DISTORTING AND UNBALANCED WORKING REGIME – A POSSIBLE DIAGNOSIS METHOD

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Key words: Distorting and unbalanced regimes, Synchronous generator, Diagnosis.

The paper deals with a synchronous generator from an energetic group with distorting and unbalanced behavior during its steady state operation. Waveforms from main and auxiliary generators and from the main generator excitation winding were analyzed. Harmonics determinations and powers calculations were done. For a low harmonic level in the main generator stator, conclusions on the generator steady state operation can be made. Even harmonics could be caused either by an asynchronous thyristors control or by the auxiliary generator unbalanced operation.

1. INTRODUCTION

The appearance of a distorting regime, either in the main generator stator, or in the winding supplied from the auxiliary generator stator from an energetic group leads to the apparition of high harmonic magnetic fields. These penetrate the stator and rotor iron cores, causing an increase of losses in iron as compared to the sine regime, determined by the fundamental harmonic. Therefore over-heating of windings and iron core, as well as pulsating couples and noises can occur [1]. Moreover, the harmonic currents (mainly those from the side toward rotor) can induce voltages that can propagate through the energetic group metallic parts and consequently they can have a negative influence over the protection apparatus operation [2]. The voltages induced as described before can start by accident the generator protections, causing unpleasant effects over the entire power system [3].

2. WAVEFORMS RECORDING

The recording of currents and voltages waveforms was done using two data acquisition systems, with sample frequency as high as 4,000 Hz. The recordings were made in a real energetic group from a large power plant that can supply up to 330 MW.

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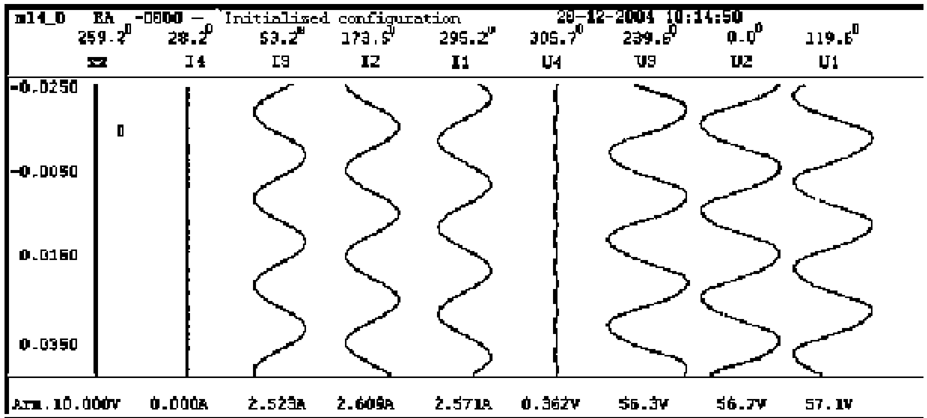

Fig. 1 – The currents and the voltages at synchronous generator terminals.

In this way it was possible to record the first 40 harmonics. The first data acquisition system was used to record data from the secondary windings of the current and voltage transformers for the main generator (Fig.1). In Fig. 1 U_1, U_2 and U_3 represent the phase voltages and I_1, I_2 and I_3 represent the currents carried by the phases of the main generator's. The data acquisition system was designed to record the voltage drop across the null wire and respectively the current through it along with the previously mentioned waveforms. The waveforms corresponding to the null wire are symbolized by means of the notations I_4 and U_4. As these waveforms presented no interest for the experiments made by the author, the respective quantities were not acquisitioned, so the I_4 and U_4 from Fig. 1 have no real significance.

The second data acquisition system was used to record data corresponding to the time – variation of the currents from the current reducing equipment (I_1, I_2 and I_3 from Fig. 2) and the data corresponding to voltages were recorded directly from the auxiliary generator terminals (U_3, U_4, U_5 from Fig. 2). The second data acquisition system was also used to record the waveforms after the rectifier that is fully-controlled by thyristors. The current after the rectifier was recorded using a 60 mV shunt (see U_2 in Fig. 2) and the voltage after rectifier was directly recorded (see U_1 in Fig. 2). All these quantities waveforms are depicted by Fig. 2.

The presented recorded waveforms correspond to an active power (as indicated by the test apparatus) of 209.26 MW and respectively to a reactive power of 24.62 Mvar (for the main generator).

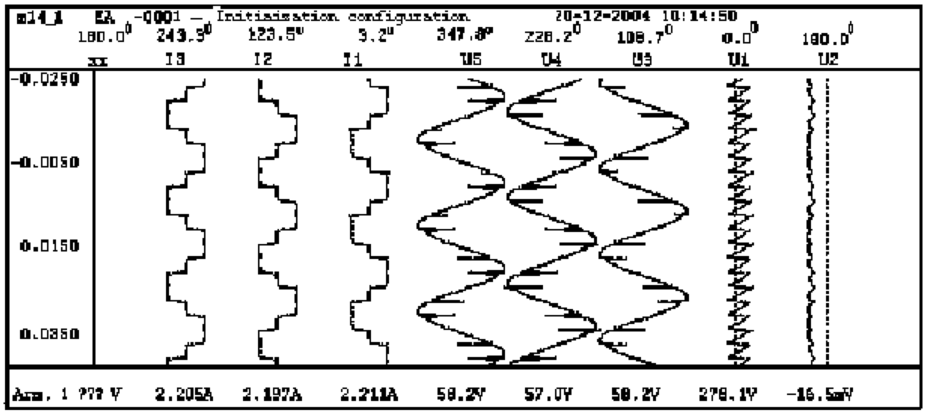

Fig. 2 – The currents and the voltages at auxiliary synchronous generator terminals and d.c. voltage and current.

3. EXPERIMENTAL DETERMINATIONS

The processing of waveforms was done in order to determine the energetic parameters for quality (shape factor, peak factor, total harmonic distortion), the phases active and reactive powers and respectively the total three-phase powers.

The original soft relies on the Fourier decomposition using a Fast Fourier Transform (FFT) of the experimental data [4, 5, 9]:

$$y(t) = Y_0 + \sum_{k=1}^{n} \sqrt{2}\, Y_k \sin\left(k\,\omega t + \gamma_k\right). \tag{1}$$

The quality and energetic parameters are calculated by means of the following equations [4]:

– RMS value:

$$Y = \sqrt{\sum_{k=0}^{n} Y_k^2}\ ; \tag{2}$$

– peak factor:

$$k_V = \frac{Y_{\max}}{Y} = \frac{Y_{\max}}{\sqrt{\sum_{k=0}^{n} Y_k^2}}\ ; \tag{3}$$

– shape factor:

$$k_V = \frac{Y_{\max}}{Y} = \frac{Y_{\max}}{\sqrt{\sum_{k=0}^{n} Y_k^2}}\ ; \tag{4}$$

– distorting factor:

$$k_d = \frac{Y_d}{Y} = \frac{\sqrt{Y_0^2 + \sum_{k=2}^{n} Y_k^2}}{\sqrt{\sum_{k=0}^{n} Y_k^2}} = \text{THD}\ ; \tag{5}$$

– single phase fundamental active power:

$$P_{11} = U_1 I_1 \cos\varphi_1\ ; \tag{6}$$

– single phase active power:

$$P_1 = U_0 I_0 + \sum_{k=1}^{n} U_k I_k \cos\varphi_k\ ; \tag{7}$$

– single phase fundamental reactive power:

$$Q_{11} = U_1 I_1 \sin\varphi_1\ ; \tag{8}$$

– single phase reactive power:

$$Q_1 = \sum_{k=1}^{n} U_k I_k \sin\varphi_k\ ; \tag{9}$$

– three-phase active power:

$$P = P_1 + P_2 + P_3\ ; \tag{10}$$

– three-phase reactive power:

$$Q = Q_1 + Q_2 + Q_3\ .$$

4. **DECOMPOSITION AND ANALYSIS OF VOLTAGES AND CURRENTS WAVEFORMS**

4.1. DECOMPOSITION AND ANALYSIS OF STATOR WAVEFORMS

The waveforms corresponding to voltages and currents from the stator phases were decomposed into 40 harmonics. Fig. 3 depicts the harmonic content of the voltage from phase no. 1 (the first 20 harmonics) and Fig. 4 depicts the harmonic

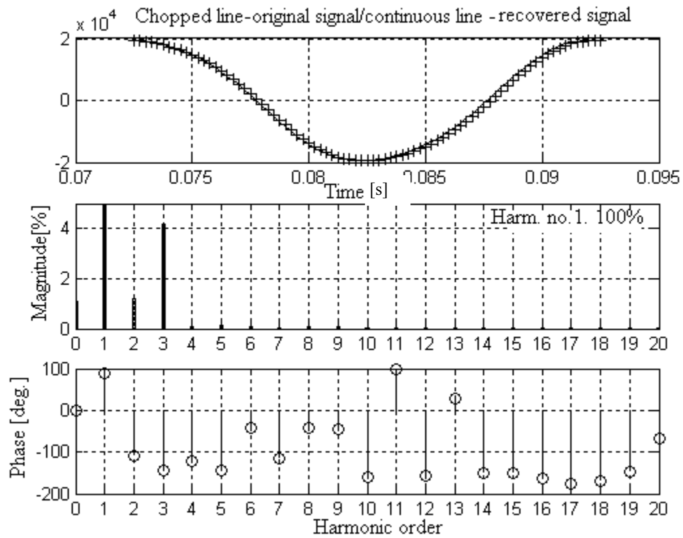

Fig. 3 – Harmonic content of voltage u_1.

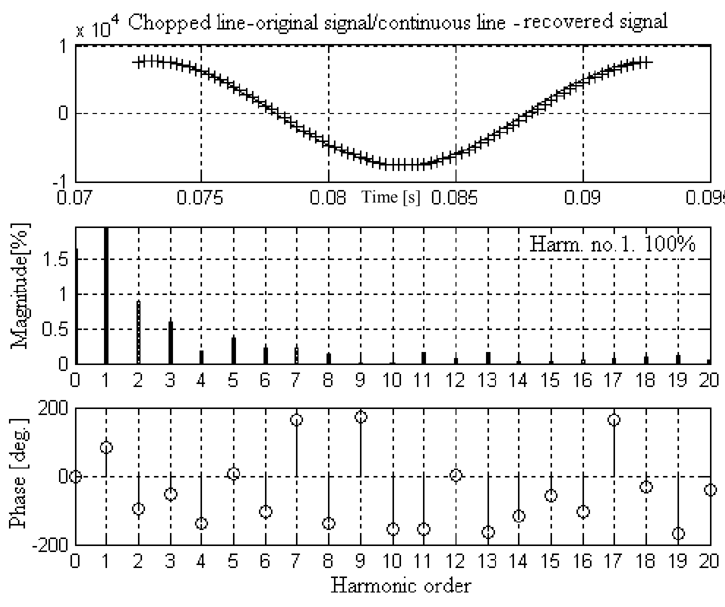

Fig. 4 – Harmonic content of current i_1.

content of the current through the same phase (for the first 20 harmonics). In both cases the initially decomposed signal was reconstructed using its harmonics up to the 40-th order. Each time there were revealed small differences between the initial values and those obtained after reconstruction. The quality parameters of the phase quantities are presented by Table 1 (for voltages) and in Table 2 (for currents).

Table 1

Quality Parameters for Phase Voltages of Main Generator's stator

Quality parameter	Phase 1	Phase 2	Phase 3
RMS value [V]	14 125	13 571	14 048
Peak factor	1.3809	1.3907	1.3964
Shape factor	1.0873	1.0888	1.089
UTHD	4.5943	3.8131	5.3452

Table 2

Quality Parameters for Phase Currents of Main Generator's stator

Quality parameter	Phase 1	Phase 2	Phase 3
RMS value [A]	5 076	4 883	5 187
Peak factor	1.417	1.4259	1.4224
Shape factor	1.0951	1.0971	1.0937
ITHD	2.6564	2.5506	2.6327

The computed total active and reactive powers are: $P = 209.25$ MW and respectively $Q = 24.212$ Mvar.

4.2. DECOMPOSITION AND ANALYSIS OF WAVEFORMS FOR ROTOR

4.2.1. DECOMPOSITION AND ANALYSIS OF WAVEFORMS AT THE AUXILIARY GENERATOR

The waveforms corresponding to voltages and currents from the stator phases at the auxiliary generator were decomposed into 40 harmonics. Fig. 5 depicts the harmonic content of the voltage from phase no. 1 (the first 20 harmonics) and Fig. 6 depicts the harmonic content of the current through the same phase (the first 20 harmonics). In both cases the initially decomposed signal was reconstructed using its harmonics up to the 40-th order. Each time there were revealed small differences between the initial values and those obtained after reconstruction.

The quality parameters of the phase quantities are presented by Table 3 and Table 4.

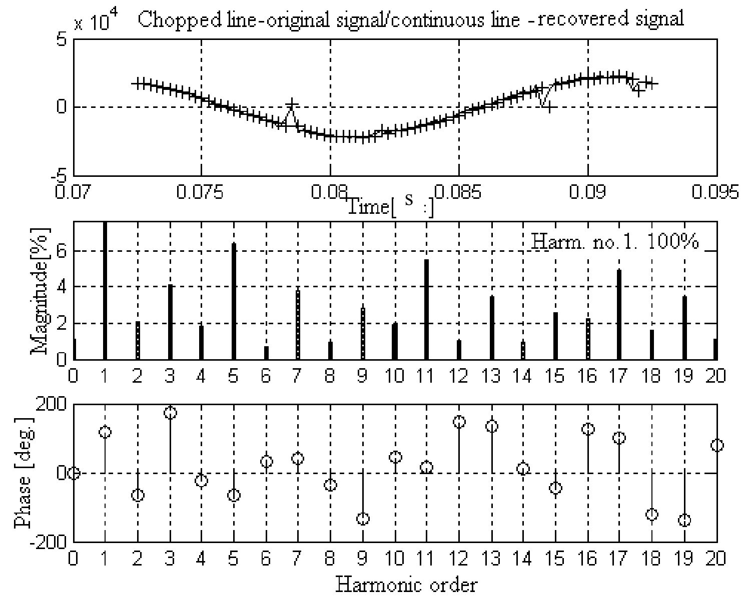

Fig. 5 – Harmonic content of voltage u_1 for auxiliary generator.

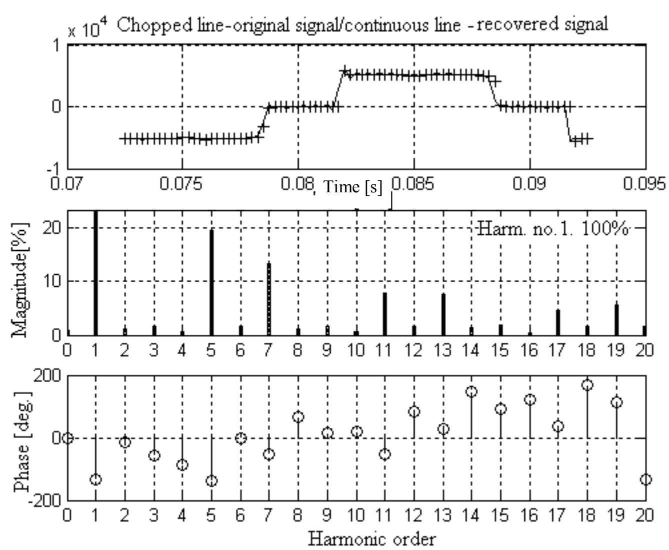

Fig. 6 – Harmonic content of current i_1 for auxiliary generator.

Table 3

Quality Parameters for Phase Voltages of Auxiliary Generator Stator

Quality parameter	Phase 1	Phase 2	Phase 3
RMS value [V]	423,12	415,11	416,2
Peak factor	1,5084	1,5287	1,628
Shape factor	1,1217	1,1245	1,1408
UTHD	18,565	22,177	25,835

Table 4

Quality Parameters for Phase Currents of Auxiliary Generator Stator

Quality parameter	Phase 1	Phase 2	Phase 3
RMS value [A]	1,399	1,389	1,373
Peak factor	1,3637	1,2797	1,2833
Shape factor	1,1957	1,2089	1,1973
ITHD	28,137	28,2	27,21

4.2.2. DECOMPOSITION AND ANALYSIS OF WAVEFORMS AFTER CONTROL RECTIFIER WITH THYRISTORS

The harmonic decompositions of the excitation voltage and current (on the d.c. side) are depicted by Figs. 7 and 8 (the first 20 harmonics). The d.c. values of voltage and current after rectifier are U_{ex0}= 208.41 V; I_{ex0}= 1657.18 A. After rectifier, the active power of the d.c. components P_0 is 345 kW and the total active power P_{ex} is 343 kW.

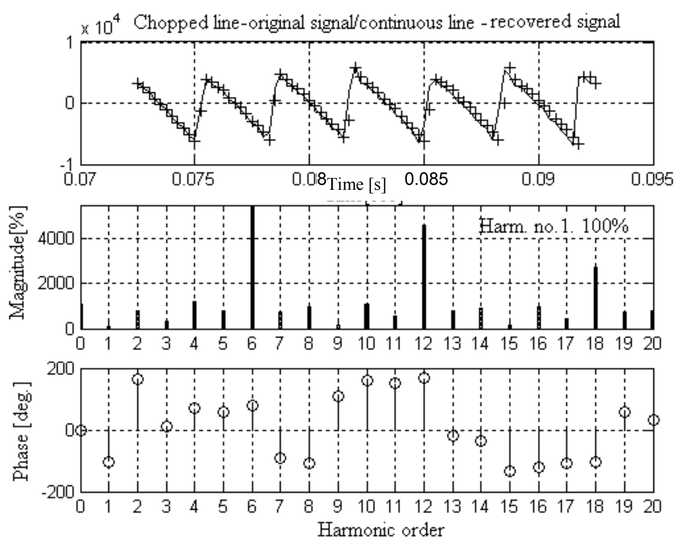

Fig. 7 – Harmonic content of excitation voltage.

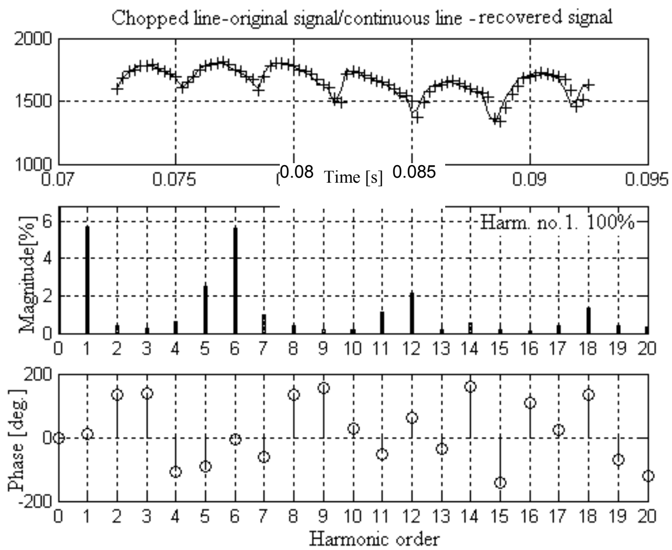

Fig. 8 – Harmonic content of excitation current.

5. **CONCLUSIONS**

The presence of some harmonics of second and third order from the main generator stator voltages and currents waveforms, even though their values are small, demonstrate that the main generator operates in an unbalanced manner [8]. Most probably the unbalance is caused by internal causes (a possible fault between some loops from the excitation winding) [6, 7].

The presence of some pulses in the voltages and currents waveforms from the auxiliary generator phases owing to the thyristors control leads to the apparition of some even harmonics, multiple of 6 in the rectified voltage waveform. Significant amounts of harmonics with the orders 6, 12 and 18 can be noticed. This leads to a value of 208.4 V for the d.c. component after the rectifier, and the excitation voltage RMS value is as high as 317 V. The presence of these pulses results into an overlapping of some harmonic components multiple of 6 in the rectified current waveform. Moreover, one can notice a significant value for the fundamental harmonic of 50 Hz in the rectified current waveform. The d.c. active power for the main generator excitation supply is approximately 345 kW, while the total active power after the rectifier is approximately 343 kW. Actually this indicates a reversed power circulation across the harmonics from the main generator excitation toward the fully-controlled rectifier. The cause could be a possible unbalanced operation of the main generator excitation. The peaks with different magnitudes of the current pulses corresponding to harmonics multiple of 6 prove an unbalanced operation of the fully-controlled rectifier.

The even harmonics presence in the voltage waveforms from certain phases proves an unbalanced control of the thyristors from the fully-controlled rectifier supplied from the auxiliary generator terminals [4]. This could be caused by an asynchronous control of the thyristors placed on the same phase in derivation from the auxiliary generator, but one can also consider another cause, namely the unbalanced operation of the auxiliary generator that could be caused by some windings constructive non-symmetrical features.

The auxiliary generator analysis proved significantly different distorting factors for phases voltages. They could also influence an erroneous control of thyristors.

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REFERENCES

1. Depenbrock, M., *The FDB-Method a Generally Applicable Tool for Analyzing Power Relations*, IEEE Tr. on Power Systems, **8**, *2*, pp. 380-386, 1993.
2. Emanuel, A.E., a.o., *New Concepts of Instantaneous Active and Reactive Powers in Electrical Systems with Generic Loads*, IEEE Tr. on Power Del., *3*, pp. 697-703, 1993.
3. IEEE Working Group on Nesinusoidal Situations – *Practical Definitions for Powers in Systems with Nonsinusoidal Waveforms and Unbalanced Loads*, IEEE Tr. on Power Del., *1*, pp. 79-101, 1996.
4. Nicolae, P.M., *Calitatea energiei electrice în sisteme electroenergetice de putere limitată*, Edit. Tehnică, Bucharest, 1998.
5. Puscasu, S., Marcovici, J., *Mărimi şi regimuri electrice nesinusoidale*, Edit. Scrisul Românesc, Craiova, 1974.
6. Ţugulea, A., *Consideraţii privind efectele energetice în regimuri deformante*, Energetica, *1*, pp. 27-31, 1986.
7. Ţugulea, A., *Factorul de putere în regim deformant şi nesimetric*, Energetica, *9*, pp. 407-414, 1986.
8. Ţugulea, A., *Consideratii privind efectele energetice in regimurile armonice nesimetrice ale retelelor trifazate,* Energetica, *3*, pp. 121-130, 1986.
9. Ţugulea, A., *Criteria for the Definitions of the Electric Power Quality and its Measurement Systems*, ETEP, **6**, *5*, p. 357-363, 1996.