

Effects of Total Harmonic Distortion on Power System Equipment

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ABSTRACT.

Total harmonic distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave. Harmonic is a sinusoidal component of a periodic wave or quantity having a frequency that is integral multiples of the fundamental frequency. Harmonics can be voltage and/or current related and present in electrical system in multiples of the fundamental frequency. This paper discusses the effects of total harmonic distortion on power system equipment. Various values of fundamental and harmonic voltages were used as input parameters for the computation of THD to establish if their limits fall within the harmonic standards. The results of the paper show that the average value of the THD for the power system equipment is 1.98% which is in agreement with the even harmonic standards of 2%. Keeping low THD values on a system will further ensure proper operation of equipment and longer equipment life span.

Keywords: *Total harmonic distortion, Power factor correction, Distribution transformers, Fundamental frequency, Harmonic standards.*

1. INTRODUCTION.

Harmonics are electric voltages and current that appear on electric power system as a result of certain kinds of electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems [5].

Harmonics, which is central focus of this study, is a specific type of disturbance that affects the quality of power, often caused by type of load attached to the power supply. It is a series of subsidiary waveforms that accompany a primary or fundamental waveform. They result when a system produces wave frequencies that are simple in ratios with the fundamental frequency (2:1, 3:1, 4:1, and so on). In electrical power system, the power supply line produces the fundamental frequency (or first harmonic), which is considered as ideal. But when this ideal is disturbed by external factors, other frequencies are produced. These subsequent frequencies are always in integral ratios of the fundamental frequency and distort the original waveform [1].

Harmonic distortion can have detrimental effects on electrical equipments. Unwanted distortion can increase the current in power systems which result in higher temperatures in neutral conductors and distribution transformers. Higher frequency harmonics cause additional core loss in motors which result in excessive heating of the motor core. These higher order harmonics can also interfere within communication transmission line since they oscillate at the same frequencies as the transmit frequency. If left unchecked, increased temperatures and interference can greatly shorten the life of electronic equipment and cause damage to power systems [3], [8].

The source of harmonics at the consumer end in power system can be any of the following [11]:

- (a) Single phase loads which include switched mode power supplies (SMPS), electronic ballast, Small UPS units and battery chargers.
- (b) Three phase loads include variable speed drives and large UPS unit.

A nonlinear load at point of consumption can be described as a single-phase non-linear load (a good example is the electronic ballast) or a three-phase non-linear load (a good example is a large UPS unit).

Electrical power is generated in the form of alternating current (AC) which is mainly generated as a sinusoidal wave as shown in Figure 1 below:

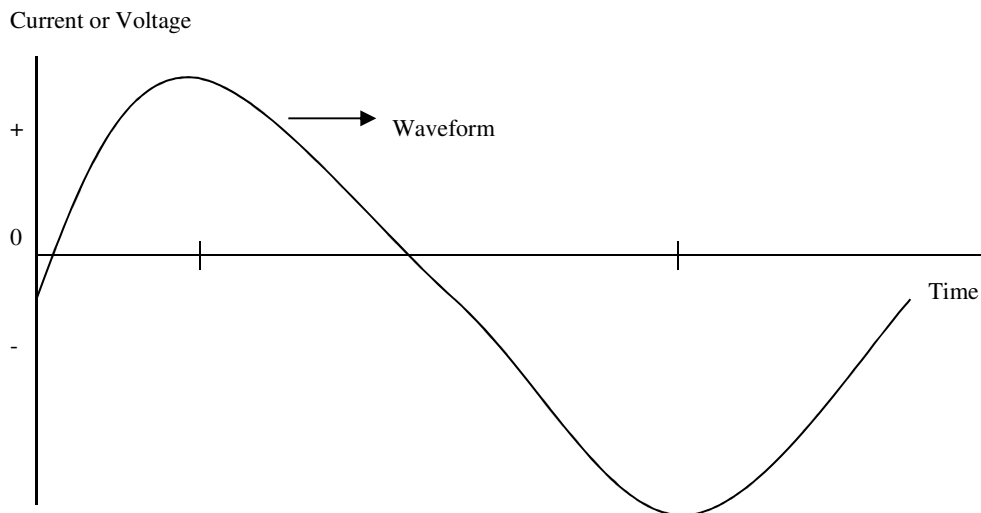


Figure 1: AC Waveform

In AC, the movement of electric charge is periodically in reverse direction. The commonest waveform of an AC power circuit is a sine wave as in the case of the wave shown above. This is one of the reasons why it is well suited for power technology and transmission and also for processing information.

AC is generated mainly by an alternating voltage source, it has constant amplitude and frequency.

Mathematically, alternating voltage and current are represented as shown below

$$V = V_0 \sin wt \quad (1)$$

$$I = I_0 \sin wt + \varphi \quad (2)$$

Where,

V_0 = Peak voltage

I_0 = Peak current

w = angular frequency

φ = Phase angle

t = time

A.C finally gets to consumer. Ideally, it is expected that the consumer of electrical power obtain the same sinusoidal waveform that was generated. As a result of unwanted factors, the received power waveform will be distorted. This is illustrated in Figure 2.

Current or Voltage

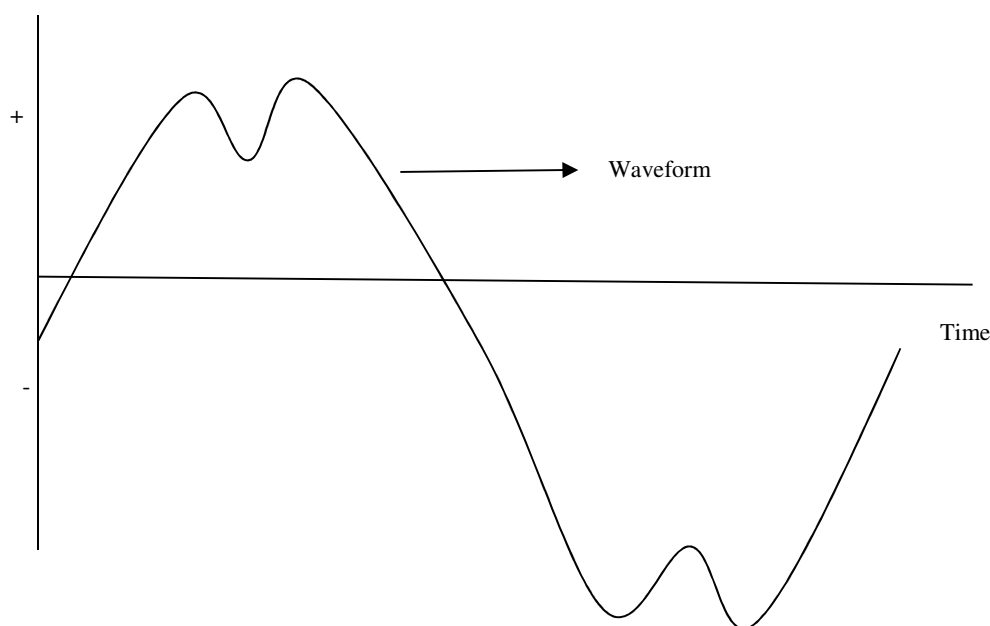


Figure 2: Distorted Waveform

The distortion affects power quality and often causes damage to electrical devices.

1.1 The Measures of Harmonic Distortion

Customers should be interested in two aspects of harmonics- equipment susceptibility and equipment emission. The first is the degree of distortion which will cause equipment damage or malfunction and is characterized by the harmonic voltage which the equipment can tolerate. The second is the measure of how equipment will affect the supply and is characterized by the harmonic current drawn [9], [13].

There are several measures of the harmonic distortion, including the level of the voltage at each harmonic. Two in particular are total Harmonic Distortion (THD) and notch depth. The first is important for long term thermal effects. The second for equipment malfunction.

1.2 Harmonic Standards

Customers need to be protected from other customers producing excessive distortion on the supply and damaging equipment or causing inconvenient malfunction. The standards address three aspects of harmonics [6]:

- i. The maximum levels of harmonic voltages which are allowed on the supply,
- ii. The maximum distortion current that household appliances can draw to ensure that the levels in (i) are met,
- iii. The maximum distortion current that industrial installation can draw to ensure that the levels in (i) are met.

1.3 Harmonics and Power Factor Correction.

The total installation current has two components of current at the supply frequency, power components which are in phase with the voltage and another so-called reactive component. The relationship between the total current and these two components is [2].

$$I_{total}^2 = I_{power}^2 + I_{reactive}^2 \quad (3)$$

The power factor of an installation is given by

$$\text{Pf} = \frac{I_{\text{power}}}{I_{\text{total}}} \quad (4)$$

Customers are to maintain their power factors between 0.9 lagging and unity. Some utilities have a tariff structure which encourages customers to keep their power factor as close to unity as possible reducing the reactive current. This can be conveniently done in most instances by the provision of a suitably sized shunt capacitor.

When harmonics are present, the current has an additional high frequency component and equation (1) has to be modified to [4].

$$I_{\text{total}}^2 = I_{\text{power}}^2 + I_{\text{reactive}}^2 + I_{\text{harmonic}}^2 \quad (5)$$

With computer installation, I_{reactive} is close to zero, but I_{harmonic} is large and the power factor is less than one. If such a customer installs power factor correction capacitors, then I_{reactive} increases due to the capacitor current, further increasing I_{total} and the power factor.

Capacitors are used by both electricity suppliers and customers to improve their power factors which can cause excessive voltage distortion.

This impedance which causes voltage drops to occur as a result of current flow is inductive and increases with frequency. Consequently the higher frequency components of current give a correspondingly greater distortion in the voltage waveform. On the other hand capacitors have impedance which reduces within frequency.

The combined effect of the two is the following [7]:-

- i. At low frequencies, the impedance of the power system is determined by the low inductive impedance of transformers and transmission lines
- ii. At high frequencies it is determined by the low capacitive impedance of power factor correction capacitors.
- iii. There is an intermediate range of frequencies where the capacitive and inductive effects can combine to give very high impedance. A small harmonic current within this frequency range can give a very high and undesirable harmonic voltage. This is the condition called resonance.

1.4 Effect of Harmonic Distortion on Equipment.

Equipment responds to harmonic differently depending on their method of operation. For example incandescent lights and most types of household electric heaters and stoves are not affected adversely at all [10].

On the other hand, induction motor windings are over heated by harmonics, causing accelerated degradation of insulation and loss of life. The operation of some equipments depends on an accurate voltage wave shape and they can malfunction when harmonic are present.

In the supply system, substation transformers and power factor correction capacitors are most affected. Transformers are affected by a distorted current waveform which can cause extra heating leading to a reduction in their service life. Capacitors are affected by the applied voltage waveform which can cause overheating of dielectric with a risk of explosion [12].

Harmonics effects can lead to equipment overheating and reduction in service life by a factor of up to half with consequent economic loss. Unlike most other types of supply problems, harmonics can go unnoticed for many years unless equipment temperature or the voltage waveform is routinely monitored.

2. MATERIALS AND METHOD.

The steps involved in this research paper are:

- i. Obtain relevant information on the power system equipment.. This is usually given in the form of the short-circuit current or fault level, from which an equivalent impedance can be calculated.
- ii. Estimate the major harmonic sources in the power system equipment.

- iii. For each harmonic order, model the power system equipment. With the assumption that inductive reactance will increase with frequency; capacitive reactance's will decrease while resistances remain unchanged.
- iv. Determine the fundamental and harmonic voltages at the point of common coupling from the distorting current injected
- v. Compute the THD.

3. DISCUSSION OF RESULTS.

The relationship between the harmonic voltage and the fundamental voltage is shown in Figure 1. At a fundamental frequency of 110V, the harmonic voltage is 1.2V while with a total harmonic distortion of 0.0208; the harmonic voltage and the fundamental voltage are 2.5V and 120V respectively. The values of the third harmonic distortions fluctuate through the study period. When the fundamental voltage and harmonic voltages are 155V and 4.5V, the third harmonic distortion is 0.0290 even though; a fundamental voltage of 165V corresponds to a harmonic voltage of 2.5V with a third harmonic distortion of 0.0152. This is a slight decrease in the total harmonic distortion of 0.0200 earlier obtained with a fundamental voltage and harmonic voltage of 160V and 3.2V respectively.

Figure 2 illustrates the correlation between the harmonic voltage and the total harmonic distortion. It is evident that the harmonic voltage fluctuates between 1.5V and 1.2V in the first instance while the total harmonic distortion also fluctuates accordingly between 0.0150 and 0.0109. The total harmonic distortion increases up to 0.0208 until it started decreasing to 0.0160 at a harmonic voltage of 2.0V. Between harmonic voltage of 2.8V and 4.5V, the third harmonic distortion increases rapidly. The harmonic voltage also increases sharply from 2.5V to 6.0V with a corresponding total harmonic distortion of 0.0122 to 0.0273 until the distortions reduced to 0.0191V at a harmonic voltage of 4.3V. In addition, this total harmonic distortion further decreases to 0.0122 at a harmonic voltage of 2.8V which is a sharp fall in the value. The harmonic voltage further increases appreciably from 2.4V to 9.5V even though, the total harmonic distortion increases appreciably from 0.0122 to 0.0404 and later decreases to 0.0158 at a harmonic voltage of 3.8V.

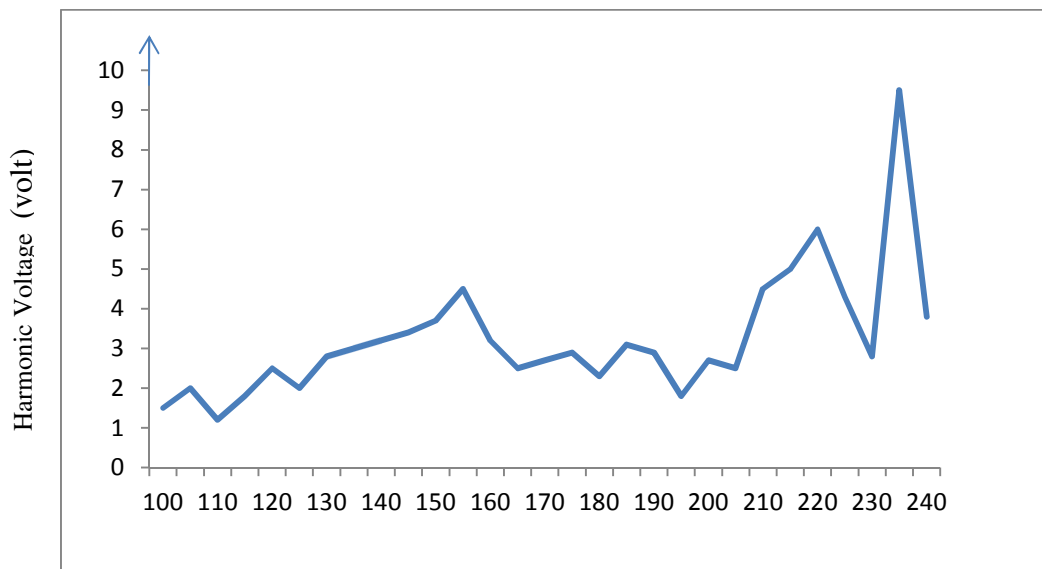


Figure 1: Harmonic Voltage Versus Fundamental Voltage

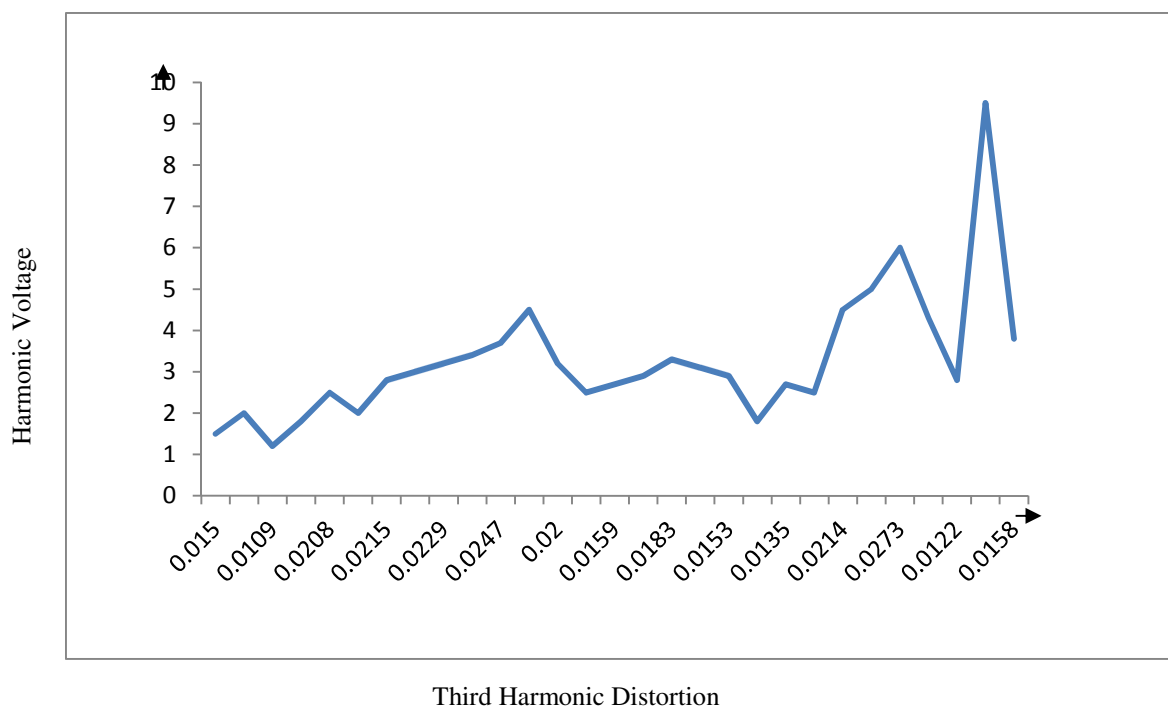


Figure 2: Harmonic Voltage Versus Third Harmonic Distortion

4. CONCLUSION.

The effect of total harmonic distortion on power system equipment has been presented. The presentation started with the computation of total harmonic distortion for power system equipment using various values of the fundamental and harmonic voltages as input parameters. It was observed that the average percentage value of the THD for the power system equipment is 1.98% which is in accordance with the even harmonic standards of 2%.

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