STUDY AND TESTING OF LARGE NON-LINEAR LOADS EFFECTS ON THE DISTRIBUTION NETWORKS

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ABSTRACT

Developments of the different industries cause various problems for the electrical power systems. One of them is the non-linear effects of the loads that take non-periodic and or non-sinusoidal currents, such as the semiconductor devices, electrical furnaces, induction furnaces, welding devices and so on. This effects can overloaded the system as well as reduction of the system performance and efficiency, and so can have destructive effects on the other system loads in the neighborhood of such non-linear loads. In this paper the effects of such non-linear loads was studied in a typical distribution network. Welding devices in this system are chosen as non-linear load for studding. Using the measurement results of voltages and currents in this system, the harmonic components of the voltages and currents due to these loads were calculated. Also the effects of the non-linear load percentage, with respect to its nominal value, were studied.

1. INTRODUCTION

Due to the ever increasing number of nonlinear loads on distribution systems, the existence of harmonics, nowadays, is inevitable. It has caused the increase of waveform voltage and current supply distortions with the consequent loss in the power quality and as a result voltage and current waveforms are rarely sinusoidal. Also damage of the components of the networks has been produced such as in user's equipment. In addition, distribution systems are quite often unbalanced in nature. This necessitates the study of the combined effect of unbalance and nonlinearity on power system voltages and currents.

Results of simulations carried out to study the effect of unbalance on the harmonics injected by a 6-pulse converter drive, are presented [1]. Initial analysis is carried out in the phasor domain, and this is corroborated with results obtained by decomposing individual harmonics into symmetrical components. The performance of arc furnace models, under unbalanced conditions is also investigated, to observe the impact of unbalance on the modelling of nonlinear loads. Some of the conclusions of this paper are: 1. Converter in the presence of unbalance injects non-characteristic (triple) harmonics into the system. 2. Degree of unbalance affects harmonics differently, i.e. with an increase in the degree of unbalance, the non- characteristic harmonics increase, whereas the characteristic harmonics show a decrease. 3. The symmetrical component decomposition of individual harmonics helps to give an insight into the behaviour of harmonics under varying degrees of unbalance. 4. Unbalanced conditions render certain models for nonlinear loads, to be inadequate for use.

In order to study the impact of single-phase non-linear loads and sources in large-scale distribution systems, a hierarchical decomposed iterative simulation methodology is outlined [2]. The distribution network up to the PCC is computed in the frequency domain, whereas the customer subsystems are treated as a whole in the time domain. The customer subsystems are generated using statistical methods applied to standard load categories.

[3] aimed towards the development of an adequate method dealing with the possibility of identification of harmonic sources and focusing the problem of interactions between supply distortion and load distortion. The developed research work is composed of two parts. The first part is concerned to detect how each load in a power system network behaves under the influence of harmonics (determining the degree of the load non-linearity). The second part is devoted to develop a suitable quantitative measure for the share of waveform distortion produced by a single customer (non-linear load) when there are many customers (linear and non-linear loads) sharing the same distribution network. An estimated degree of waveform non-linearity is introduced and evaluated through the indication of a new harmonic factor that is known as the non-linearity factor (NLF) This factor was useful to asses the responsibility share of the distortion level of each individual distorting load connected to the same feeding point

Power system simulation over a few cycles is performed producing sampled current and voltages, which subsequently can be analyzed by Fourier transforms [4].

As it is usually difficult to gather enough information about nonlinearity of individual loads in large distribution networks, it is often easier to measure the current and voltage distortion at the substation level, which can then be used to calibrate the simulation model. The substation monitoring data can provide information about the level of individual harmonic distortion contribution (voltage *VDh* and current *IDh*), which can be reproduced by the current and voltage harmonic sources *ISh* and *VSh*. The current source *ISh* represents the distortion injected into the network by the nonlinear loads connected to the substation. Voltage source *VSh* is present in order to simulate the harmonics induced from the supply side.

With the aim to study the distortion in the network studies of harmonic flows with appropriate models for that, these simulations will be carried out with the Electromagnetics Transients program ATP (Alternative Transients Program) [5]. In this case, it will be made a study over a network of AT/MT (High voltage/ Medium voltage) (132/13.2kV), which has installed capacitor banks in different substations. The purpose of this study is to get the impedance versus frequency in different system points with both load models, using the capacity of ATP to make frequency scan.

Fluctuation of voltage is considered one of the most harsh power quality events because of its detrimental effects on most electronic and control circuits [6]. These circuits are generally characterized by its sensitivity to any variation in the supply voltage. Voltage fluctuations are systematic variations in the voltage envelope or a series of random voltage changes. The magnitude of these fluctuations lay between 10% of the rated voltage. One of voltage fluctuation effects is causing the light to flicker, so voltage fluctuation, being an electromagnetic phenomenon, is always referred to as voltage flicker. Beside its effect on light, other flicker consequences are to reduce the life span of electronic, incandescent, fluorescent and cathode ray tubes, malfunction of phase locked–loops PLLs and misoperation of electronic controllers and protection devices. Sources of voltage flicker are numerous. Arc furnaces and arc welders head the list. Motor starting, fans, pumps, elevators, and switching of power factor capacitors are among the most common cause of voltage flickers. Cyclic voltage flicker exists when there is a slow change in the voltage magnitude with frequencies between 0.5Hz to 25Hz, which appear as a superimposed signal on the fundamental signal (carrier signal). The superimposed signal, which is generated due to the voltage flicker, appears as a change in the fundamental signal envelope and is commonly known as “the instantaneous flicker level”. Deregulation has emphasized the necessity for new schemes, which are capable of tracking and mitigating voltage disturbances due to non-linear loads. This paper introduces a new approach to track the voltage flicker levels in distribution systems, which is produced by large non-linear loads like arc furnaces. The new tactic depends on an innovative technique for voltage disturbance tracking, which utilizes the Teager Energy Operator TEO. This paper discloses that TEO is capable of tracking the amplitude variations of the flicker voltage in industrial systems. Results are presented to validate and verify the tracking capability of TEO and to indicate superior performance of TEO to track voltage flicker.

2. CASE STUDY

A subsystem as in Fig. 1 is considered as a case studying system. Measuring instruments were installed in three points of the system (A, B and C), for measurement of the system variables such as voltage, current and power. Parameters of all of the system cables, such as resistance, reactive and capacitive reactance are shown in this diagram.

In this typical system, non-linear loads are single phase welding devices (MILER welding device with maximum output of 250 A) that feed from this system. When the welding devices are feeds from a system, normal operation condition of the system will be disturbed. This disturbance is due to the pulsating currents of the welding devices that can have 0.5 A/μs increasing intensity with maximum of 700 A. This pulsating feed currents cause dips in the voltage waveform of the system and can increase of the flicker generation probability in the system.

For studying of the harmonics caused by these non-linear loads, and the secondary effects on the different parameters of the system near or far from these loads, some different variables of the system were measured. For this purpose some measuring devices are installed in different points of the system near and far away from these loads. These points are shown as point A, B and C in Fig. 1.

For better studying of the effects caused by these loads, measurements are down for many load values of the welding devices. For this purpose output power range of the welding devices were varied from 10% to 80% of their maximum value, and the voltage, current and power were measured in all the conditions in all three measuring points synchronously and simultaneously.

All dates are measured for over 3200 ms, which applied for voltage and current total harmonic distortions (THD_v, THD_i) using Fast Fourier Transform (FFT).

In Fig. 2 variations of the THD values of the measured voltages in the three different points (A, B and C) of the system and measured current in the point C of the system are shown.

By starting of the welding, result to increase of the voltage distortion level of the network from its base value of 0.83%. This distortion level depends on the output of the devices. These curves show that the distortions were maximized in about 65% of devices nominal ratings.

Harmonic distortion values, using harmonic numbers 3, 5, 7 and 11, of voltages and current measured in all three points A, B, and C are shown in Figs. 3-6.

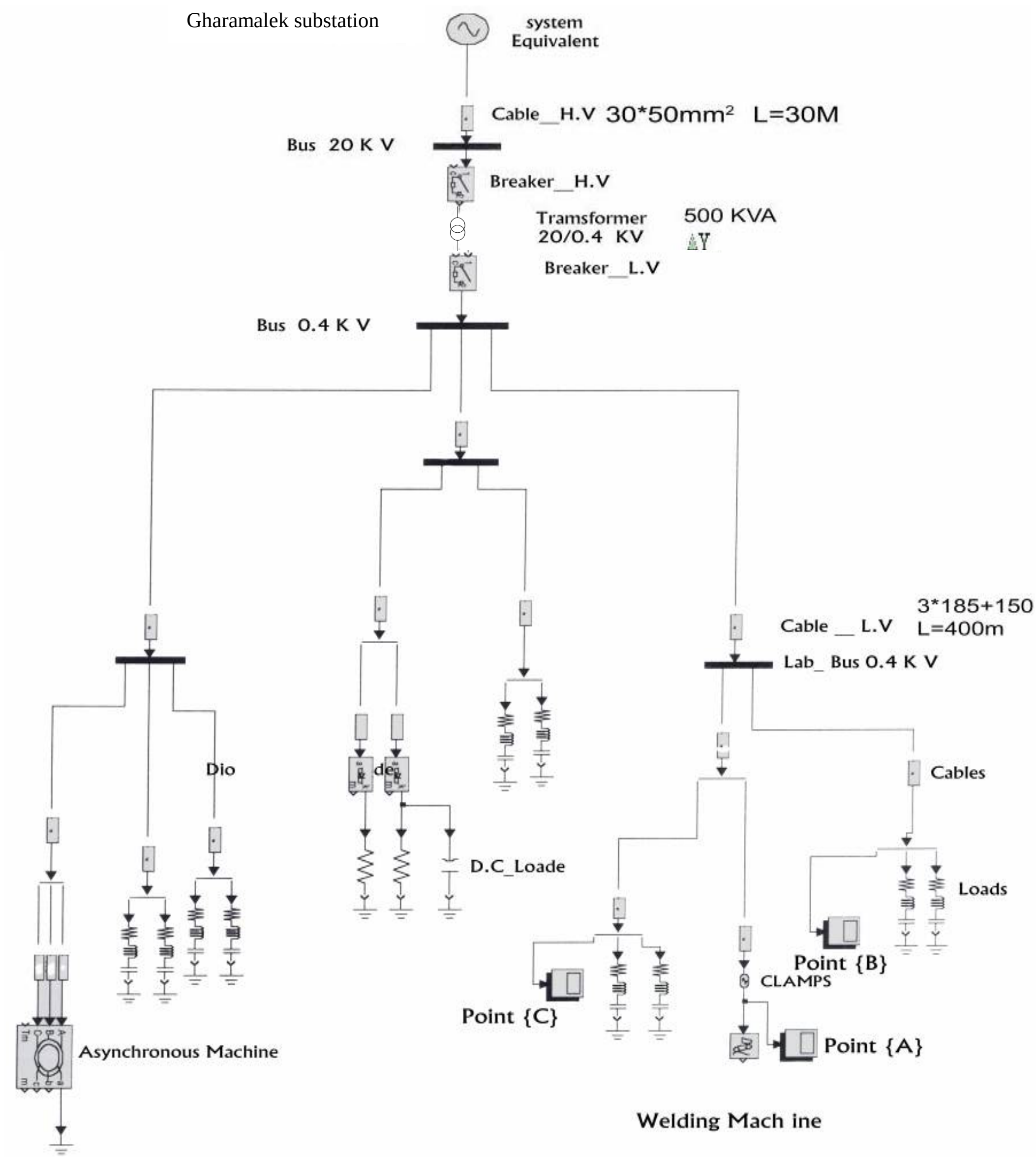

Fig. 1. Sub-distribution system as the case study

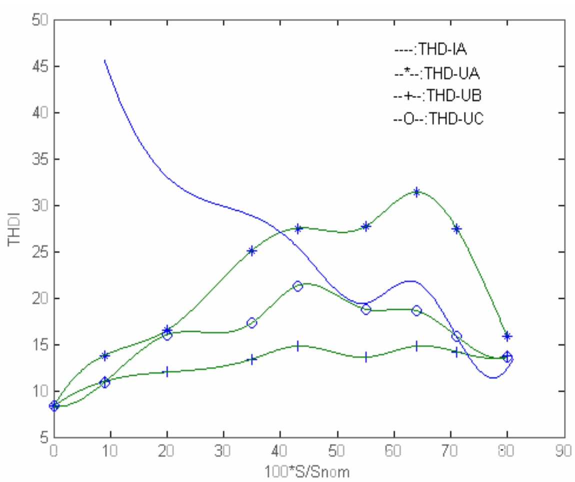

Fig. 2. THD variations versus load level

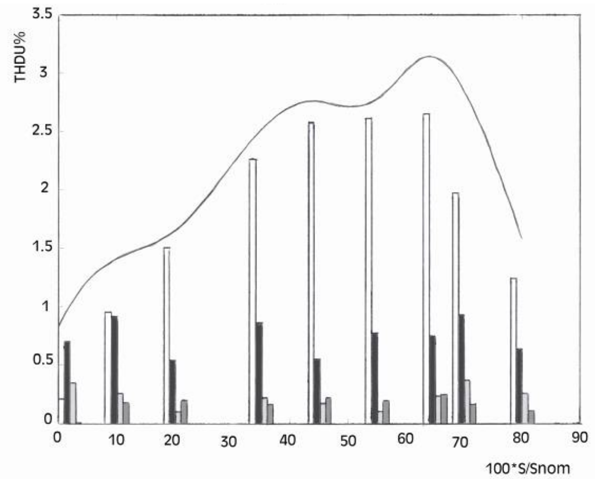

Fig. 3. Variation of voltage distortion factors in point A versus load

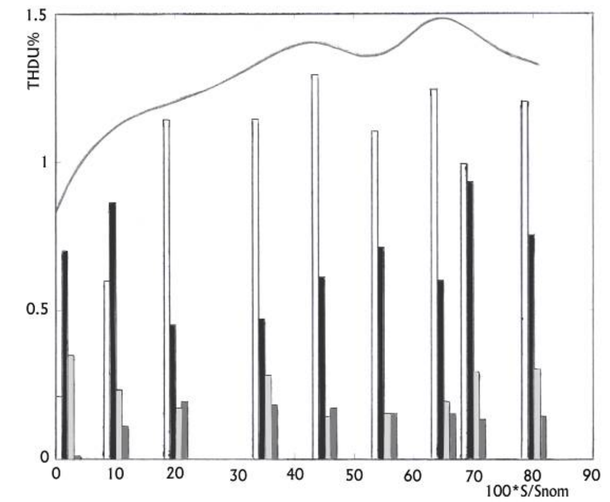

Fig. 4. Variation of voltage distortion factors in point B versus load

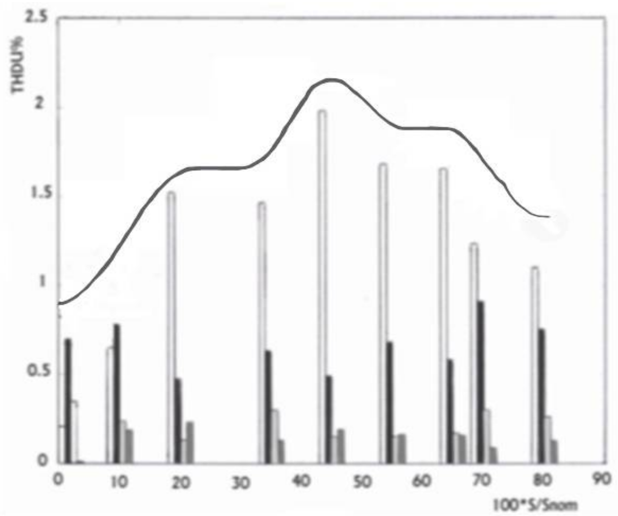

Fig. 5. Variation of voltage distortion factors in point C versus load

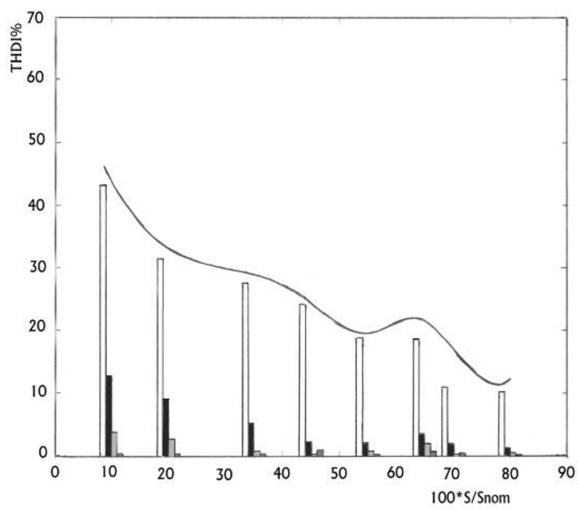

Fig. 6. Variation of current distortion factors in point A versus load

Above the 65% of the devices load level, distortion of the voltage starts to decrease. Because of the fixed values of the system impedances, this effect can be made due to the decreasing of the non-linearity of the welding devices in larger loads.

3rd and 5th harmonics are the major ones of the voltage distortion. This fact can be shown using figs. 3-5 when the load is zero (%S=0). Increasing of the devices loads, lead to the increase of the 5th harmonic value, hence the value of the 3rd harmonic is largely increases.

Current distortion starts to decrease with increase of the devices load. We can show this fact in Figs. 2 and 6. Fig. 7 shows the current waveforms with increase of the devices loads.

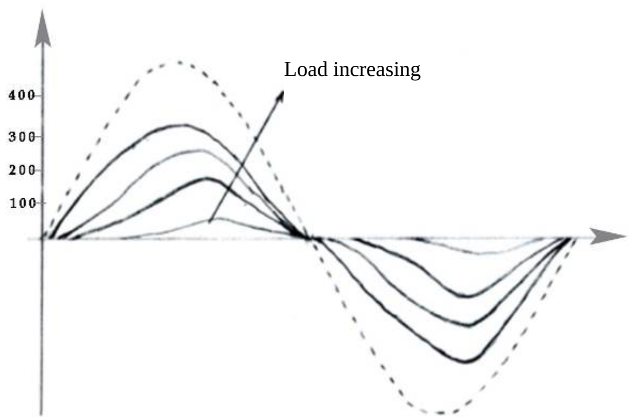

Fig. 7. Current waveforms with increase of the devices loads

In lower loads, distortion of the current is very high, but due to the low value of rms current, voltage distortion is lower.

Figs. 2-5 show that the distortion caused by the welding devices near the point B, was distributed through the network, such as points A and B that are far from the loads. Harmonic currents flow through the network, causes voltage harmonics drops through the system impedances that they leads to distribution of the voltage distortions the system. Because of different impedances of the system in different points, the value of the voltage distortion is different in three points A, B and C.

We can use equation 1 for reactive power calculation and study of the non-linear loads effects in the reactive power distribution in the system.

$$Q = \sqrt{S^2 - P^2} \qquad (1)$$

where S and P can b4e calculated using equations 2-5 as follows:

$$P = \frac{1}{128}\sum_{i=1}^{128} U_{xi} \times I_{xi} \qquad (2)$$

$$S = U_x \times I_x \qquad (3)$$

$$U_x = \sqrt{\frac{1}{128}\sum_{i=1}^{128} U_{xi}^2} \qquad (4)$$

$$I_x = \sqrt{\frac{1}{128}\sum_{i=1}^{128} I_{xi}^2} \qquad (5)$$

Fig. 8 shows the variation of the welding devices reactive power versus their apparent power. Reactive power of the devices is increased proportional with their apparent power approximately.

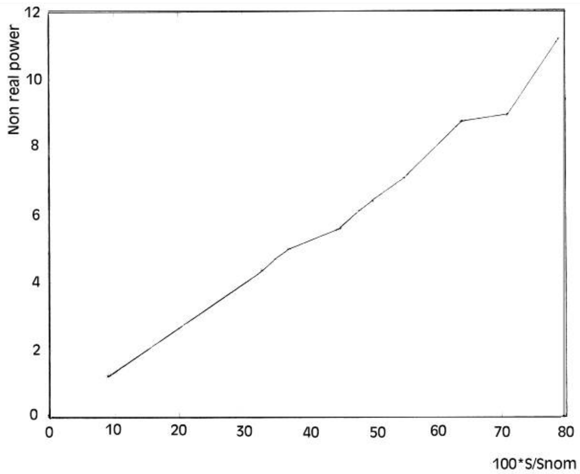

Fig. 8. Variation of the reactive power versus apparent power of the welding devices

3. CONCLUSION

In this paper case study was made using measurement and calculation over the single phase welding devices as non-linear loads. Effects of these non-linear loads upon the system parameters were studied. Although the value of disturbances caused by a single welding device can't be effective on the system, but huge number application on these devices in the industrial production companies simultaneously, can cause majority of harmonics in such a systems. These harmonics leak in neighborhood of the system, and affect the standard load condition of the loads that are supplied from adjacent bus-bars. The results show that other than the harmonic effects of these loads, reactive power of the devices is increased proportional with their apparent power approximately, and the overall power drop of the system can be increased, leads to the poor efficiency of these systems.

4. REFERENCES

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