harmonic current in non-sinusoidal current blends in with power distribution framework impedance, causing voltage distortion affecting both the framework and associated loads. Expanded utilization of power electronics and time-changing nonlinear loads in industry prompts serious electrical cable contamination, corrupting power supply quality, and effectiveness, and causing overheating. Therefore, the incorporation of harmonic mitigation units is essential to minimize the effects of harmonic distortions and ensure the steady & reliable operation of the distribution network. As harmonic-creating loads rise, their effect becomes vital for framework changes. The paper frames harmonics, its effects and sources and various methods to mitigate it and talks about non-linear loads.

Keywords: Harmonics, non – Linear loads, Total Harmonic Distortion, Filters

INTRODUCTION

In recent years, various non-linear loads have become predominant across various enterprises, presenting harmonics and influencing power factor. These loads create three types of harmonics: positive sequence, negative sequence, and zero sequence. Triplen harmonics (third, ninth, and fifteenth) flow through neutral wires and can lead to overheating. Power quality issues, coming about because of non-linear loads in electrical power frameworks, have become a huge worry for enterprises because of their significant effect on time and cash. These issues incorporate interruptions to life expectancy and the future. Different methodologies have been recommended to upgrade power quality, planning to keep up with ideal sinusoidal voltage signals, although this is challenging in practice. Harmonics, characterised as frequency multiples of the fundamental power frequency, introduces waveform distortion. Non-linear loads bring harmonics into the framework, influencing both current and voltage waveforms. This disturbance can, for example, fire risks, inordinate intensity, and support costs [1][2]. Right now, odd harmonics characterize harmonic elements within the power grid. Odd harmonics relate to waveforms that display symmetry across the time axis. On the other hand, harmonics start only from waveforms lacking symmetry along the time axis [3].

HARMONICS EVALUATION

Harmonics are sinusoidal components of a periodic waveform or quantity with frequencies that are integer multiples of the fundamental power frequency, resulting in waveform distortion. Harmonic analysis involves determining the magnitudes and phases of fundamental and higher-order harmonics within the power system.The frequency of the harmonic order f_h is defined as.

$f_h = n * f_0$

Where,

n = integer,

f_0= fundamental frequency, (e.g., 50 Hz in India)

For instance, with a fundamental frequency of 50 Hz, the 2nd, 3rd and 4th harmonics will occur at 100Hz, 150Hz and 200Hz respectively.

Harmonics can be categorized based on the type of signal (voltage or current) and their order (even, odd, triplen, or non-triplen odd). In a three-phase system, they are further classified by phase sequence (positive, negative, zero).

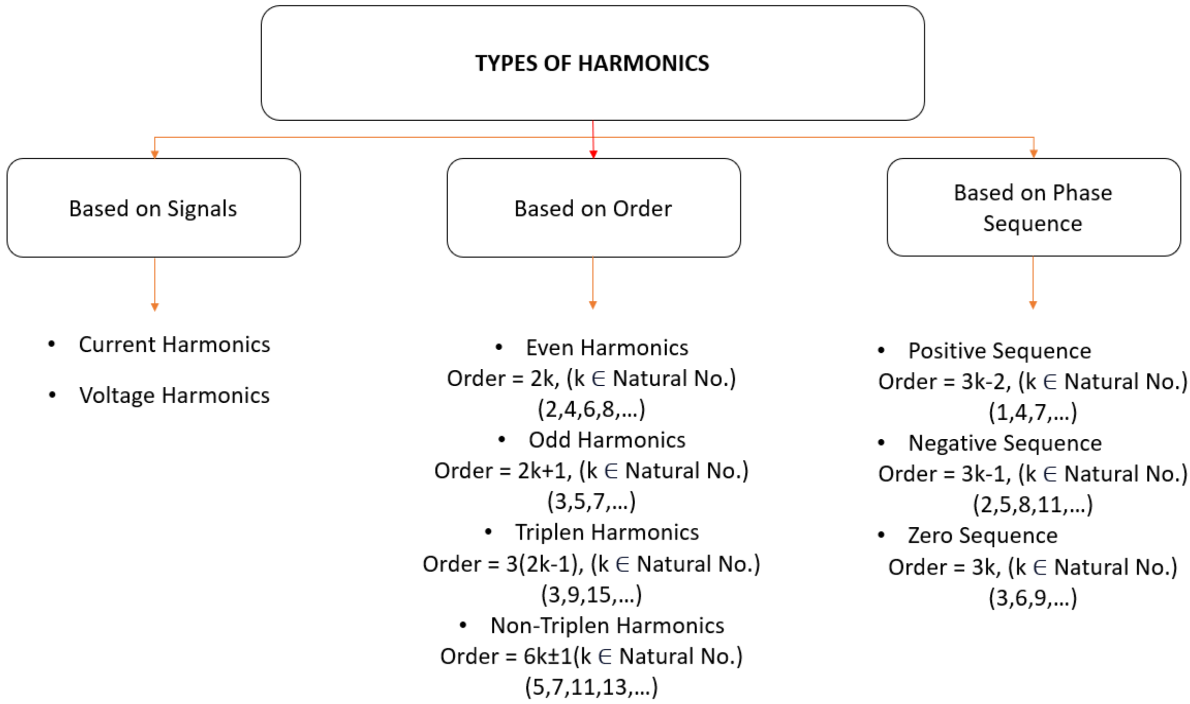

Fig. –1 Types of Harmonics

Table 1 – Harmonics order with their respective frequency and sequence

Name	Fundamental	2nd	3rd	4th	5th	6th	7th	8th	9th
Frequency	50	100	150	200	250	300	350	400	450
Sequence	+	-	0	+	-	0	+	-	0

Table 2 – Harmonics Types and their orders

Types of Harmonics	Order of Harmonics
Odd	5th,7th,11th,13th,17th
Even	2nd,4th,6th,8th,10th
Triplen	3rd,9th,15th,21st

Harmonic distortion is brought about by non-linear devices in the power system. A non-linear device is one in which the current isn't corresponding isn’t corresponding to the applied voltage. Non-linear loads bring harmonics into the framework, influencing both current and voltage waveforms. At the point when a sinusoidal voltage is applied to a non-linear load which causes current is contorted. Average instances of single non-linear loads are fax – machines, scanners, TVs, VCRs etc. Similarly, Three Phase Non-linear loads are Arc Furnace, SCR, Battery chargers, UPS system etc.

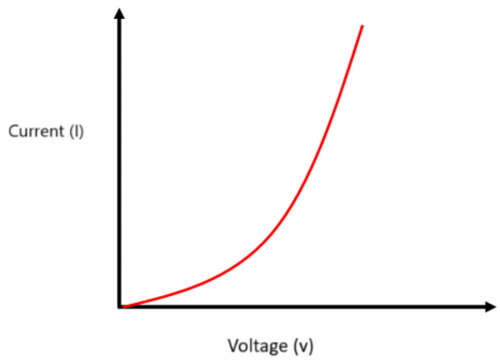

Fig. 2.a

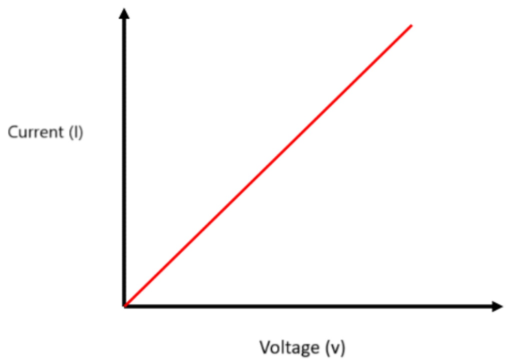

Fig. 2.b

Fig. 2.a and 2. b show the V-I characteristics of the Linear and Non-linear loads respectively.

Sources of Harmonic

- **Power electronic devices -** Various Power electronic devices that are sources of harmonics are Rectifiers, Inverters, Switching Power Supplies, Variable frequency drives, Battery chargers, Uninterruptible Power Supplies (UPS), Electric vehicle chargersetc. These devices include components like diodes, transistors, or thyristors that switch on and off rapidly to control power flow. The non–linear nature of their switching introduces distortion in the waveform.
- **Renewable energy sources -** Renewable energy sources introduce harmonics into power systems primarily through power electronics used for energy conversion and regulation. A few examples are - Wind energy systems, small hydro plants, and solar photovoltaic systems.
- **Office and household appliances -** Many modern appliances use Switch Mode Power Supplies and Variable Frequency Drives that generate harmonics. Several examples are Computers, printers, washing machines, televisions etc.
- **Rotating machines –** Rotating machines such as generators and motors are sources of harmonics. The harmonics generated by rotating machines are typically due to factors including non-linearities in magnetic circuits and control systems and the interaction of stator and rotor.

Effects of Harmonics

- **Poor Power Factor –** harmonics introduce additional current components at frequency multiples of fundamental frequencies. These harmonic currents do not contribute to real power but still increase the total current, which results in the reduction of the power factor.
- **Increased losses –**Harmonics induce eddy currents in the iron cores of transformers, which flow in closed loops within the core material. the presence of harmonics causes the magnetic material in transformers and motors to cycle more frequently, increasing hysteresis losses. Total iron losses due to harmonics:
  $P_{iron} = P_{eddy} + P_{hysteresis}$

The additional harmonic currents flow through conductors, cables, transformers and other equipment, causing copper losses.
$P_{loss} = I^2 R$
Where I is harmonic current and R is the resistance of the conductor.

- **Neutral Conductor Overloading**–in three-phase systems, the 3rd harmonic and its multiples (triplen harmonics) are additive in the neutral conductor rather than cancelling out as fundamental frequencies do. This leads to neutral conductor overloading.
- **Transformer Derating** – the capacity of transformers are reduced when significant harmonic content is present. This is because the additional harmonic losses increase the temperature of the transformer, reducing its effective capacity to handle the same amount of load as under pure sinusoids
- **Sin effect** – Harmonics cause skin effect, where current tends to flow near the outer surface of conductors. This reduces the effective cross sectional area through which the current flows, increasing the conductor's resistance which leads to more losses even for the same amount of current.
- **Capacitor Heating and Overloading** – Harmonics cause resonance between inductive components and capacitors used for power factor correction. the resonance amplifies harmonic currents, overloading the capacitors and causing overheating that leads to capacitor failure.
- **Power Quality Degradation** - Harmonics can interfere with communication systems, including those that use power lines for data transmission. This interference can lead to signal distortion and data errors.

- **Overloading of Equipment** - Non-linear loads that generate harmonics can cause transformers and other equipment to operate above their rated capacities, leading to overheating and premature failure.

MEASUREMENT OF HARMONIC DISTORTION

Harmonic Spectrum

The harmonic spectrum displays the amplitude of each harmonic frequency. For an oscillating signal with a fundamental frequency f_1, the frequency of the n^{th} harmonic is given by:

f_n = n $*f_1$

Where:
f_n is the frequency of the n^{th} harmonic.
f_1 is the fundamental frequency.

Harmonic Power

The power associated with each harmonic component can be computed using:

$P_n = I_n^2 *$ R

where:
P_n is the power of the n^{th} harmonic.
I_n is the RMS current of the n^{th} harmonic.
R is the resistance of the load or circuit.

Total Harmonic Distortion (THD) - measures the extent of harmonic distortion relative to the fundamental frequency. THD widely defines harmonic content level by comparing the power of all harmonic components' power to the fundamental frequency's power. it is given by:

$$\text{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 \ldots\ldots + V_n^2}}{V_1} * 100\%$$

Where,
V_1 is the RMS value of fundamental frequency.
V_2 , V_3, …, V_n are RMS worth of harmonics (2nd harmonic, 3rd harmonic …resp.)

Total Demand Distortion (THD) - Total Demand Distortion (TDD) is a measure of the harmonic distortion of the current demand in an electrical system. It evaluates the impact of harmonics on the total current demand of a system, rather than just the individual harmonics or their total distortion as seen in Total Harmonic Distortion (THD).

$$\text{THD}_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 \ldots\ldots + I_n^2}}{I_1} * 100$$

Where,
I_1 s the RMS value of fundamental current.
I_2 , I_3, …, I_n are RMS value of harmonics (2nd harmonic, 3rd harmonic …resp.)

HARMONIC MITIGATION STRATEGIES

Effective harmonic mitigation includes a blend of these strategies tailored to the particular qualities of the electrical framework and the nature of the harmonic distortion. The decision of technique relies upon elements like the level of harmonic distortion, the type of equipment, cost contemplations, and the general framework plan. Carrying out a very much arranged harmonic mitigation strategy can essentially further develop power quality, safeguard gear, and upgrade the dependability of electrical frameworks. Mitigating harmonics is crucial for maintaining power quality and ensuring the reliability and longevity of electrical systems. Here’s an overview of common harmonic mitigation strategies

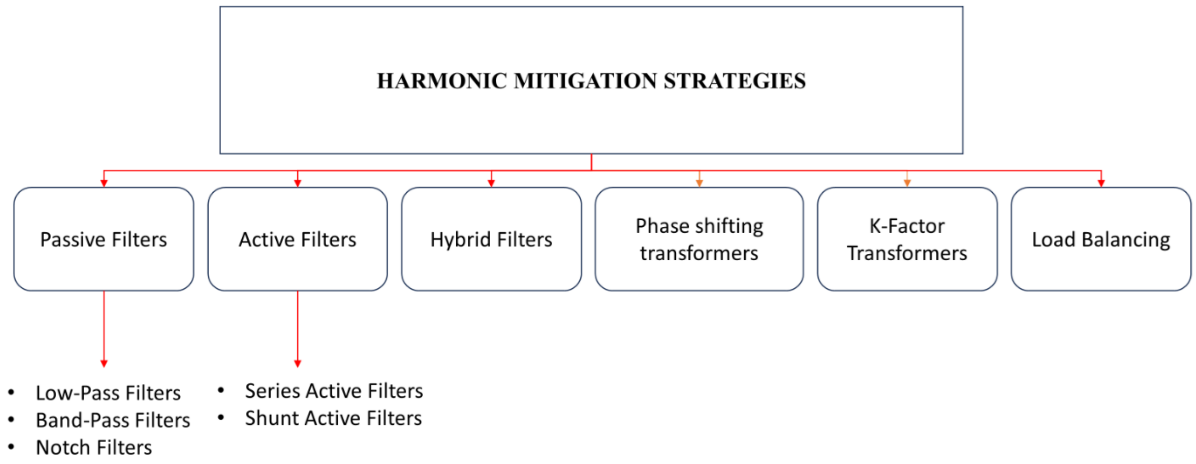

Fig. 3 – Different Harmonics Mitigation Strategies

Table 3 – Various Harmonic mitigation strategies advantages and disadvantages

	Advantages	Disadvantages
Passive Filters	Simple design and installation. Cost-effective for specific harmonic problems.	Limited flexibility in adapting to varying harmonic conditions. Potential for resonance with system impedances
Active Filters	Adaptable to varying harmonic conditions. Effective for a wide range of harmonic frequencies.	Higher initial cost and complexity. Requires ongoing maintenance and calibration.
Hybrid Filters	Effective across a broad range of harmonic frequencies. Balances cost and performance.	Complexity in design and installation. Requires coordination between passive and active components.
Phase Shifting Transformers	Effective for reducing certain harmonic orders, particularly the 5th and 7th harmonics. Useful in large installations with multiple transformers.	High initial cost. Limited to specific harmonic orders.
K-Factor Transformers	Protects against overheating due to harmonics. Suitable for environments with high harmonic content	More expensive than standard transformers. Does not eliminate harmonics but rather mitigates their effects.
Load Balancing	Simple and cost-effective. Improves overall system efficiency and reduces harmonic effects.	May not completely resolve harmonic issues if significant non-linear loads are present

CONCLUSION

The presence of non-linear loads prompts the emergence of harmonic distortions, bringing about related challenges that were momentarily talked about. An overview of harmonics and terms that are related for harmonic calculation were discussed. Sources of harmonic distortions that can happen because of the non-linear loads in the power system and related effects/issues were analyzed momentarily. An outline of the effective strategies to mitigate harmonics was examined There is a need for further research on mitigating techniques to minimize the impact of harmonics that occurs due to non-linear loads on the system's power quality, dependability and proficiency.

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