KTE
FACULTY OF ELECTRICAL ENGINEERING
September 10 - 12, 2007
Pilsen, Czech Republic

COMPUTATIONS OF THE ELECTRICAL PART OF RYBNIK POWER PLANT GENERATING UNIT PARAMETERS BASED ON MEASUREMENTS

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Abstract: *The paper presents the methodology and results of the generator and electromachine excitation system model parameters computations. The computations were based on real dynamic waveforms obtained from possible to perform in Rybnik Power Plant measurements of the generator steady state disturbed with different test disturbances. The disturbances used for parameters estimation are a load rejection test and a step change in AVR voltage reference value by +/- 5%. The voltage controller was operating (automatic control) during the test. The methodology of parameter determination consists in performing a number of simulations and comparing the simulation results with test results. The estimation process is iterative and in each iteration the model parameters are changed so that the simulated response becomes as close as possible to the test results. In the effect, the parameter estimation problem is transformed into an optimisation one, where the objective function is defined as the squared deviations between the test and simulation results and then it is locally minimised using the large-scale, trust-region, reflective Newton gradient algorithm. The methodology of filtering measurement signals recorded is also given in the paper.*

Key words: *dynamic stability of power systems, optimization, study of dynamic models*

INTRODUCTION

Long-lasting exploitation of generating units has essential influence on parameter values of their elements. Current repair and modernisation works change parameter values given by a manufacturer so that they cannot be the reliable basis for further use. It is then necessary to perform research targeted at development of the efficient method for determining true parameter values of generating units operating in the national power system.

This paper proposes such a method and presents the results of verification of the Rybnik Power Plant generator and excitation system parameters. Dynamic waveforms occurring in the generating unit due to appropriately chosen disturbances of the steady state were measured and recorded. They were the basis for the verification.

1 INVESTIGATED OBJECT

The analysed generating unit includes a TWW-200-2A turbogenerator driven by a steam turbine. The generator is equipped with an electromachine excitation system containing a three phase exciter and ETP 1500/1000D type diode rectifier with an ETEF – 200C type voltage regulator. The two latter were designed and started by Energotest Gdańsk. Rated parameter values of the generating unit elements are given in Table 1

Generator		Exciter		Rectifier	
S_n [MVA]	235	S_n [kVA]	1150	I_n [A]	1500
U_n [kV]	15.75	U_n [V]	330	U_n [V]	3x300
$cos\ \varphi_n$ [-]	0.85	$cos\ \varphi_n$ [-]	0.87	f_n [Hz]	500

Tab. 1: Parameter values of the generating unit elements

2 MATHEMATICAL MODEL OF THE ANALYSED SYSTEM

The classical generator model was applied to the investigations. It is described by reactances and time constants in d and q axis together with the obligatory assumptions [2]. The state and output equations as well as structural diagram of the synchronous generator model are presented in [4, 5]. The electromachine excitation system model contains models of the voltage regulator (Fig. 1), three phase exciter (Fig. 2) and diode rectifier (Fig. 3). Fig. 4 shows the input and output signals used for measurement identification of the generator and electromachine excitation system, where: U – generator terminal voltage, U_{zad} – regulator reference voltage, U_R – regulator output voltage, I_{ww} – exciter field current, U_e – exciter output voltage, I_{fd} – generator exciting current, E_{fd} – generator field voltage and *Fex_s* – function determining the diode rectifier operating range.

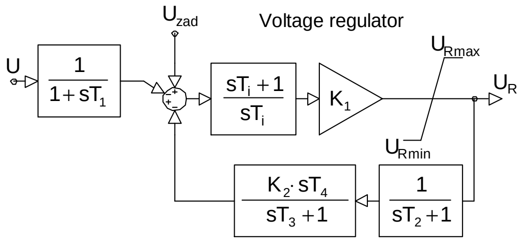

Fig. 1. Voltage regulator structural model

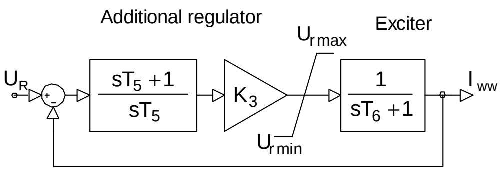

Fig. 2. Additional voltage regulator and exciter structural model

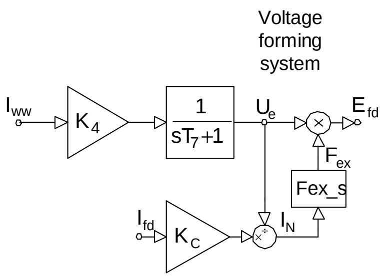

Fig. 3. Voltage forming system structural model

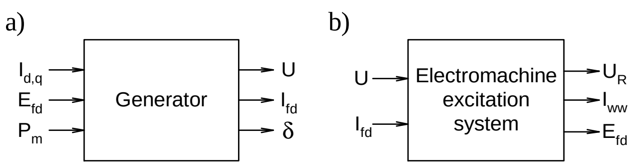

Fig. 4. Input and output signals of the generator model (a) and electromachine excitation system (b)

3 FILTRATION OF THE MEASURED SIGNALS

The dynamic waveforms obtained from the measurements performed in the Rybnik Power Plant were strongly disturbed. The frequency during measurements and recording was too high, especially when compared with the frequency resulting from the mathematical model equation integrating step. The zero phase filtration was used [4]. The exemplary waveforms of the field current measured before and after filtration are shown in Fig.5.

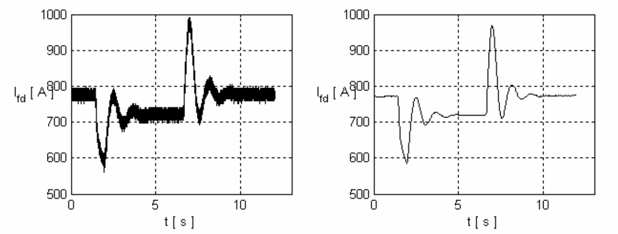

Fig. 5. Exemplary waveforms of the field current measured before and after filtration

4 ESTIMATION OF THE MATHEMATICAL MODEL PARAMETERS

Estimation of the assumed mathematical model of the generator and excitation system was carried out in an iterative process in such a way that the dynamic waveforms computed on the basis of these parameters approximated the measured waveforms with a definite accuracy [1, 3].

Computations of the generator model parameters in d axis were brought to minimisation of the objective function given by:

$$\varepsilon_d(\boldsymbol{P}) = \sum_{j=1}^{z} \sum_{i=1}^{n_j} \boldsymbol{w}_{ji} \left| \boldsymbol{U}_{ji(m)} - \boldsymbol{U}_{ji(a)}(\boldsymbol{P}) \right|^2 , \qquad (1)$$

where: U_{ji} – terminal voltage values (induced only in q axis) under j-th disturbance at i-th time instant, z – number of considered disturbances (load rejection at P_0=0, step change in AVR at generator no-load), $\boldsymbol{P}$ – vector of searched parameters, n_j – number of measurement points at j-th disturbance, w_{ji} – weighting coefficient. The measured values are marked with index m, while approximated ones with index a.

The proposed methodology for computing generator parameters in q axis was based on the dynamic signals obtained from simulations because no measured signals were available. The objective function when estimating the generator parameters in q axis is of the form:

$$\varepsilon_q(\boldsymbol{P}) = \sum_{i=1}^{n} \left| \boldsymbol{U}_{i(m)} \sin\left(\delta_{i(m)}\right) - \boldsymbol{U}_{i(a)}(\boldsymbol{P}) \sin\left(\delta_{i(a)}(\boldsymbol{P})\right) \right|^2 , \qquad (2)$$

The denotations are the same as in (1).

Saturation of the machine magnetic core was taken into account in the investigated model by assumption of the nonlinear characteristic of magnetic flux linkage *Ψ”* subtransient reactances from the right in the d and q axis [3]. In order to do it, the no-load characteristic of the generator voltage U as a function of the field voltage E_{fd} and field current I_{fd} measured in the power plant was used (the identical shape of the both characteristics expressed in p.u.).

The excitation system was analysed separately. The influence of the generator on it was modelled by using the terminal voltage U and generator field current I_{fd} waveforms as the input signals of the excitation system.

In order to improve effectiveness of the excitation system parameter computations, the estimation process was divided into three stages.

At the first stage, the voltage regulator model parameters were determined (Fig. 1): gains K_1 i K_2 and time constants T_1, T_i, T_2, T_3 i T_4. It should be noted that the values of these parameters were known since they were the digital regulator settings fixed by the user during the block starting. Computations at this stage allowed verifying the correctness of the assumed measurement method and the measurement accuracy. At this stage the generator terminal voltage waveform was an input signal, whereas the voltage regulator output voltage was the output signal (Fig. 1).

At the second stage, the additional voltage regulator and exciter parameter values were determined (,gains K_3 as well as time constants T_5 and T_6) (Fig. 2). The voltage regulator output voltage was an input signal and the exciter field current was an output signal (Fig. 2).

At the third stage, the field voltage forming system parameter values were determined (gains K_4 and K_C as well as time constant T_7) (Fig. 3). During this stage the exciter and generator field current waveforms were input signals, while the generator field voltage was an output signal (Fig. 3).

The objective functions minimised at particular computation stages were:

$$\varepsilon_1(\boldsymbol{P}_1)=\sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \left|\boldsymbol{U}_{\boldsymbol{R}i(m)}-\boldsymbol{U}_{\boldsymbol{R}i(a)}(\boldsymbol{P}_1)\right|^2, \qquad (3)$$

$$\varepsilon_2(\boldsymbol{P}_2)=\sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \left|\boldsymbol{I}_{\boldsymbol{wwi}(m)}-\boldsymbol{I}_{\boldsymbol{wwi}(a)}(\boldsymbol{P}_2)\right|^2. \qquad (4)$$

$$\varepsilon_3(\boldsymbol{P}_3)=\sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \left|\boldsymbol{E}_{\boldsymbol{fdi}(m)}-\boldsymbol{E}_{\boldsymbol{fdi}(a)}(\boldsymbol{P}_3)\right|^2. \qquad (5)$$

where: U_R – voltage regulator output values at i-th time instant, $\varepsilon_1(\boldsymbol{P}_1)$, $\varepsilon_2(\boldsymbol{P}_2)$, $\varepsilon_3(\boldsymbol{P}_3)$ – error values. The approximating waveforms are inexplicit functions of the vector $\boldsymbol{P}_1$, $\boldsymbol{P}_2$, $\boldsymbol{P}_3$, respectively, whose elements are the searched parameters of the excitation system regulator model.

5 COMPUTATION RESULTS

Computations of the generator parameters in d axis were performed basing on the dynamic signals measured during the following disturbances:

load rejection test consisting in the opening of the main circuit-breaker connecting the generator with the system (pre-disturbance $P_0 = 0$, $Q_0 = 0.5531$ – both in p.u.) ,

step change in the AVR reference value by +/-5% when the generator was not loaded ($P_0 = 0$, $Q_0 = 0$).

Computations of the generator parameters in q axis were based on the dynamic signals obtained from simulation of the load rejection test with pre-disturbance $P_0 = 0.2$, $Q_0 = -0.0723$, both in p.u. The performance of such a test was impossible in Rybnik Power Plant because of the refusal of its servicing personnel.

The disturbance used for computations of the electromachine excitation system parameters was a step change in the AVR reference value by +/-5% when the generator was not loaded ($P_0 = 0$, $Q_0 = 0$). No load caused that the external power system did not influence the generator and the turbine.

The analysis and computations of the generating unit parameters were performed while the voltage controller was operating (automatic excitation control).

The estimation of the generator and excitation system parameters consisted in minimisation of the deviations between the measured and simulated waveforms over a given time period. The optimisation was performed with use of the large-scale, trust-region, reflective Newton gradient algorithm.

The computation results of the generator parameters are presented in Table 2. Figs. 6 and 7 show the dynamic waveforms: measured and approximated obtained from the generator parameter estimation process.

Parameter	Value	
	computed	catalogue
T_{d0}' [s]	7.8174	5.47
T_{d0}" [s]	0.1455	0.139
X_d	2.1	1.86
X_d'	0.2251	0.254
X_d" $=X_q$"	0.2132	0.213
T_{q0}' [s]	0.7948	0.675
T_{q0}" [s]	0.0507	0.051
X_q'	0.4120	0.418
Assumed values of parameters	$R_a = 0.00164$, $X_q = 1.89$, $X_l = 0.113$, $T_m = 7$[s]	

Tab. 2: Generator parameter values

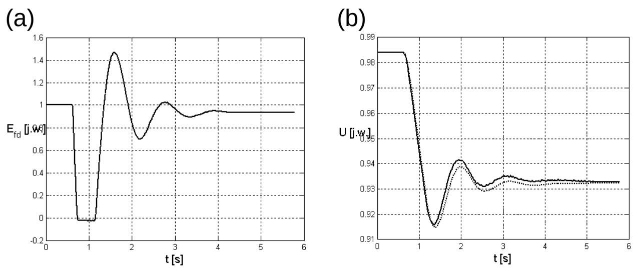

Fig. 6. Waveforms of the generator field (a) and terminal (b) voltage (measured and approximated) during step change in AVR voltage reference value by -5%

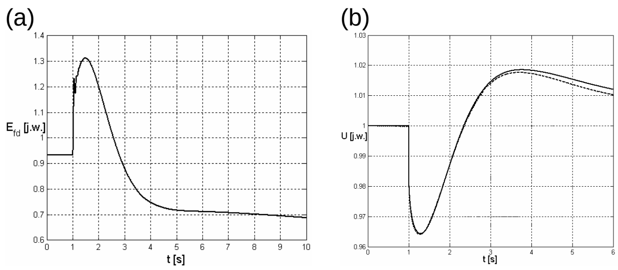

Fig. 7. Waveforms of the generator field (a) and terminal (b) voltage (measured and approximated) during load rejection test in q axis

Computation results of the electromachine excitation system parameter approximation are given in Table 3. Waveforms (measured and approximated ones) obtained from the excitation system are presented in Figs. 8, 9 and 10.

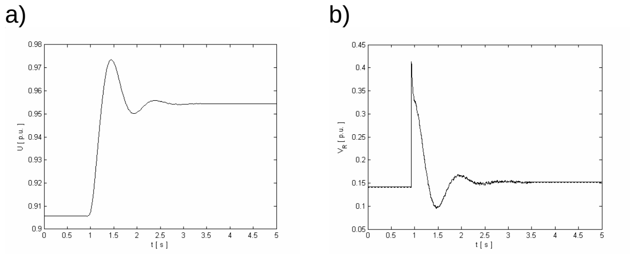

Fig. 8. Waveforms of the generator terminal (a) and regulator output (b) voltage (measured and approximated) during step change in AVR voltage reference value by +5%

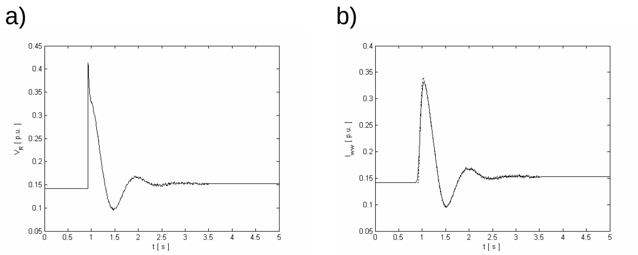

Fig. 9. Waveforms of the regulator output voltage (a) and exciter field current (b) (measured and approximated) during step change in AVR voltage reference value by +5%

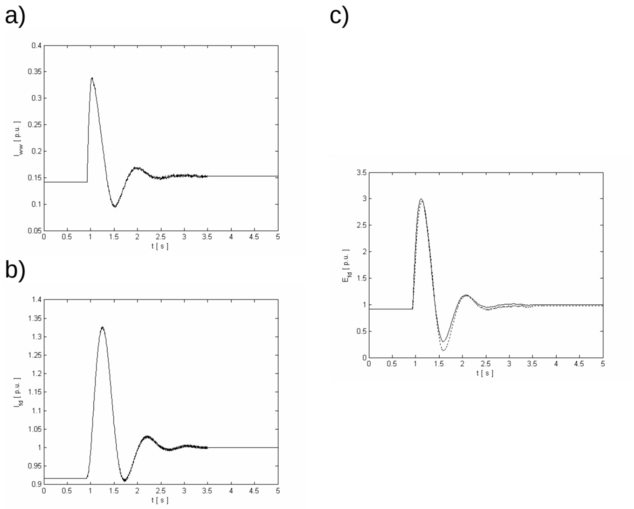

Fig. 10. Waveforms of the exciter (a) and generator field current (b) as well as generator field voltage (measured and approximated) during step change in AVR voltage reference value by +5%

Parameter and its value							
voltage regulator				exciter		rectifier	
K_1	6	K_2	0.0245	K_3	3.43	K_4	12.525
T_1	0.02	T_2	0.05	T_5	0.1	K_C	1.312
T_i	3	T_3	0.25	T_6	0.071	T_7	0.0869
		T_4	1				

Tab. 3: Electromachine excitation system parameter values

6 CONCLUSIONS

From the performed computation results of the generator and excitation system model parameters the following conclusions can be drawn:

Measurement of the selected dynamic waveforms in a power plant is a sufficient basis for identification of true values of the synchronous generator model parameters. In order to obtain accurate results, other reliable measurement sets, especially those concerning the steady state (e.g. V curves) and dynamic waveforms, should be taken in a power plant.

The excitation system model proposed represents the electromechanical excitation system installed in the Rybnik Power Plant obtained from measurements.

The proposed approach of dividing the excitation system mathematical model into three submodels makes the analysis much easier.

Accessibility to greater number of measurement signals and their use for computations improves the parameter estimation process considerably (smaller computation errors).

The measurement signals are strongly disturbed and require adequate filtration. The zero-phase filtration applied gives satisfactory results.

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