

HARMONIC ANALYSIS IN NON – LINEAR LOADS OF POWER SYSTEM

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Abstract- Harmonics in a power system are caused by highly non-linear loads. The use of non linear loads is increasing day by day. This increasing use of non linear loads has created more distortions in current and voltage waveforms. Controlling and reducing such harmonics have been a major concern of power engineers for many years. This increased power quality disturbances has lead to various optimizations techniques and filter designs. Harmonic distortions are the major cause for power quality problems. For this analyzing the harmonics present in non linear loads is significant. Here a survey is made to show details of harmonics present in various non linear loads. This paper discusses the problem of harmonic pollution in electrical networks and it proposes how the waveforms of voltage/current is distorted and harmonics are injected in to the system due to nonlinear loads such as Variable Speed Drive, Arcing Devices, UPS, Personal Computer, Printers, Fluorescent Lamp, Cell Phone battery charger.

Keywords: Harmonics, Non-linear load, Harmonic Distortion, Neutral Current

I. INTRODUCTION

The main objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. This objective is complicated by the fact that there are loads their influence when making any additions or changes to an installation. To fully appreciate the impact of these phenomena, there are two important concepts to bear in mind with regard to power system harmonics. The first is the nature on the system that produce harmonic currents. These currents result in distorted voltages and currents that can adversely impact the system performance in different ways. As the number of harmonic producing loads has increased over the years, it has become increasingly necessary to address of harmonic- current producing loads (non-linear loads) and the second is the way in which harmonic currents flow and how the resulting harmonic voltages develop [1].

In field of acoustics, harmonics is generally a vibration of a string or an air column at a frequency that is

a multiple of the base frequency. A harmonic component in a power system is defined as the sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system [2] – [5]. It is given by,

$$F_h = h * \text{Fundamental frequency,}$$

where h is the integer to be multiplied.

If the fundamental frequency is f, then the harmonics have frequency f,2f,3f,4f,5f...Even harmonics are 2f,4f,6f,8f...and odd harmonics are f,3f,4f,5f,7f... Generally even harmonics get cancelled because of their symmetrical nature, but odd harmonics should be eliminated by some filtering or compensation techniques.

The collision of harmonics and waveform distortion on the quality of electrical power harmonic distortion is the changes in the waveform of the supply voltage from the sinusoidal waveform. It is caused by the interaction of distorting customer loads with the impedance of the supply network.

Its major adverse effects are Malfunctioning and failure of electronic equipment, Overheating and failure of electric motors, Overloading, overheating and failure of power factor correction capacitors, Resonance due to interaction of capacitors with harmonics, Excessive measurement errors in metering equipment, Spurious operation of fuses, circuit-breakers and other protective equipment, Voltage glitches in computers systems resulting in lost data.

Harmonics is one of the major power quality problems in industrial and commercial power systems. A harmonic of an electrical signal is defined as the content of signal whose frequency is an integral multiple of the fundamental frequency. IEEE Standard 519 Harmonics is defined as "a sinusoidal component of a periodic wave or quantity having a frequency that is an integer multiple of the fundamental frequency". Harmonic analysis is the process of calculating the magnitudes and phases of the fundamental and higher order harmonics of the power system.

Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied

voltage. When a sinusoidal voltage is applied to a non-linear load which causes current is distorted. Increasing the voltage by a few percent may cause current to double and take on a different wave shape. This is the source of most harmonic distortion in a power system.

2. CAUSES AND EFFECTS OF HARMONICS

In an ideal power system voltage and current waveforms are purely sinusoidal. In practice, non sinusoidal currents result when the current flowing through the load is non linearly related to the applied voltage. In a simple circuit containing only linear circuit elements (resistance, inductance and capacitance), the current which flows is proportional to the applied voltage. So that it results in a sinusoidal current flow. The situation where the load is simple full wave rectifier, current flows only when the supply voltage exceeds that stored on the reservoir capacitor. It says that waveforms tend to distort from the sine wave and this is the cause for harmonics. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner as shown in the fig.1.

2.1. Harmonic Indices

Harmonic distortion measurements are normally given in “total harmonic distortion” or THD. THD defines the harmonic distortion in terms of the fundamental current drawn by a load. Thus IEEE-519 uses a term called TDD (total demand distortion) to express current distortion in terms of the maximum fundamental current that the consumer draws.

2.2. Harmonic Current flow and Voltage distortion

Fig.1 shows a typical power distribution network. When the nonlinear load is supplied from a sinusoidal voltage source, it injects harmonic current. The Harmonic currents cause harmonic volt drops in the supply network and therefore distort the voltage at the PCC. Any loads, even linear loads connected to the PCC, will have harmonic current injected into them by the distorted PCC voltage.

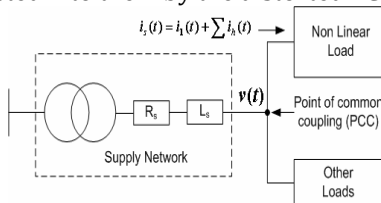


Fig.1 Typical Power distribution network

3. NON LINEAR LOADS

If the current is not proportional to the applied voltage then it is called the Nonlinear load. Typical examples of Single phase non-linear Loads are Computers, Fax Machines, Photocopiers, UPS's, TV's,

VCR's, Lighting dimmers & Electronic ballasts for high efficiency lighting, Single-phase AC & DC drives, Ultra-violet disinfection systems. Similarly Three Phase Non-linear loads are Variable speed AC & DC drives, UPS systems, Arc furnaces, SCR, temperature controllers, Battery chargers, etc.

Due to the changes in the operating conditions and the rapid growth of advanced power conversion devices, electronics equipments, computers, office automation, air-conditioning systems, adjustable speed heating ventilation can cause current distortions. This is due to increase in harmonics drastically. According to the Electric Power Research (EPR) in 1995, 35-40% of all electric power flows through electronic converters. This is expected to increase to 85% by the year 2012 [6]-[11]. All these devices are named as non linear loads and become sources of harmonics. The simple block diagram in Figure illustrates the current distortion problem due to harmonic at low voltage levels.

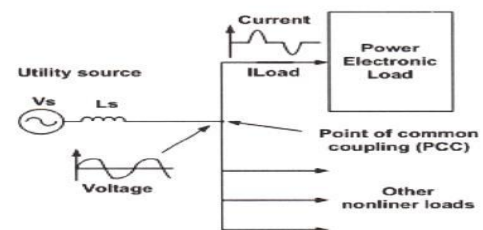


Fig.2. Current distortions at point of common coupling

The above fig.2. shows that the voltage waveform at the Point of Common Coupling (PCC) is distorted due to harmonic current generated by the power electronic or non linear load.

In this paper a survey is done for various non linear loads to know the levels of harmonics present in each loads. These surveys are generally conducted with the objectives such as

- Identify the trends of harmonic distortion level present in the system.
- Identify the future trends of metering in the presence of non sinusoidal current and voltage waveforms. And increased awareness and concern for customer's quality of service.

Here various loads and its harmonics are studied in detail.

4. THE DIFFERENT TYPES OF NON-LINEAR LOADS

4.1. Variable Speed Drive

The voltage and current waveform on the line and load side of a variable speed drive (VSD) is shown in Fig.3 In that Fig. the VSD draws two current pulses for each half cycle of the voltage waveform. This is typical of most VSD's which employ six pulse conversion to commutate the three-phase line voltage to a DC voltage. Six pulse converters have two switches per phase; this

accounts for the two current pulses during each half cycle of the voltage waveform as shown in Fig. The current is discontinuous, i.e. goes to zero during each half cycle, because this particular VSD does not have any line inductors. A pulse width modulation (PWM) switching scheme is used in the VSD which invert the Voltage from its DC into a sinusoidal AC output. The PWM output contains noise and this phenomenon is identified by the power analyzer measurements.

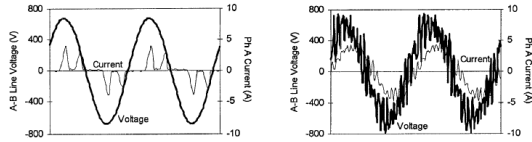


Fig.3. Variable speed drive of line and load side waveform

4.2 Arcing devices

ARC furnaces are used for melting and refining metals. It is one of the most important non-linear loads in the electric power network and it is a time varying, non-linear load. The voltage-current characteristics of electric arcs are nonlinear. Following arc ignition, the voltage decreases as the arc current increases, limited only by the impedance of the power system. This gives the arc the appearance of having a negative resistance for a portion of its operating cycle such as in fluorescent lighting applications. As the popularity and use of the arc furnace loads in the industry increase, so does the power-quality problem as a result of this progress. Among the most common adverse power quality effects introduced by electric arc furnace are voltage and current harmonics, voltage and current imbalance, low power factor, and voltage flicker. The energy consumed in the each basket of the melting cycle may be dividing into three main steps

1. Drilling period,
2. Melting period,
3. End of melting and reheating.

The Fig.4 shows the active power consumed as function of time for the above melting period given.

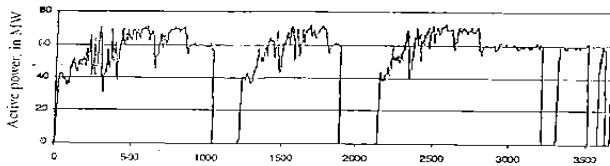


Fig.4. Active power consumed in MW as function of time in seconds for the above melting period with reheating.

4.3. Uninterrupted Power Supply

UPS provides protection from loss of a voltage source, many on-line UPS's demand current that has considerable harmonic content and/or supply a voltage to the load that has distortion. The UPS for which the waveforms are shown in Fig. was 3-phase, 37.5 kVA, 480 V

input, and 120/208 V output. This particular UPS draw a line current that averaged 19.0 % THD for the three phases and had an absence of triple n harmonics (Fig.5). The UPS input consists of a six pulse rectifier circuit with smoothing inductor which draw a line a line current whose harmonic spectrum consists of odd harmonics from 5th harmonics to 19th harmonics. The load current had a crest factor above 2.0 which caused the flat-topping of the voltage output as shown in Fig.6. The UPS output voltage waveform for each of the three phases had a distortion ranging from 8.0 to 16.8 % THD. IEEE 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, states that voltage distortion should not exceed 5% at the end use loads. Obviously, this UPS did not meet these requirements.

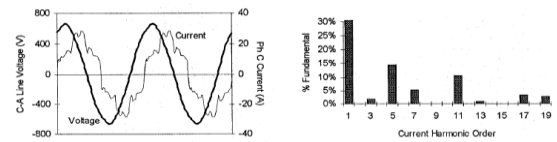


Fig.5. Uninterruptible power supply line and current harmonic spectrum

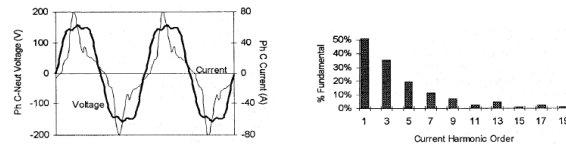


Fig.6. Uninterruptible power supply load and current harmonic spectrum

4.4. Personal Computer

A day-to-day increasing the usage of the personal computers (PC), these produces harmonics in the power system network. The experimental activity has concerned the harmonic monitoring of several PC types. Some selected results have been reported at PCC (point of common coupling) with varying impedance value are given in fig (7)

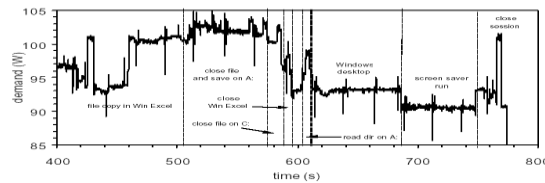


Fig.7. Demand diagram recorded for some typical Operations of PC.

4.5. Printers

A operation of the printer consists of stand-by mode, print starting and print. The demand for the above operations is different. This causes harmonics in the power system. Typical waveforms given in fig (8).

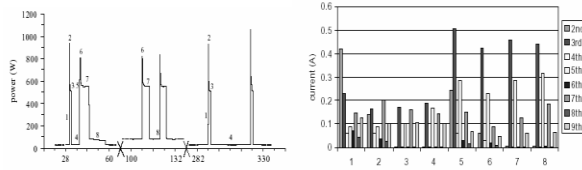


Fig.8. Expanded view of Printer typical duty with Harmonic current spectrum cycles (points 4,8: stand-by, points 3,5,7 print, points 2,6 print starting).

4.6. Fluorescent Lamps

Fig.9 shows the phase voltage and current and the neutral current for a lighting load of fluorescent lamp with magnetic ballasts. The harmonics in the current waveform are caused by the nonlinearity of the lamp arc itself in series with the ballast. The typical waveforms of Phase voltage and current and Neutral current for a three phase, four wire are given in Fig. (9 and 10).

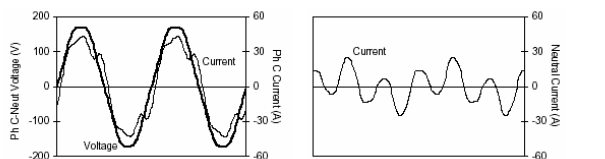


Fig.9. Waveforms for magnetic ballasts.

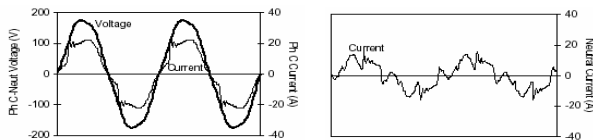


Fig.10. Waveforms for electronic ballasts.

4.7. Cell Phone Battery Chargers

Cell phones require battery chargers (BC) equipped with single phase switching mode power supplies of very low demand. However, the high number of BC dispersed in end user areas can determine a significant cumulative impact on distribution grid voltage quality. The continuous monitoring activity has involved several samples of cell phone BC for Li-Ion batteries are reported in the Fig.11 and 12. In particular, Fig.11 reports the BC power demand for a whole charging cycle. The demand level results decreasing with charging level increase & Fig.12 is reported in order to better illustrate the demand modulation operated during charge and controlled by battery charging status.

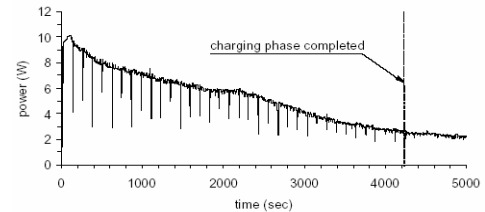


Fig.11. Demand diagram recorded for a whole BC charging cycle.

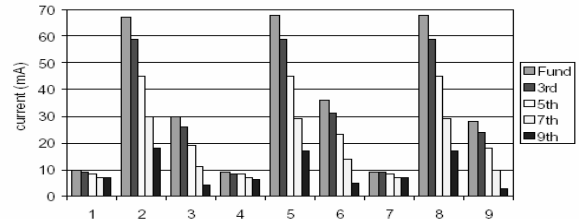


Fig.12. Harmonic currents recorded at instants

5.CONCLUSION

In this paper harmonics injected by some very commonly used nonlinear loads are studied. This article was intended to identify the harmonics introduced in the system due to various nonlinear loads and helps to identify the levels of harmonic voltages and currents may be present. It is observed that significant distortion in the current exists due to the use of computers and other electronic equipments in residential and commercial areas too. Increasing use of these equipments may result in serious problems in near future. The current distortion differs widely from one section to the next. Although, voltage distortion is recorded below the acceptable limit, but it is found above the recommended limit at the places of high current distortion, as it depends on the circuit impedance as well as harmonic generation characteristics. Significant distortion in the current is recorded at customer end with high percentage of 5th and 7th harmonic components. Though various optimization techniques are present, research is being done for the best eliminated results of THD.

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