HARMONIC ANALYSIS OF AN INDUSTRIAL SYSTEM

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Keywords: Power System Harmonics, Power Factor Correction, EMTP program

ABSTRACT

It is becoming increasingly important for power system planning and operating engineers to be capable of improving power factor high at systems. Traditionally it has been improved by using capacitors. With the widespread use of nonlinear loads, power factor improvement has become more complicated and it is a good engineering practice to analyze the impact of the power system by performing harmonic modeling analysis of the system. This paper presents the results of current, voltage, power, and harmonic measurements in a real low voltage industrial system. The system behavior is analyzed using the simulation program EMTP/ATP which is a powerful tool for power system simulation. The results of measuring and simulations are discussed.

I. INTRODUCTION

Harmonic distortion is today presents in almost all power systems. The distortion level varies much from system to system and at different voltage levels. The total voltage distortion varies from %10 at some distribution transformers to about %1 at transmission level. The total current distortion varies from %200 at some load terminals to a few percentages at transmission level [1].

The increase of the total voltage distortion is due to the increase of the current distortion, but it is also depends on the lower short circuit power and the rated power at lower voltage levels, compared to higher voltage levels [1,2]. This can be dangerous to some sensitive equipment (e.g. protection devices, capacitor banks) and some sensitive loads (motors, computers, etc) [3]. The distortion of voltage and current cause additional losses in power system components and linear loads.

Three phases unbalanced voltages also cause harmonic currents for three-phase equipment. Some components of the system effect both fundamental voltage and harmonic frequency; for example harmonic filters. Power factor correction capacitors are linear elements with impedance that decrease with harmonic order and they form an additional path for the harmonic current. Harmonic resonance is a well-known consequence of this path.

Harmonic filter design problems can be classified into two categories common to industry: one where equipment injects harmonic currents at unacceptable levels, and one where equipment injects harmonic currents that excite a resonance.

In this paper we introduce the problem of the presence harmonic distortion in an industrial system because of compensation. We concentrated on the measurements in the system. Measurements were in process according to conditions specified in [4]. It has been observed that the magnitude of distortion of voltage and current depends on the power factor of the system. The results of measurements are discussed for different conditions of the system with EMTP/ATP.

II. POWER DEFINITIONS AND HARMONIC LEVEL

Existing power definitions for single-phase and three-phase system work well when voltage and current are sinusoidal. However, the power definitions under non-sinusoidal conditions are nowadays strongly discussed. There isn't a consensus in the interpretation and definition of non-active powers in circuits with distorted and/or unbalanced voltages and current. For a single-phase, the instantaneous voltage and current expressions under nonsinusoidal conditions are defined as:

$$v(t) = V_0 + \sqrt{2}\sum_{h=1}^{\infty} V_h \sin(h\,w\,t + \alpha_h) \qquad (1)$$

$$i(t) = I_0 + \sqrt{2}\sum_{h=1}^{\infty} I_h \sin(h\,w\,t + \beta_h) \qquad (2)$$

where:

V_0, I_0 = DC voltage and current components
V_h, I_h = rms value of the h_{th} voltage and current harmonic
α_h, β_h = phase angle of the h_{th} voltage and current harmonic
w= 2π f = angular speed of fundamental frequency f

In industry the most popular expression of power is Budeanu's definitions [5]. This definition is based on the superposition of the reactive power at each frequency to obtain the total reactive power in nonsinusoidal conditions and is given by:

$$Q = \sum_{h=1}^{\infty} I_h V_h \sin\theta_h \qquad (3)$$

The apparent power is:

$$S = \sqrt{P^2 + Q^2 + D^2} \qquad (4)$$

Here, P is active power and D is Distortion power, which should reflect the level of distortion injected by nonsinusoidal current and voltage.

There are various national and international limits on harmonic current injection into the system by nonlinear loads. The most common indication of harmonics presence is Total Harmonic Distortion factor (THD), which can be obtained both voltage and current as:

$$THD_{(V)} = 100\sqrt{\frac{\sum_{h=2}^{\infty} V_h^2}{V_1^2}} \qquad THD_{(I)} = 100\sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{I_1^2}} \qquad (5)$$

Total Demand Distortion factor (TDD) also used during calculation of current distortion at the point of common coupling between customer and utility. The limits for the harmonic pollution are defined both for the whole harmonic span (THD) and for each harmonic (HD) and inter-harmonic component of the system [5].

III. MEASUREMENTS IN INDUSTRIAL SYSTEM

The diagram of the industrial system is presented in Figure 1. The system under investigation consists of a power source representing a practical distribution transformer and a nonlinear load combination.

All data were determined from 45 minutes metering provided by the utility over one typical week operation. Figures 2-6 are some measurements taken from the system.

The Power Factor Control relay (RVC), takes current data from Phase 2. It's cosφ parameter was set to 0.99 and also some of its parameters were set wrong (for example sequence, C/k). So there isn't a good compensation for the system.

When the measurements are examined, it is observed that there is a failure because of compensation of the system. The power factors of the phases are very low. Phase–1 is capacitive % 80 of total measurement period. Also Phase-2 and Phase-3's power factors are less than 0.8.

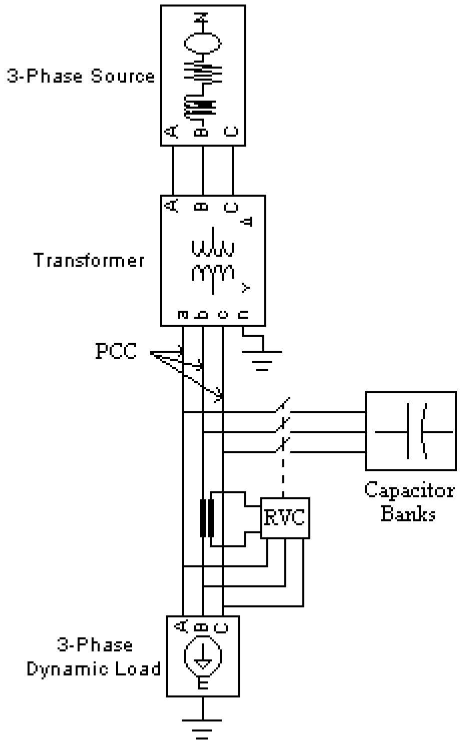

Figure 1. Diagram of industrial system.

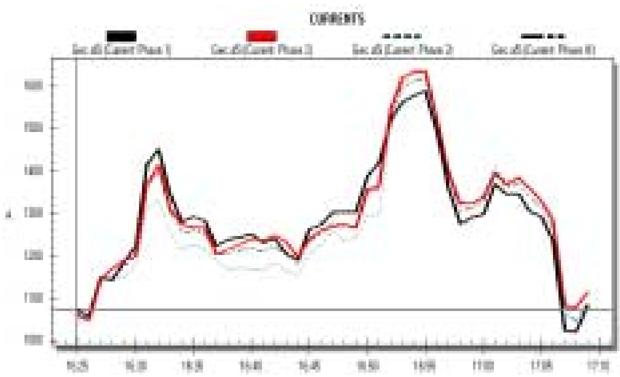

Figure 2. Phase currents.

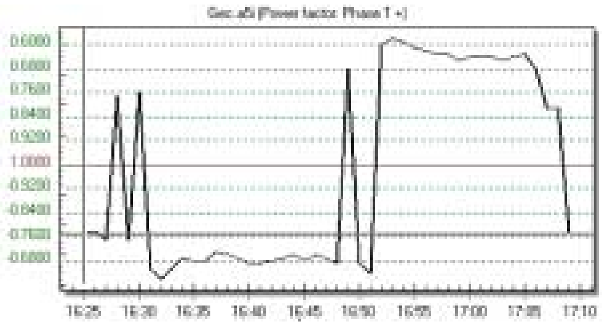

Figure 3. Power factor of Phase-1.

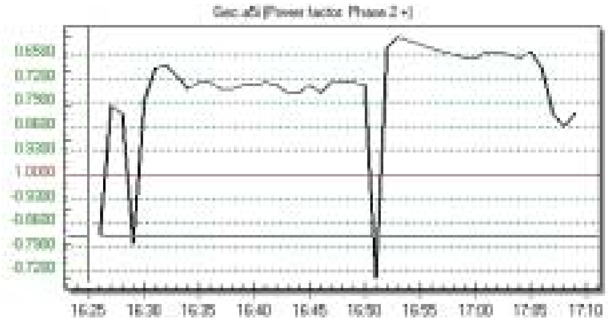

Figure 4. Power Factor of Phase-2.

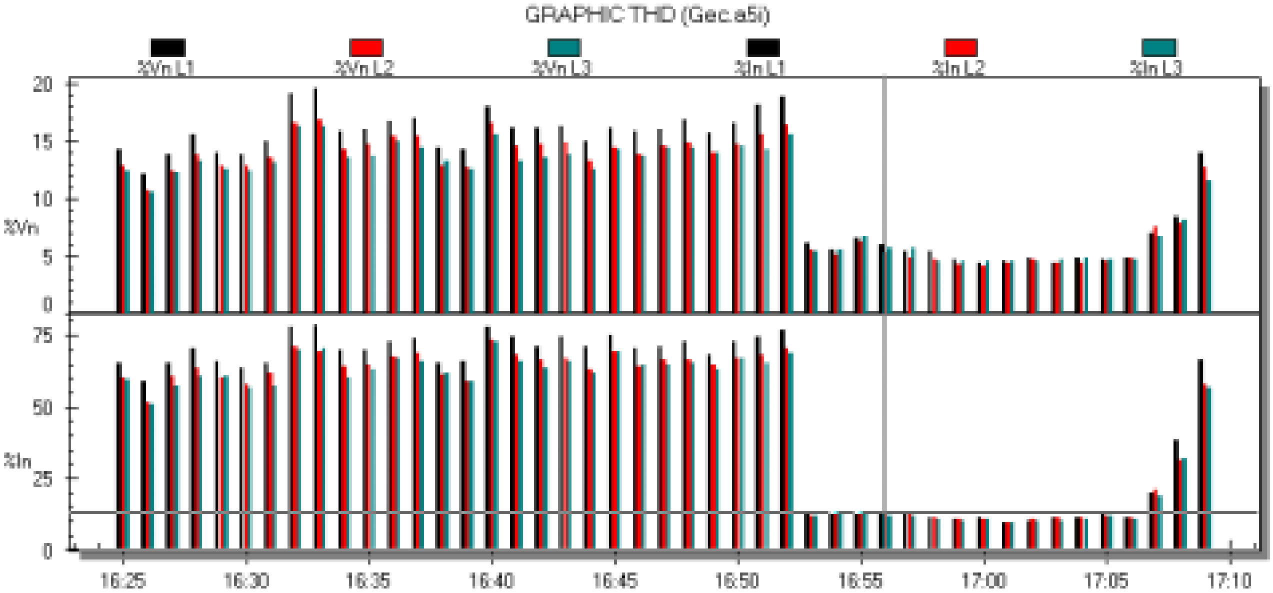

Figure 5. Voltage and current distortion of the system.

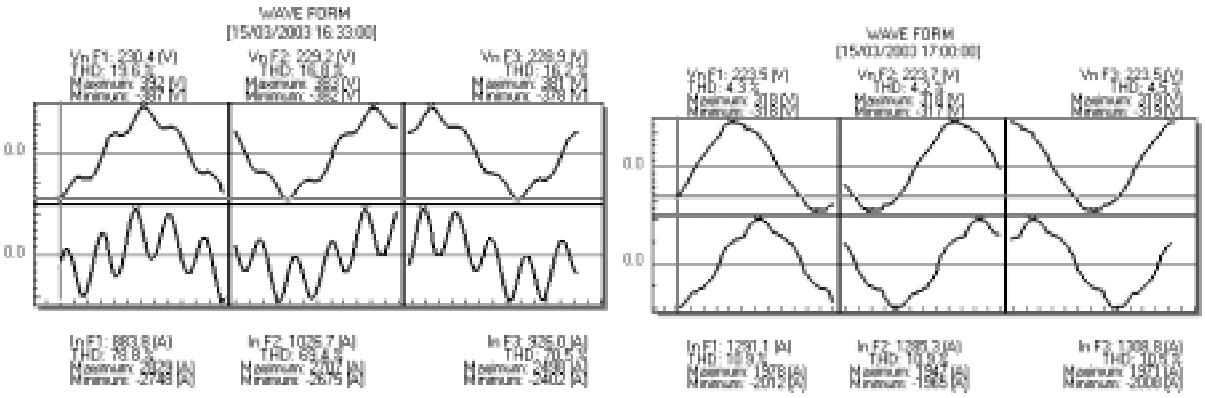

Figure 6. Voltage and current waveform of the system at 16:33 &17:00.

When THD's of voltage and current are taken into consideration, it can be seen that the voltage and current harmonics are rather high levels. Their minimum levels are between 16:53-17:56. So it is interesting to see what is happing during this time and why THDs are decreasing?

If we look the power factors of the phases, we can answer this question. During this time power factors are: Phase-1: 0.58-0.68, Phase-2: 0.6-0.69, Phase-3: 0.58-0.67 inductive. So it is required to analysis the system at minimum and maximum THD. For example the displacement power factor of Phase-1 is 0.6 and voltage and current distortions are %4,35 and %10.935 respectively. At 16:33 the displacement power factor of Phase-1 is –0.65 capacitive and voltage and current distortions are %19.61 and %78.814. The voltage and current waveforms at 16:33 and 17:00 are shown in Figure 6.

IV. SYSTEM MODELLING AND ANALYSIS

The most popular technique used for harmonic analysis is the frequency scan in which the frequency response at particular node or bus is calculated [6].

The common way of harmonic analysis is performed using steady state, linear circuit solution techniques. Harmonic sources, which are non-linear elements, are generally considered to be injection sources into the network models.

The EMTP model was developed based on the simplified circuit given in Figure 7. to evaluate the impact of nonlinear loads on distortion in the distribution system. All capacitances and inductive coupling between phases in all cables were neglected. The source system was modeled as a pure sinusoidal source with impedance derived from short circuit data.

The waveforms of the injected current for the dominant non-linear load were taken the measurements described above. The harmonic currents are modeled using harmonic current injection. The frequency and magnitude of the injected harmonic currents was obtained in measurements carried out at point of common coupling (PCC).

Distribution transformer with the similar characteristics is monitored. This consideration is very important because in the detailed system, the transformers are important source of lower system harmonics. It is because sinusoidal magnetization of iron needs a third harmonic, also 5^{th} 7^{th} etc., components of current [7].

The transformer is represented by a combination of series and parallel impedances. The values of these elements, at he h^{th} harmonic order, are calculated directly from the fundamental frequency series-impedance of the transformer [8]:

$$Z_T = R_T + X_T \qquad (6)$$

$$R_S = R_T \qquad (7)$$

$$X_p = hX_T \qquad (8)$$

$$R_P = 80X_T \qquad (9)$$

Thus the equivalent harmonic impedance of the transformer is:

$$Z_{th} = R_S + \frac{h^2 X_T{}^2 R_P}{R_P{}^2 + h^2 X_T{}^2} + j\frac{hX_T R_P{}^2}{R_P{}^2 + h^2 X_T{}^2} \qquad (10)$$

The positive/negative sequence equivalent-circuit used for the EMTP/ATP simulation is shown in Figure 6.

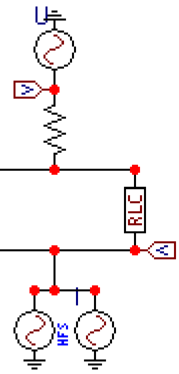

Figure 7. ATP model of the industrial system (One phase simulation)

Figure 8 and 9 show the waveform of the system voltage and current at 16:33 and 17:00.

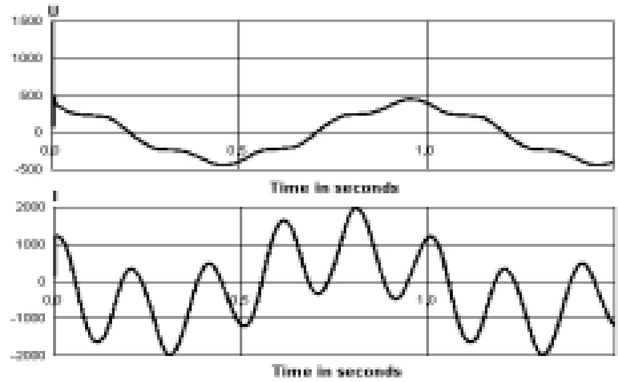

Figure 8. Waveform of harmonic voltage and current at 16:33

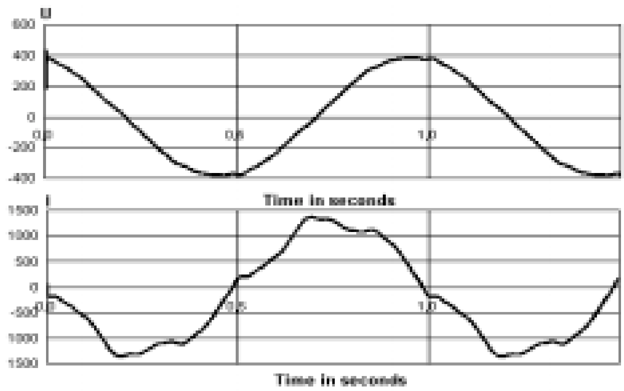

Figure 9. Waveform of harmonic voltage and current at 17:00

V. CONCLUSIONS

In this paper we have investigated harmonics of an industrial system. The cases, when the capacitors are installed and not installed considered. Simulations were done for both cases.

From Figure 8 and 9, it can be seen that, for such a system, when the capacitor banks are out the distortions of voltage and current are decreasing. So it is very important to make a good compensation for systems as improving power factor as distortion.

From the application point of view, this analysis showed that is very difficult to compare experimental with simulation results. However the proposed modeling is practical and provides good results take in consideration the complexity of harmonic analysis.

The type of analysis employed here is straightforward and should be employed when nonlinear loads are to be added to industrial system for three phases.

VI. REFERENCES

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