THE EFFECT OF POWER QUALITY DISTURBANCES 
ON THE ELECTROMAGNETIC COMPATIBILITY

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Key words: Electromagnetic compatibility, Harmonics, Power quality, Transients.

The paper presents measurement results of a power quality monitoring on the industrial plant. The measurements proved that supply conditions are correct, but a cumulative effect of increasing use of electrical and electronic equipment and electrical disturbances can have an important impact on the electromagnetic compatibility. A case of possible resonance between power factor correction capacitors and the stray inductance of the supply system at or near one of the harmonic frequencies is described. When this happens, high voltages and currents can be generated often leading to catastrophic failure of the power electronic equipment.

1. INTRODUCTION

For most utilities, a good assumption is that the sine-wave voltage in electrical power system stations is very good. The distortion of sine-wave voltage increases closer to the non-sinusoidal load. The progress of power electronics applications, especially in distribution networks, introduces new inconveniences to proper system operation. Electrical equipment has become increasingly complex and it interacts with other electrical equipment through the medium of the electrical network [1].

According to [2] the Electromagnetic Compatibility EMC is defined as: the ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

An increasing important feature is the cumulatively disturbing effect of emission from equipment connected to the network in large numbers and operating simultaneously [1]. A nonlinear device caused a harmonic distortion of current waveform. Static Power Converters are used in industrial plants for controlling loads, they are nonlinear, so that they require current from the power system that is non-sinusoidal [3, 4, 5].

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In the power systems, the response of the system is equally important as the sources of harmonics. There are three primary variables affecting the system response characteristic: the system impedance, the presence of a capacitor bank, and the amount of resistive loads in the system. When the natural frequency in power system is equaly with harmonic frequency of a non-linear device a resonance may develop in which the voltage and current at that frequency continue to persist at very high values.

2. MEASUREMENTS PERFORMED AT THE CUSTOMER

In Fig. 1a are illustrated the monitoring power quality display bar graphs at customer’s 6 kV substation on a considered interval. The monitored parameters was: the RMS values of the voltages for each phase (first three bars), the content of harmonics for each phase (second group of three bars), flicker for each phase (the third group of bars), voltage dips, interruptions, rapid voltage changes, swells, unbalance and frequency (sequent bars).

The trend screen (Fig. 1b) shows the changes over time of the RMS voltage over the monitoring period (92 hours) for AB phase. The calculated values of the trend at the cursor was: maximum value 99.4 V, average value 99.2 V and minimum value 99.1 across a 10-minute period.

Fig. 2 shows the content of harmonics of the A phase current with the variation of the distortion coefficient over the same monitoring period. The mean value of the total distortion (THD) factor over the monitoring period was 2.2 % and the maximum value was 2.6 %.
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Voltages and currents dips, interruptions, rapid voltage changes and swells for all three phases don’t violate their limits.

Fig. 3 shows the graphics of the variation of the unbalance of the three-phase system of voltages and the variation of the frequency.

The main conclusion is that all monitored parameters never surpassed their standard limits at customer’s service entrance during an observation period (over 92 hours). Measurements were performed with Fluke 434 Three Phase Power Quality Analyzer. All different screen types to present measuring results have common information: \( \text{9} \text{2} \text{0} \text{1} \text{5} \text{1} \) - time that measurement has been going on, \( \text{01/21/06 16:45:22} \) - date and time, \( 100 \text{ V} 50 \text{ Hz} \) – nominal line voltage and frequency, \( 3\Omega \text{ DELTA} \) – number of phases and wiring configuration, EN50160 – name of the limits for the power quality MONITOR, \( 2\times \) horizontal ZOOM.
3. MEASUREMENTS AT THE NONLINEAR DEVICES

Due to the damages claimed by the industrial plant in the 0.4 kV network in the Adjustable-Speed Drives (ASD) circuits of the asynchronous motor of 110 kW which draws the ventilation fan, measurements have been performed at the nonlinear devices of the customer.

Fig. 4 – Scope waveform screen of C phase voltage and current (a) and harmonics table (b) of currents for 0.4 kV capacitors bank.

Fig. 4 shows the shape of the waveform of the voltage and the current on one phase (Fig. 4a) and the content of harmonics of the currents over all three phases (Fig. 4b). We may notice large total harmonic distortion of the current wave and an

Fig. 5 – Scope waveform screen of C phase voltage and current (a), harmonics bar graph of current (b) for induction motor, 110 kW, 1000 rpm, ASD.
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important weight of the harmonics of 7 and 11 order. At the induction motor of 110 kW powered through frequency converters we noted large distortions of currents and a harmonics content like in Fig. 5 a,b.

Thus at a speed of 1000 rpm the most significant weights are presented by the harmonics of order 3, 5, 7, 11, and 13. Fig. 6a shows the weights of the harmonics for the currents of all three phases. At a speed of 1400 rpm the wave shape of the currents is similar like we may notice in the oscillogram shown in Fig. 6b.

At the DC motor of 200 kW powered through a power three-phase rectifier the shape of the voltage and current wave on one phase and the content of harmonics of the current wave are shown in Fig. 7.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>N</th>
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<td>68.2</td>
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<td>97.6</td>
</tr>
<tr>
<td>10.1</td>
<td>9.8</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>51.0</td>
<td>54.5</td>
<td>52.3</td>
<td>0.3</td>
</tr>
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<td>35.0</td>
<td>36.4</td>
<td>0.2</td>
</tr>
<tr>
<td>2.7</td>
<td>2.0</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td>12.1</td>
<td>12.0</td>
<td>11.3</td>
<td>0.2</td>
</tr>
<tr>
<td>7.2</td>
<td>7.4</td>
<td>6.8</td>
<td>0.2</td>
</tr>
<tr>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Fig. 6 – Harmonics table of currents for induction motor, 110 kW, 1000 rpm (a) and scope waveform screen of C phase voltage and current for induction motor, 110 kW, 1400 rpm (b) ASD.

Fig. 7 – Scope waveform screen of C phase voltage and current (a) and harmonics bar graph of current (b) for DC motor, 200 kW.
The system is properly sized to handle the power demands of the loads and the distortion of the voltage waves is not significant but we may notice a significant distortion of the currents waves. The harmonics of order 2 and 4 have the same size as the harmonics of order 3. The content of harmonics for all the currents is shown in Fig. 8a and the harmonics spectrum is shown in Fig. 8b.

![Fig. 8 – Harmonics table (a), and harmonics bar graph (b) of all currents for DC motor, 200 kW.](image)

4. **THE ASSESSMENT OF RISK SITUATIONS OF TRANSIENT OVERVOLTAGES APPEARANCE. PROPOSED SOLUTIONS**

The provider or the customer does not have continuous monitoring systems of power quality and consequently, we made studies and calculations to evaluate the possibility of favorable situations for appearance of transient overvoltages.

We calculated the rank of the parallel resonance frequencies \([1, 6]\) at the setting place of the capacitors bank to compensate the power factor. At the customer, for the 0.4 kV capacitors bank, having an adjustable power of 400 kV Ar, we obtained an order of the resonance harmonic of \(n_{ar} = 8.26 \ldots 16.5\). The current absorbed in the capacitors battery has a specter with large weights for the harmonics of order 7 and 11. This fact implies a great risk of harmonical overvoltages especially when the network is weakly loaded.

At the provider where the short circuit power was of 157 MVA, we obtained a rank of parallel resonance frequencies at the setting place of the capacitors bank of \(n_{ar} = 11.44\). We must mention the fact that in the previous calculations we took into consideration the value of the short circuit power at the setting place of the capacitors bank. This value varies in large limits which leads to great variations of the parallel resonance frequency.
In consequence, the values calculated previously for the rank of the parallel resonance frequency give indications concerning only the interval of variation of the resonance frequencies. Any presence of superior harmonics in the voltage or current waves with frequencies close to the calculated values may generate harmonical overvoltages especially in case of a weakly loaded network.

We identified some risk situations that may appear in the electric plant and that may lead to dangerous overvoltages:

- **Resonance phenomena at the provider’s setting place of the 0.4 kV capacitors bank.** As we mentioned above, at the setting place of the capacitors bank we obtained an order of the resonance oscillation harmonic of \( n_{nr} = 8.26 \ldots 16.5 \). The customer has receivers of large power with a high degree of harmonical pollution. Superior harmonics of order 7 and 11 with significant weight are present in the wave of the current absorbed by the capacitors battery of 0.4 kV. In conclusion there is a risk of generating resonance overvoltages on the frequencies of order 7 and 11.

- **Oscillation phenomena at the emergence of some faults on the 20 kV lines leaving from the provider’s installation.** At the emergence of some faults on the 20 kV lines powered by a 6/20 kV transformer, it appears a supplementary contribution to the short circuit current due to the discharged currents by the capacitors bank. The customer’s oscillation frequency of the 0.4 kV capacitors bank at the appearance of a short circuit on the 20 kV lines is of \((5.6–11.15) \times 50 \text{ Hz}\) when the battery of capacitors has a power between 100–400 kVAR.

- **The magnification of some transitory overvoltages due to the correction capacitors at the customer location.** For the magnification of transitory overvoltages due to the correction capacitors there is a typical [1] powering scheme. Usually in the case of some capacitors the transitory overvoltages with values of 1.3–1.4 p.u appear only on the 6 kV side [1,7]. If there are capacitors to compensate the power factor on the customer’s low voltage poles these transitory overvoltages are amplified up to values of 3.0–4.0 p.u which may lead to the destruction of the customer’s equipment. The electronic devices will be mostly affected because they are more sensitive to overvoltages.

Proposed solutions for the provider:

- Adoption of powering solutions for the polluting customers so that the rank of the parallel resonance oscillation at the setting place of the batteries to compensate the power factor must not be close to the rank of non-sinusoidal current harmonics absorbed by the polluting customer,

- Setting up continuous monitoring systems of power quality,

- Application of new solutions for the connection devices of the capacitors bank: switches with resistance pre-insertion and asynchronous switches,
Proposed solutions for the customer:

- Analysis and application of solutions to reduce the current harmonics like the connection of some smoothing induction coils, reducing of harmonical impedance of the powering source, structural modification of the powering scheme of the polluting customers, introduction of some transformers with adequate connection, the use of some anti-harmonical inductances, or the setting of some harmonics filters,
- Analysis and application of solutions to avoid situations in which the natural resonance frequency of the network is close to the frequencies of the superior dominant harmonics of the non-linear customers,
- Setting up converters/rectifiers without harmonics of the current absorbed from the source,
- Setting up compensators of active harmonics.

5. CONCLUSIONS

The short circuit power on the customer’s poles is large enough so that the distortion of the powering voltages due to the polluting receivers is negligible.

There are situations in the powering scheme which may lead to the appearance of transitory overvoltages or resonance phenomena on superior harmonics due to the values of the resonance frequency close to those of the harmonics of nonlinear loads.

Received on 15 September, 2007

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