

# Harmonic Analysis of Non Linear Domestic/Industrial Loads: A Review

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**ABSTRACT:** With the enhancement in technologies and advancement in power electronic devices, conventional domestic and industrial devices are now being converted into power electronic based devices due to many advantages like less switching time, more control and larger energy efficiencies. But the replacement of these conventional devices by power electronic based devices affects the power quality due to the non-linear characteristics of these power electronic based switches. All the power electronic based devices are commonly known as non-linear devices or loads. For efficient use of these non-linear loads, it is essential to analyze the related power qualities issues along with mathematical relations of their harmonic indicators. This paper also proposes a study based on harmonics with help of Harmonic Analyzer of non-linear domestic/ industrial loads which is being later compared with results of IEEE power quality standards

**KEYWORDS:** Power Quality, Harmonics, Non-Linear Loads, Total Harmonic Distortion, Total Demand Distortion.

## I. INTRODUCTION

Power Quality is becoming an area of major concern these days which needs a lot of attention from the energy users as well as energy providing companies. Various factors affecting the power quality are Harmonic distortion, Blackouts, Sags and swells and Transients etc. Harmonics will cause generation of harmonic currents, leading to non-sinusoidal variation of voltage. Harmonics may lead to overloading of power factor correction capacitors, interference with telephonic circuits, corruption of data in computers and malfunctioning of control equipment's etc[1,3]. With the analysis of harmonics by Harmonic Analyser, the harmonic emission from various devices can be checked and harmonic filters can be designed accordingly which leads to a better power quality.

There are generally two types of loads i.e. linear and non-linear. The load that will draw instantaneously proportional current to the applied voltage, i.e., its impedance is maintained constant throughout the whole alternating period is known as linear load. In case of a 50 Hz. sinusoidal voltage frequency for public electricity supply, this will mean a pure sinusoidal current waveform also. Secondly, a non-linear load will change its impedance with instantaneous applied voltage that will lead to a non-sinusoidal current drawn by the applied voltage. These types of loads do not have a constant relation between voltage and current along the alternating time period. The power electronics loads, CFL, UPS, and VFD are the common examples of non-linear loads [2, 3, 4]. Major sources of voltage and current harmonic generation in power system are [2, 4, 5];

- Imbalance in the power system is caused due to the controlling action of power electronic devices such as chopper, inverter etc.
- Use of non-linear loads such as UPS, SMPS, and battery charger leads to harmonic distortion.
- Rotary converters, traction and power converters, variable frequency drives leads to the harmonic distortion.
- Electronic chokes, compact fluorescent lamps (CFL), solid state fan regulators also produces harmonics in the power system.

Harmonics on a network may lead to the non-sinusoidal currents which has severe effects on the power system. Some of the impacts of the Harmonics on the power system are [5, 7];

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- Presence of Harmonic currents in the power system leads to the heating of equipment's, such as transformers and generators. This in turn would increase the overall copper losses.
- Due to the skin effect produced from harmonics, there will be additional losses or need of over sizing of conductors.
- The life of the components or equipment's is reduced due to the distorted supply voltage having harmonics.
- Interference with the telephonic circuits.
- Flickers and fluctuation in light intensity may occur due to the harmonics presence in supply voltage.
- The data may be corrupted if there is distortion in power supply.
- The motors with excessive Harmonic currents leads to low power factor resulting in reduction in the efficiency.

To improve the performance of power system by the elimination of harmonics, various devices/equipment can be used. Some of the devices/equipment's widely used are [6, 8];

- Harmonic reduction by using Transformer Phase Shifting
- Line reactors (Inductive reactor)
- Isolation transformers (provide isolation of high power circuit from low power circuit)
- Harmonic filters i.e. Active filters and Passive filters.

## II. HARMONICS AND ITS ORDERS

Harmonics is a periodic, steady-state distortion of voltage or current waveform in a power system. These distortions are produced by devices which exhibit non-linear relationship between voltage and current. The non-linear device characteristics lead to generation of harmonic currents, causing non-sinusoidal variation of voltage [3]. Harmonics are of many orders like 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> and so on depends upon which type of components frequency it contains. If components frequency is twice of the fundamental frequency is called 2<sup>nd</sup> harmonics. Therefore, on a 50Hz frequency power system in India, harmonics are always multiple of 50. The sinusoidal harmonic components of order 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> having 50Hz system frequency are expressed in Fig. 1.

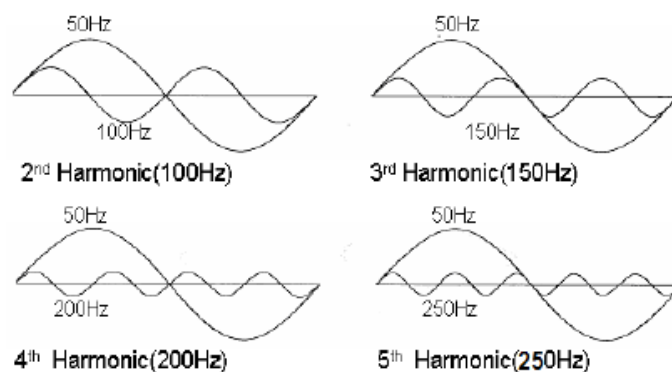


Fig.1 Harmonics components of 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> orders [3]

Sinusoidal waves that are not multiple of fundamental frequency are not called harmonics but are defined in terms of the fundamental frequency as per-unit frequencies system.

## III. LITERATURE REVIEW

*M. Jzhar et. al* [1] presented the harmonic phenomenon in order to interpret waveforms behaviour due to non linear loads carried out in Fourier series. The harmonics theory, definition of harmonic quantities, related harmonics problems in power distribution systems are explained. *D. Daniel Sabin et. al* [2] presented that many electricity consumers are adversely affected by more subtle voltage disturbances such as harmonic distortion. In response to the increased

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sensitivity of end-use equipment, many utilities are implementing extensive monitoring systems to assess service quality levels and presents indices developed to quantify system service quality with respect to measured harmonic distortion levels. *Srijan Saha et. al* [3] shows that the linear customer loads are being dominated by sensitive and sophisticated non-linear customer loads such as computer, fluorescent lamp, CFL lamp and small scale industry loads such as adjustable speed drive, arc welder and lift with the growth in the power electronics and control system industries these have a catastrophic impact on a power system and equipment increasing harmonics pollution. *Mahendar Kumar et. al* [4] discussed the demand of electricity can be fulfill in short-term and best solution for users in terms of instant and back up supply can be through uninterruptible power supply (UPS) it could be more effective and efficient with hybrid storage source and active power filter. The author also discussed brief look regarding UPS types, control techniques and reliability and also investigate the optimal power transfer for sustainable power source including minimizes the total harmonic distortion (THD) from 46% to 1.46% with proposed active power filter (APF), in order to save more than 15% energy during conversion. *Chen Duo et. al* [5] presented that the extensive use of nonlinear elements in the power system, the harmonics generated by nonlinear elements cause the voltage and current waveform distortion and it has been a threat to the power system and other equipments. This paper makes help of harmonics as setting point and summarizes the various measures of harmonic control; it can provide effective reference to harmonic control. *Nilesh B. Mirajkar et. al* [6] discussed that the use of powers converters and other nonlinear loads in industry has increased the deterioration of the power system voltages and current waveforms. This Harmonic distortion is considered to be most significant reason for power quality problems. This paper also discusses how to design electrical harmonic system and its simulation which is used for harmonic analysis. *Morteza H. P. et. al* [7] investigates harmonic pollution aspects to be taken into consideration in utilizing LED lighting products in street lighting projects. An experimental setup utilizing a power quality analyzer is assembled to achieve exact data of harmonic components of equipment under test. Results show that LED lamps are compliant with IEC61000-3-2 Standard. *Purushothama Rao Nasini et. al* [8] discusses the modeling of nonlinear electrical loads used in domestic and small scale industrial distribution systems. Simulation models are developed for various nonlinear loads based on practical waveforms of voltage and current obtained in the laboratory. Analysis of voltage and current harmonics is performed for these loads individually. Validation of the load models is done by performing case study for an industrial supply system and comparing the THDs obtained from simulation using PSCAD/EMTDC package with the THD values obtained by measurement. *Anne Ko et. al* [9] demonstrated that harmonic analysis in non-linear loads can be carried out by two ways; the first method is by using semiconductor devices such as diodes and the other is by using current source parallel with resistor load. *S. F. Mekhamer et. al* [10] studies that harmonic analysis are necessary to analyze the current and voltage harmonic levels and check if these levels comply with the contractual or international standard limits. If the studies reveal that the preset limits are exceeded, then a suitable harmonic mitigation technique should be installed. Harmonic analysis studies in the industrial electrical systems are discussed in many references. However, a comprehensive procedure for the steps required to perform a harmonic study is rarely found in the literature even though it is strongly needed for design engineers. *Tony Hoevenaars et. al* [11] presents the IEEE Std 519 showing two of the more difficult aspects of applying IEEE Std 519 are; determining an appropriate point of common coupling (PCC) and establishing a demand current at the design stage. This is because the standard does not provide a concise definition of the PCC and the recommended definition of demand current is a value that can only be determined by measurements taken after installation.

## IV. HARMONIC INDICATORS

The commonly used harmonics indicators to determine or analyze the impacts of the presence of harmonics in the power system are explained one by one in subsequent sections [7-11].

A. **Total Harmonic Distortion (THD):** THD is the most commonly used harmonic index and is given by equation (1) and equation (2) for voltage and current respectively.

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$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots}}{V_1} \quad (1)$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_1} \quad (2)$$

Total Harmonic Distortion is defined as the ratio of the rms value of the harmonic component to the rms value of fundamental component and is generally expressed in percentage. This index is used to measure the deviation of a periodic non-sinusoidal waveform from a perfect sine wave. THD for a perfect sine wave (containing only the fundamental frequency) is zero. Similarly, the measure of individual harmonic distortion for voltage and current at  $h^{\text{th}}$  order are defined as  $V_h/V_1$  and  $I_h/I_1$  respectively. The THD factor is related to the rms value of the waveform is given by equation (3).

$$\text{RMS value} = \sqrt{\sum_{h=1}^{\infty} V_h^2} = V_1 \sqrt{1 + THD_V^2} \quad (3)$$

Variations in the THD factor over a period of time follow a distinct pattern representing non-linear load profile in the system. The THD index is most often used to describe voltage harmonic distortion.

**B. Total Demand Distortion (TDD):** Total Demand Distortion (TDD) is defined as:

$$TDD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L} \quad (4)$$

Where  $I_L$  is the maximum demand load current at the Point of Common Coupling (PCC), calculated as the average current of the maximum demand for the previous twelve months. Current distortion levels can be characterized by a THD value, but it can be misleading in some situations. A small current may have a high THD value but may not be a significant problem for the system. For example, many adjustable-speed drives exhibit high THD values for the input current when they are operating at very light load. This may not be a major concern because the magnitude of harmonic current is low, even though its relative current distortion is high. This difficulty can be addressed by referring THD to the fundamental of the peak demand load current rather than to the fundamental of the present sample. The term TDD is particularly relevant while applying IEEE 519-1992 Standard.

**C. Power Factor:** Power factor (pf) is the ratio of useful (real or active) power to the apparent power supplied by a utility, i.e.

$$\text{pf} = \frac{P}{S} \quad (5)$$

In the sinusoidal case there is only one phase angle between the voltage and current (since only the fundamental frequency is present); the power factor is computed as the cosine of the phase angle ( $\text{pf} = \cos \phi$ ) and is also referred as displacement power factor. In the non-sinusoidal case the power factor cannot be defined as the cosine of the phase between voltage and current. The power factor that takes into account the contribution from all active

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power, including both fundamental and harmonic frequencies, is known as the true power factor or the total power factor. When voltage and current contain harmonics, the rms voltage and current can be expressed by the relations:

$$V_{rms} = V_1 \sqrt{1 + \left(\frac{THD_V}{100}\right)^2} \quad (6)$$

$$I_{rms} = I_1 \sqrt{1 + \left(\frac{THD_I}{100}\right)^2} \quad (7)$$

Substituting the values of  $V_{rms}$  and  $I_{rms}$ , the total power factor in the system under non-sinusoidal conditions is given by:

$$pf_{total} = \frac{P}{V_1 I_1 \sqrt{1 + (THD_V / 100)^2} \sqrt{1 + (THD_I / 100)^2}} \quad (8)$$

In most cases, the total harmonic voltage distortion  $THD_V$  is less than 10 %, hence equation (8) can be rewritten as:

$$pf_{total} = \frac{P_1}{V_1 I_1 \sqrt{1 + \left(\frac{THD_I}{100}\right)^2}} = \cos(\theta_1 - \delta_1) pf_{dist} \quad (9)$$

The first term,  $\cos(\theta_1 - \delta_1)$  is known as the displacement power factor, and the second term,  $pf_{dist}$ , is defined as the distortion power factor.

**D. Transformer K-Factor:** Transformer K-factor is an index used to calculate the de-rating of standard transformers when harmonic currents are present. K-factor is defined by the expression in equation (10)

$$K = \frac{\sum_{h=1}^{\infty} h^2 (I_h / I_1)^2}{\sum_{h=1}^{\infty} (I_h / I_1)^2} \quad (10)$$

Where  $h$  is the harmonic order and  $I_h/I_1$  is the corresponding individual harmonic current distortion. Equation (10) is based on the assumption that the transformer eddy current loss produced by each harmonic current component is proportional to the square of the harmonic order and square of magnitude of the harmonic component. The K-rated transformer is constructed to withstand more voltage distortion than standard transformers. The K-factor actually relates to the excessive heat that must be dissipated by the transformer and is considered in the design and installation stage for non-linear loads.

### V. PROPOSED WORK AND METHODOLOGY

In this paper the following work is proposed to carry out;

- To study the causes of development of various order harmonics in domestic and industrial loads daily used loads.
- To develop non-linear load model using CFL bulb, UPS and power electronic devices etc. and carry out harmonic analysis by using Power and Harmonic Analyzer PHA5850 at different loading conditions.
- To carry out the harmonic Analysis of industrial load (Cold Store) at their point of common coupling.
- To verify these harmonics with various IEEE standards.
- Propose the suitable filter circuit for the elimination of present harmonic content to maintain power quality standards.

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The methodology of proposed work is shown below in Fig. 2

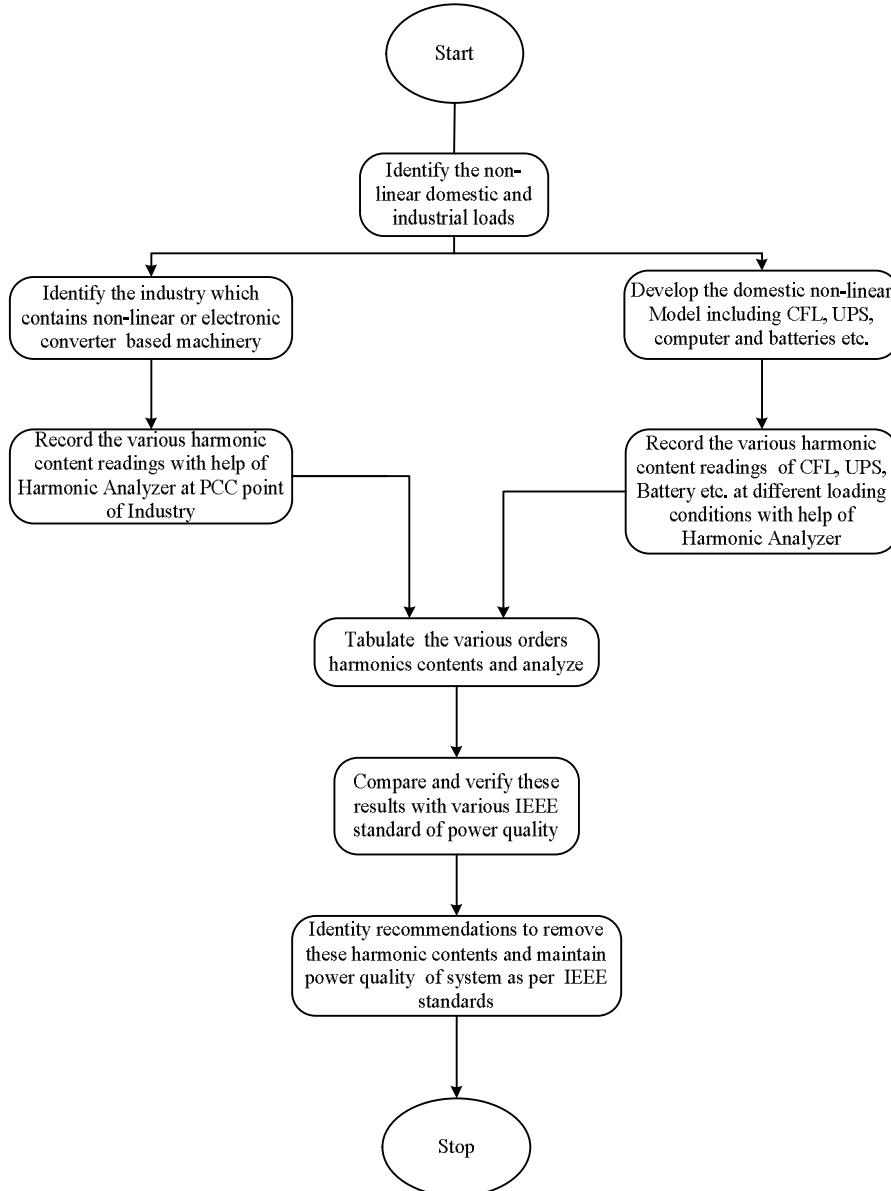


Fig.2 Flow Chart of Proposed Work

## VI. CONCLUSION

This paper gives overviews of various aspects of harmonics like causes, effects and their mitigation techniques. The presented literature review facilitates interested researchers in detailed harmonic analysis of non-linear domestic/industrial loads. In this paper mathematical representation of harmonic indicator are directly used to calculate the magnitude of various order harmonics. The proposed work is carried with the help of Harmonics Analyzer and analyzed results are compared with IEEE standard and further recommendations to improve the power quality issues with non-linear loads are to be prepared on the basis of analyze results.

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