EFFECT of SINGLE-PHASE, NON- LINEAR LOADS, AS SOURCES of HARMONIC CURRENTS in LOW VOLTAGE ELECTRICAL DISTRIBUTION SYSTEM

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ABSTRACT

Single-phase, full-wave, non-linear electronic loads, which are connected phase-to-neutral in a 220/380V, three-phase, four-wire distribution system, generate high levels of odd positive-, negative- and third-order, zero-sequence harmonic current. In office and data processing environments, these currents are principally the byproduct of switch-mode power supply technology. The switch-mode power supply's AC voltage source is rectified to DC. The DC voltage is then applied to a large storage capacitor. In the first half-cycle, the capacitor is charged to the average value of the AC voltage. The electronic equipment then draws DC current from its power supply's charged capacitor, to a predetermined low voltage level. Before reaching the lower limit, the capacitor is again recharged to the average value of the AC voltage in the next half cycle.

***A**lmost all productivity equipment, used in office and data processing environments, contain switch-mode power supplies. These devices include personal computers, terminals, monitors, and peripheral devices, such as controllers, servers, printers, scanners, photocopiers and facsimile transmitters.*

Then in this paper we discuss The effect of single-phase, non- linear loads, as sources of positive-, negative- and third-order, zero-sequence harmonic currents in low voltage electrical distribution systems in south delta Company of Electric Distribution,

A traditional method for dealing with these harmonic currents is outlined and their shortcomings identified. Alternative method, which provides harmonic current reduction, and power quality improvement, are presented. Results of the application of alternative devices in typical environments are given.

INTRODUCTION

Single-phase, full-wave, non-linear electronic loads, which are connected phase-to-neutral in a three-phase, four-wire distribution system, generate high levels of odd positive-, negative- and third-order, zero-sequence harmonic current [1]. almost all productivity equipment, used in office and data processing environments, contain switch-mode power supplies. These devices include personal computers, terminals, monitors, and also fluorescent lamps. Peripheral devices, such as controllers, servers, printers, scanners, photocopiers and facsimile transmitters. The relationship between the voltage across and the current is non-linear[2]. These loads which may represent 98% - 100% of the sub-system's total loads, generate the highest harmonic current [3]. They will add rather than cancel on the neutral conductor of a 3-phase, 4-wire system. This can overload the neutral if it is not sized to handle this type of load. Also, the power supply units draws pulses of currents which contain large amounts of third harmonic current (I_3), which is the first third order, zero-sequence harmonic current in the series, flowing on each phase of the four-wire system, are 'in-phase'. As a result, zero-sequence secondary windings of the source transformer combine arithmetically at its neutral terminal. These currents return to their source via the neutral conductor as shown in Figure 2 [4]. Also, triplen harmonics cause circulating currents on the delta winding of a delta-wye transformer configuration. The result is transformer heating similar to that produced by unbalanced 3-phase current. The filters fitted at supply inputs has no effect on the harmonic currents that flow back to the supply.These symptoms will affect the performance and cost of maintaining the distribution system and its loads, the cost of power, and the cost of lost productivity should any of its components malfunction or fail. Ironically, the very devices that generate these harmonic currents may be the most sensitive to the power quality problems they create Zero sequence harmonic voltages will cause "flat-topping" of the voltage waveform or the reduction of peak voltage. In severe cases, data processing may be corrupted due to a momentary loss of power from the switch-mode power supply, or the power supply itself may fail. Additionally, the outcome may be costly and even hazardous. So, in this paper concerns the sources of distortion (loads) and the interaction between those and the propagation of the distortion in the power system. Effects on the power system are also studied, e.g. additional losses and, harmonic resonance.

1. CHARACTERISTICS of SINGLE PHASE LOADS

Electronic equipment, supplied from the low voltage power system, rectifies the ac power to dc power for internal use at different dc voltage levels.. The dc voltage is smoothed by a dc capacitor, Figure 1. The power range for each device is small, from a few W up to some kW. The total harmonic distortion, THD, of the line current is often over 100 % and consists of all odd multiples of the fundamental component. In some case the THD can be nearly 150 %, mainly depending on the design of the DC-link and the crest factor of the supply voltage

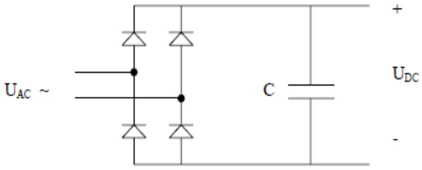


Fig 1.Single phase, two-pulse diode rectifier with capacitive DC-link

<u>1.1 Load Neutral Current</u>

Current pulses in single phase, non-linear loads increase in the three phase neutral circuit [5], the current pulses are typically so narrow as to be "non-overlapping" on the three phases. This means that only one phase of the three phase system carries current at any instant of time. Under these circumstances, the only return path for current is the neutral conductor. As a result, the number of current pulses accumulated in the panel neutral is three times that in the lines. The root mean square (rms) current increase, from one to three current pulses in a common time interval, is 173% as shown by the following equation:

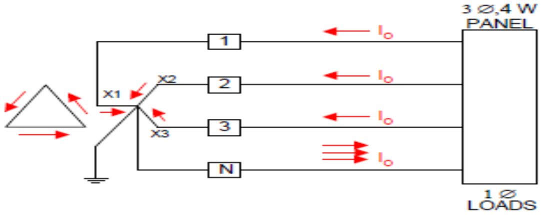


Figure 2. Characteristics of single phase non linear load

$$I_{o\varphi1} + I_{o\varphi2} + I_{o\varphi3} = I_{oN} \quad (1)$$

$$I_{N,rms} = \sqrt{3} * I_{phase,rms} \quad (2)$$

Moreover, single phase electronic loads produce current distortions that contain large amounts of 3rd harmonic, with decreasing percentages of 5th, 7th, 9th, 11th, 13th, 15th, and so on. Of those harmonics, only the 3rd, 9th, 15th, etc., contribute to the neutral problem. Because of their lower current levels and higher frequencies8]. The strong relationship between the 3rd harmonic and neutral current leads to an equally strong relationship between neutral current and line current THD Since all harmonics other than 3rd have an insignificant effect on neutral current as follows [6]:

$$\% \text{ Neutral} \approx 300\% * I_3 \quad (3)$$

1-2 Current Harmonic Content (%) for 1-Phase

Overall, single-phase, non-linear loads generate the highest harmonic current profiles. Of these, the 3rd harmonic current (I_3), which is the first third order, zero-sequence harmonic current in the series as the following equation:

$$THD_1 = \frac{\sqrt{\sum_2^{\infty} I_n^2}}{I_1} = \frac{\sqrt{I_3^2 + I_5^2 + I_7^2 + \cdots}}{I_1} \quad (4)$$

W here; THD_I = current total harmonic distortion
I_n = harmonic rms current (in amps or %)
I_1 = fundamental frequency rms current

1-3 Effects on Voltage Distortion

The distorted load current drawn by the non linear load causes a distorted voltage drop in the cable impedance. The resultant distorted voltage waveform is applied to all other loads connected to the same circuit, causing harmonic currents to flow in them even if they are linear loads. The higher the harmonic current levels, the greater the resulting harmonic voltages, thus creating distortion in the electrical system voltage. The harmonic voltage measured across harmonic current generating load is the result of voltage drop due to the harmonic current passes through the impedance of the distribution system as:

$$V_h = Z_h * I_h \quad (5)$$

The voltage drop appears as harmonic voltage and the accumulation of these voltages at all harmonic frequencies produces the voltage distortion as [7]:

$$V_{TH} = (V_2^2 + V_3^2 + V_4^2 + V_5^2 \ldots\ldots V_h^2) \quad (6)$$

Where;
V_{TH} : is the total harmonic distortion of the voltage
V_h : votage at harmonic h
Z_h : system impedance

1-4 Effects on Transformers

Transformers are affected in two ways by harmonics, firstly, the eddy current losses, normally about 10% of the loss at full load, will increase with the square of the harmonic number, and the total transformer losses would be twice as high as for an equivalent linear load [9] as the following equation:

$$P_{EC} = P \sum_{h=1}^{h_{\max}} h^2 I^2 \quad (7)$$

Another problem is that the capacitor and stray inductance of the supply system can resonance at or near one of the harmonic frequencies, when it happens, very large voltages and currents can be generated leading to failure of the capacitor system.

1.5 Effect on average power transferred to the load.

the distortion power factor' describes how the harmonic distortion of a load current decreases the average power transferred to the load as following:

$$S_1^2 = P^2 + Q_1^2 \quad (8)$$

$$Q_t^2 = Q_1^2 + D^2 \quad (9)$$

$$S^2 = Q_t^2 + P^2 \quad (10)$$

Then the total power factor $\cos\gamma = P/S \leq$ the displacement factor $= P/S_1$ and could be improved by either reducing the amount of harmonic distortion power *(kVAd)* or reactive power *(kVAr)*

From equation 3:

$$\frac{P}{S} = \frac{\cos\theta}{\sqrt{1+THD^2}} \quad (10)$$

Where:
P : active power in $kW = V_1 I_1 \cos\theta$
Q_1 : Reactive power in $kVAr = V_1 I_1 \sin\theta$
D^2 :Distortion factor in $kVAd$

$$D^2 = V_1^2.(I_2^2 + I_3^2 + I_4^2 + \ldots\ldots) \quad (11)$$

2- ZERO-SEQUENCE HARMONIC FILTERS

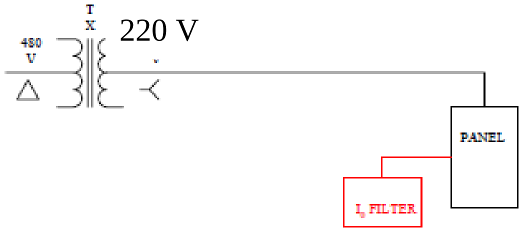


Figure 3. zero-Sequence harmonic filter

Application of Zero-Sequence Harmonic Filter will reduce neutral current, neutral ground voltage, peak phase current, total harmonic distortion and all circuit losses. Zero sequence filters I_0 are normally connected to a three-phase, four-wire panel that supplies single-phase, the I_0 Filter will remove most of the zero sequence currents from the phase and neutral conductors. **T**he sizing of an I_0 Filter is ordinarily based on the capacity of the sub-system's ultimate level of non-linear loads to generate zero-sequence harmonic currents, The equation for determining these ultimate values is as follows [8]:

$$I_{o\max Neut} = I_{FL\,Max\,\Phi} * HF_o * LF * 3 \qquad (11)$$

$I_{omaxNutral}$: Maximum zero seqquence harmonic curren that could flow on the nutral conductor

$I_{FLMax\Phi}$: Maximum fundamental current that will flow on phase terminals

HF_o : harmonic factor for zero sequence harmonic current

LF : is the load factor normally 80% of the transformer name plate.

3- APPLICATION:

Figure 2 shows the characteristics of Single-phase, non-linear loads which are prevalent in offices. Figure 4 illustrates the distorted wave as a result of 80 % third harmonic and 50 % fifth harmonic added . Also, third harmonic as zero sequence and its consequent additive effect in the neutral are studied. Applying Ohms law, all harmonic currents from the third to fifteen, we can show how the voltage drop across a neutral conductor creates a high neutral ground voltage , if a 30 mh reactor inserted in the neutral and shown in figure 5. Also, for low distortion levels, as for the voltage $V_{rms} = V_{,1}$ figure 6 shows the relation between rms voltage and THD. Also, effect of non linear loads on distribution transformer losses is illustrated in figure 7. The impact of these harmonics in distribution transformers is illustrated in figure 8. The harmonic distortion of a load current decreases the average power transferred to the load and their impacts are shown in figure 9. Considering a shunt zero-sequence impedance of <0.005Ω (compared to ≤0.1Ω for a source transformer), taking HF_o =0.6 and LF =.8 , the I_0 Filter will remove most of the zero sequence currents from the phase and neutral conductors as shown in figure 10. The calculated I_0 Max values for standard transformer kVA ratings is given in table 1.

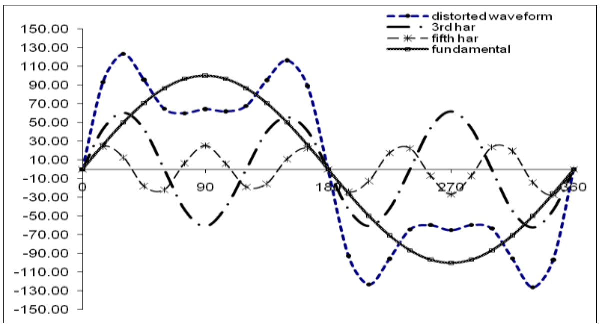


Figure 4. distorted waveform due to 3rd and fifth harmonic

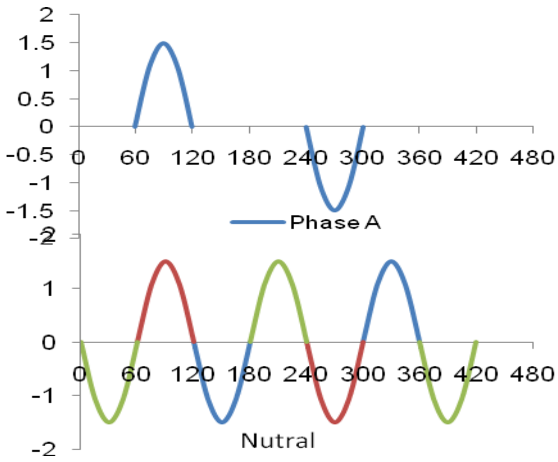


Figure. 5 third harmonic as zero sequence and its consequent additive effect in the neutral.

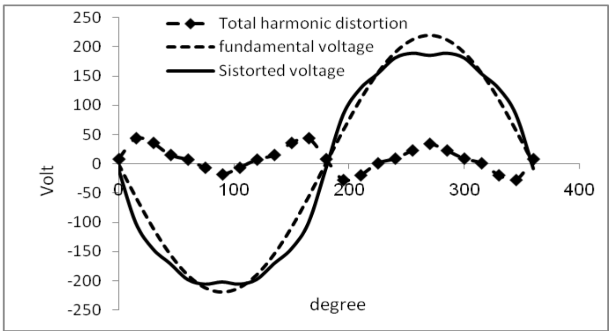


Figure. 6 effect of single phase non linear load on system voltage.

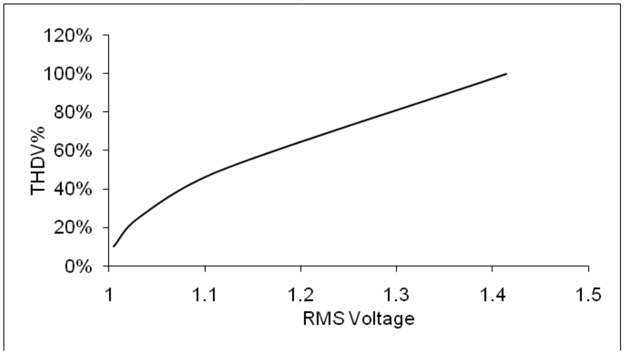


Figure 7 the relation between rms voltage and THD

Table 1. Maximum zero sequence harmonic currents

Rated transformer, kVA	I_{omax}
9	36
15	60
45	180
75	300
112.5	450
150	600
225	900
300	1200
500	2000

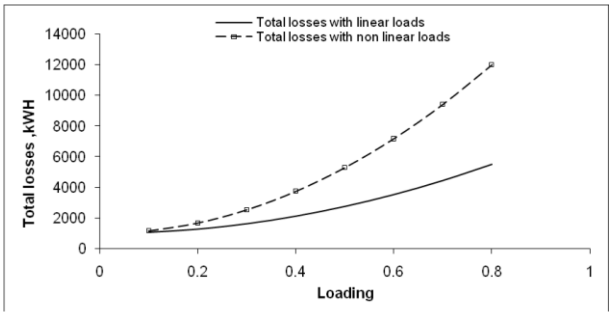
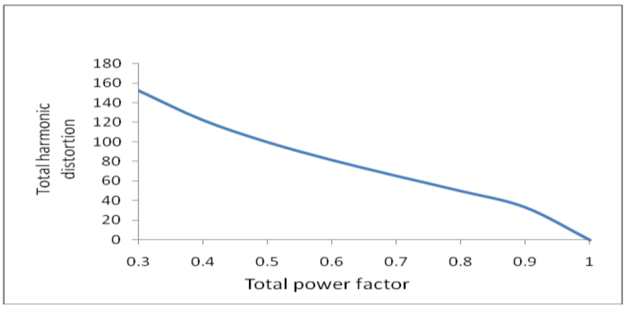


Figure. 8 effect of non linear loads on distribution transformer losses



Fgure 9. Effect of harmonic distortion of a load current on the average power transferred to the load

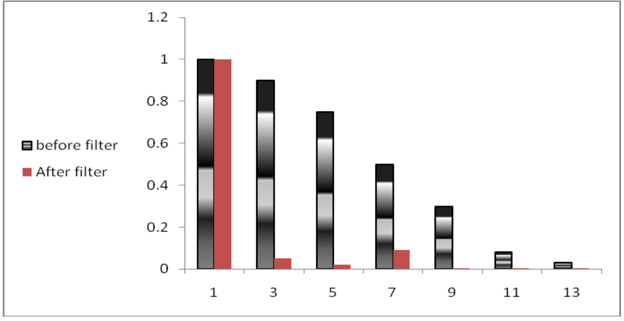


Figure 10 Harmonic current profiles with zero sequence filters

CONCLUSION

Harmonic pollution produced by electronic equipment such as PCs. It is this class of equipment that is causing many of the harmonic problems seen in industry and commerce today. partly because there are so many of them installed and because the type of harmonics they produce – and cause so many problems. So, In this paper case study was made using measurement calculation over a single phase, non-linear loads that are prevalent in offices. Effects of these non-linear loads upon system parameters were studied. Although the value of disturbances caused by a single load device can't be effective on the system, but huge number application of these devices in the industrial companies Simultaneously, can cause majority of harmonics in such systems. These harmonics leak in neighborhood of system, and affect the standard condition of the load that are supplied from adjacent bus-bars**.** The remarkable d

- THD of 35.36 % is the minimum limit of line current distortion required to produce 100% neutral current in a balanced wye system In some case the THD can be nearly 150 %.
- The number of current pulses accumulated in the panel neutral is three times that in the lines. The root mean square (rms) current increase, from one to three current pulses in a common time interval, is 173%.
- The devices create Zero sequence harmonic voltages will cause "flat-topping" of the voltage waveform or the reduction of peak voltage . In severe cases, data processing may be corrupted due to a momentary loss of power from the switch-mode power supply, or the power supply itself may fail.
- the higher the harmonic current levels, the greater the resulting harmonic voltages, thus creating distortion in the electrical system voltage
- Then the total power factor cos γ =P/S ≤ the displacement factor = P/S_1 and could be improved by reducing the amount of harmonic distortion power

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