Harmonic Distortion Produced by Synchronous Generator in Thermal - Power Plant

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Abstract: - At the present time, the area of energy interference is highly relevant cause of these reasons: wide-range of power electronics usage, using of new (renewable) sources of electric energy, massive usage of light sources with electronic ballasts. Experimental results obtained with large synchronous generator in thermal-power plant are presented in this paper, to provide experimental evidence that the synchronous machine does indeed have ability to generate harmonic distortion in power system.

Key-Words: - Energy Interference, Harmonics, Synchronous Generator, Power Quality.

1 Introduction

Electromagnetic interference is any electromagnetic effect, which can impair equipment functionality or functionality of system. Electromagnetic interference is any electromagnetic effect, which can impair equipment functionality or functionality of system. From the viewpoint of frequency spectrum and physical impact of electromagnetic interference, we can divide electromagnetic interference to low-frequency and radio-frequency. Low-frequency interference has bad impacts on power system (energy interference) and to low-frequency information transport systems (acoustics interference).

Energy interference acts in frequency band from 0 Hz to 2 kHz and can cause harmonic distortion of voltage or current wave. Energy interference impacts on controlling and information systems, lightening equipments, condensers, cables, protective device and electrical protection. Energy interference sources are mainly nonlinear loads which consume deformed non-sinusoidal current from network (mainly power controlled semiconductor changers), but also source of electric power itself.

At the present time, the area of energy interference is highly relevant cause of these reasons: wide-range of power electronics usage, using of new (renewable) sources of electric energy, massive usage of light sources with electronic ballasts.

That is why it is important to define sources of energy interference exactly and to analyze their impact on power sys-tem equipment, mainly from point of view of right and reliable function (electrical protections), losses (transmission, distribution and compensation equipments) and possible damage of equipments (high-voltage insulating systems of rotary machines).

In the project we focus on possible sources of energy interference:

- renewable sources of electric power,
- conventional sources of electric power,
- selected light sources,
- power equipments with semiconductor electronic devices.

2 Harmonic Distortion in Power System

We assume that waveform of voltage and current in AC circuits has sinus form with constant amplitude and frequency, but more or less, each device produce deformation of voltage and current waveform and deviations from sinus waveform.

Currents of nonlinear equipments produce voltage drops on net impedances. These voltage drops lead to voltage wave-form deformation in comparison with the ideal sinus wave-form.

In assumption of constant deformation of waveform, volt-age or current waveform can be divided into more sinus waveforms with different amplitude and phase, while frequency of these components is multiples of fundamental frequency. In Fourier transformation, multiples of fundamental frequency are called harmonics.

Harmonics in power systems can cause:

- network resonation for defined harmonic, that can expose equipment of power system to higher strain by overvoltage or overcurrent,
- overheating and overloading of transmission, distribution and compensation devices,
- incorrect functionality of electric protection,
- interference of telecommunication devices,
- incorrect functionality of control circuits.

3 Harmonics Produced by Synchronous Machines

3.1 Voltage Harmonics Produced by Synchronous Machines

If the magnetic flux of the field system is distributed perfectly sinusoidal around the air gap, the e.m.f. (electro motoric force) generated in each full-pitched armature coil is

$$\text{e.m.f.} = 2\pi f\phi . \sin\omega t \ \text{[V per turn]} \qquad (1)$$

Where f is the total flux per pole and f is frequency related to speed and pole pairs.

However the flux is never exactly distributed in this way, particularly in salient pole machines. A non/sinusoidal field distribution can be expressed as a harmonic series:

$$F(x) = F_1 \sin\left(\frac{2\pi x}{\lambda}\right) + F_3 \sin\left(\frac{3.2\pi x}{\lambda}\right) + F_5 \sin\left(\frac{5.2\pi x}{\lambda}\right) + \ldots.. \qquad (2)$$

The machine can be consider to have 2p fundamental poles together with 6p, 10p, … 2np harmonic poles, all individually sinusoidal and all generating electromotoric forces in an associate winding. The winding e.m.f. can be expressed as a harmonic series:

$$E(t) = E_1 \sin\omega t + E_3 \sin 3\omega t + E_5 \sin 5\omega t\ldots.. \qquad (3)$$

The magnitudes of the harmonic e.m.f.s are determined by the harmonic fluxes the effective electrical phase spread of the winding, the coil span, and the method of interphase connection.

For an integral slot winding with g slots per pole per phase and an electrical angle α between slots, the distribution factor for the nth harmonic is

$$k_{dn} = \frac{\sin\left(ng\alpha/2\right)}{g\sin\left(n\alpha/2\right)} \qquad (4)$$

If the oils are chorded to cover $(\pi \pm \theta)$ electrical radians, the flux linked is reduced by $\cos(\theta/2)$ and the e.m.f. is reduced in proportion. The effective chording angle for harmonics of order n is nθ. Hence the general coil/span factor is

$$k_{sn} = \cos\left(\frac{n\theta}{2}\right) \qquad (5)$$

By suitable choice of kd and ks many troublesome e.m.f. harmonics can be minimized or even eliminated. The triplen harmonics in a three-phase machine are generally eliminated by phase connection, and it is usual to select the coil span to reduce 5th and 7th harmonic.

Slotting (the slots being on the stator) produce variation of permeance. The fundamental rotor m.m.f. (magnetomotive force) can be represented as a traveling wave. The slot ripple component of flux density is of the form

$$F_1A_2 \sin\left(2mg\frac{2\pi x}{\lambda}\right)\cos\left(\frac{2\pi x}{\lambda} - \omega t\right) \qquad (6)$$

This can be resolved into two counter-rotating components, which are slow-moving multi-pole harmonics. Their wavelengths are $\frac{\lambda}{(2mg \pm 1)}$ and the corresponding velocities are $\frac{f\lambda}{(2mg \pm 1)}$. As the number of waves passing any point on the stator per second is $(\text{speed/wavelength})$, obviously each component induces an e.m.f of fundamental frequency in armature.

Relative to the rotor, however, these two waves have different velocities. The rotor velocity being fλ, the waves travel at velocities $f\lambda - \left(\frac{f\lambda}{2mg+1}\right)$ and $f\lambda + \left(\frac{f\lambda}{2mg-1}\right)$ with respect to rotor. In any closed rotor circuit each of these will generate currents of frequency 2mgf (by considering the ratio of speed to wavelength) and these superimpose a time-varying m.m.f at frequency 2mgf on the rotor fundamental m.m.f. This can be resolved into two counter-rotating components relative to the rotor, each traveling at high velocity 2mgfλ, and therefore at 2mgfλ± fλ relative to the stator. The resultant stator e.m.f.s have frequencies $(2mg \pm 1)f$.

Slot harmonics can be minimised by skewing the stator core, displacing the center line of damper bars in successive pole faces, offsetting the pole shoes in successive pairs of poles, shaping the pole shoes, and by the use of composite steel – bronze wedges for the slots of turbogenerators.

It can be shown that the distribution factor for slot harmonics is the same as for the fundamental e.m.f.. It is not reduced by spreading the winding. Fractional instead of integral slotting should be used.

3.2 Synchronous Machines –Source of Harmonic Currents

Synchronous machines represent a source of harmonic currents on two counts: the frequency conversion effect, and the non-linear characteristic due to magnetic saturation.

The frequency conversion effect: a synchronous generator feeding an unbalanced, three-phase load may experience the flow of a negative sequence current in the rotor, which in turn may induce a third-order harmonic current on the stator winding. In special cases when the generator feeds static converter equipment the machine can be important source of harmonic generation.

The saturation of the stator's circuit represents another harmonic source.

4 Measurements on the Synchronous Generator

Measurements were performed on a generator with a round rotor in a thermal-power plant.

The goal of measurements was to detect harmonic distortion produced by synchronous machines.

The measurements were performed in this case of generator operation:

1. Measurement of voltage harmonics on non-load power plant block: generator - transformer.
2. Measurement of voltage and current harmonics on loaded power plant block: generator - transformer.
3. Measurement of voltage and current harmonics on minimal-loaded power plant block: generator - transformer.

4.1 Measurement of voltage and current harmonics on non-load power plant block: generator - transformer

The generator was connected to a block transformer and the generator was operated with nominal revolutions and nominal voltage on its terminals during measurement.

The block transformer was disconnected from a power system.

Results from measurements are in fig. 1 – 2.

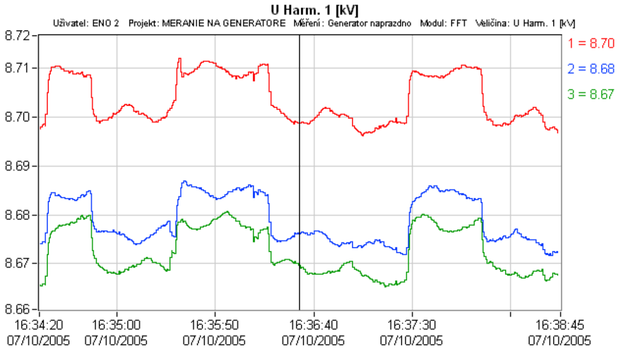

Fig. 1 Voltages of Generator – rms values

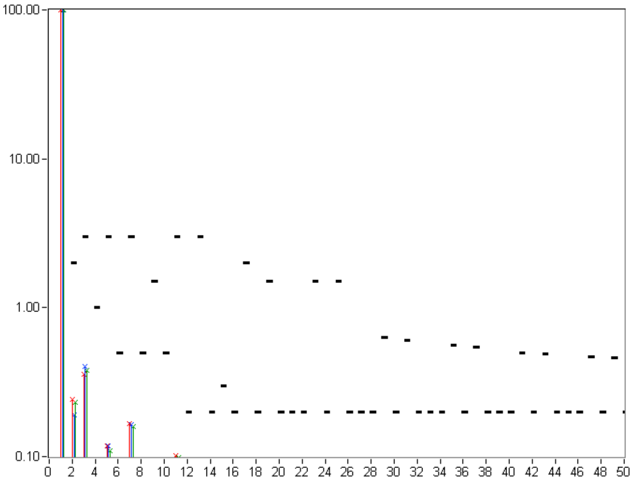

Fig. 2 Voltage Harmonics Produced by Generator

4.2 Measurement of voltage and current harmonics on loaded power plant block: generator – transformer

The power plant block was connected to the power system and power output and a terminal voltage were regulated from the power system dispatch.

Results from measurements are in fig. 3 – 6.

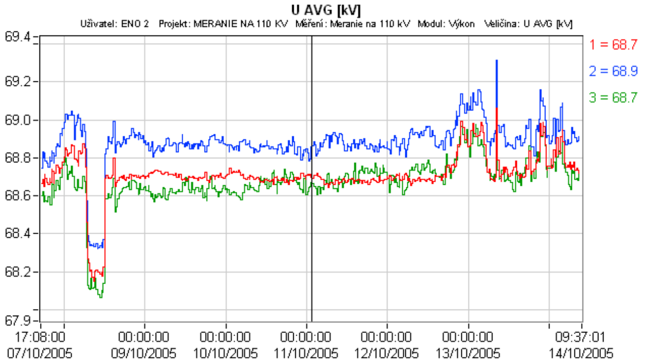

Fig. 3 Voltages of Power Plant Block (on the 110 kV side of transformer) – rms values

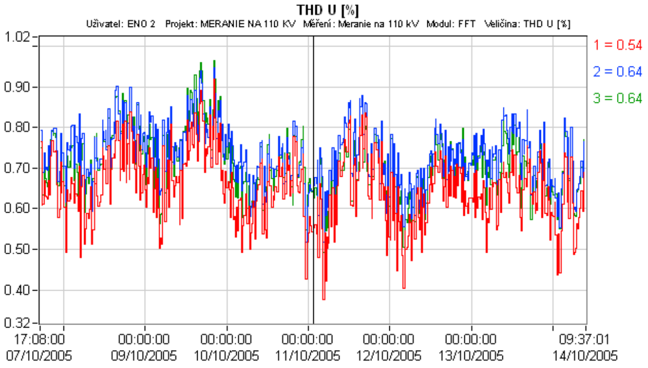

Fig. 4 Total Harmonic Distortion of Voltage on the 110 kV side of Transformer

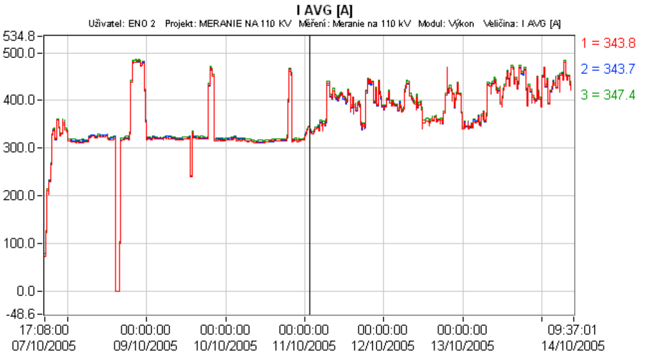

Fig. 5 Currents of Power Plant Block (on the 110 kV side of transformer) – rms values

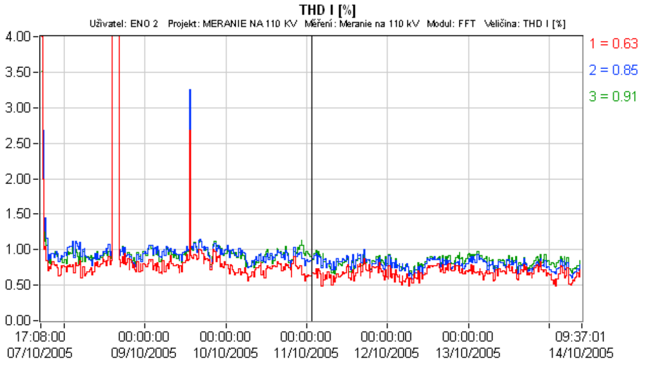

Fig. 6 Total Harmonic Distortion of Current on the 110 kV side of Transformer

4.3 Measurement of voltage and current harmonics on minimal-loaded power plant block: generator – transformer

The power plant block was connected to the power system and power output was on minimal value.
Results from measurements are in fig. 7 – 12.

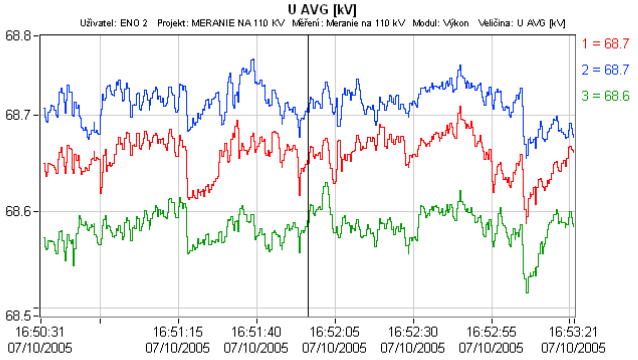

Fig. 7 Voltages of Power Plant Block (on the 110 kV side of transformer) – rms values

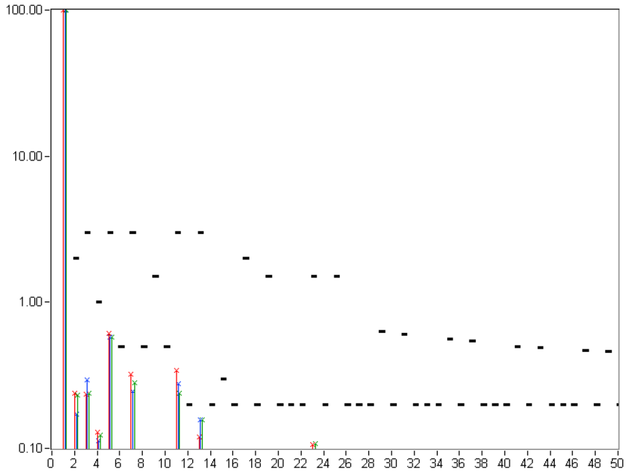

Fig. 8 Voltage Harmonics of Power Plant Block (on the 110 kV side of transformer)

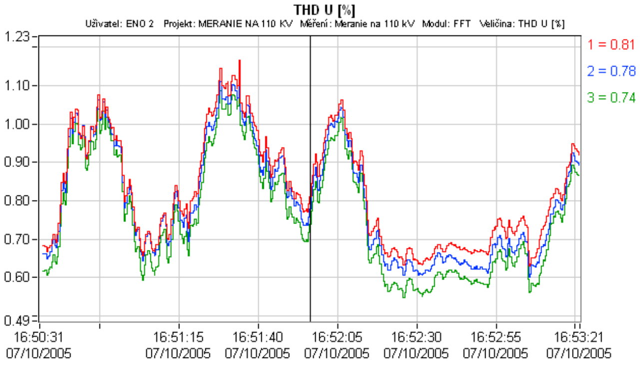

Fig. 9 Total Harmonic Distortion of Voltage on the 110 kV side of Block Transformer

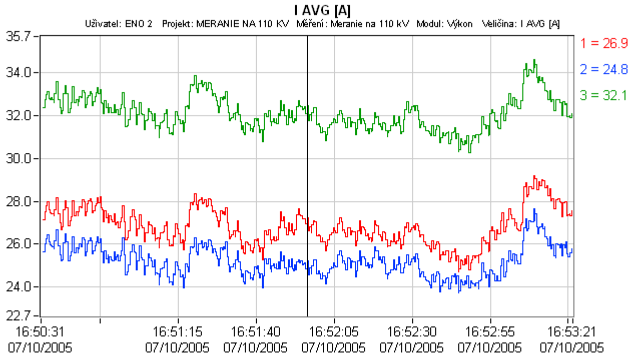

Fig. 10 Currents of Power Plant Block (on the 110 kV side of transformer) – rms values

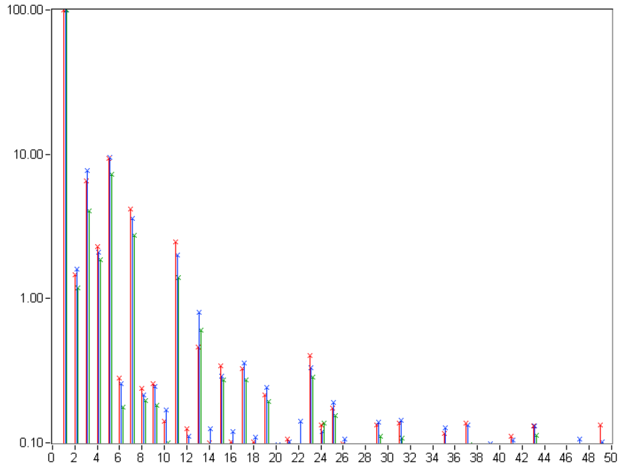

Fig. 11 Current Harmonics of Power Plant Block (on the 110 kV side of transformer)

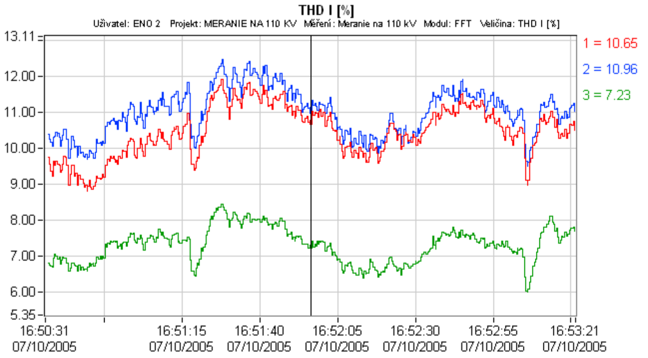

Fig. 12 Total Harmonic Distortion of Current on the 110 kV side of Transformer

5 Conclusion

Energy interference impacts on controlling and information systems, lightening equipments, condensers, cables, protective device and electrical protection. Energy interference sources are mainly nonlinear loads which consume deformed non-sinusoidal current from network (mainly power controlled semiconductor changers), but also source of electric power itself.

At the present time, the area of energy interference is highly relevant cause of these reasons: wide-range of power electronics usage, using of new (renewable) sources of electric energy, massive usage of light sources with electronic ballasts.

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