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MODELING OF THE TURBOGENERATOR REGULATION SYSTEMS

Abstract: This paper presents the ability to connect field-circuit model of the turbogenerator with regulation systems in power plant. An excitation and a turbine regulator were used in modeling of the power plant regulation system. This article is being considered for thermal power stations.

Keywords: *field-circuit modeling, finite element method, regulation systems, thermal power plant, turbogenerator*

1. Introduction

Synchronous generators are the main sources of active and reactive power in the power system. Their regulation systems have an impact on the power system performance in steady state (regulation of voltage, active and reactive power) and in unsteady state (dynamic voltage regulation and influence on the power system stability).

Regulation of the synchronous generators is an important issue of the power system stability. If it is badly chosen it can cause irreparable damage to not only energy block but also in the energy system components and at recipients of electrical energy [1].

Generator takes energy from the rotor drive shaft (turbine) and from the magnetic field. Source of energy for the magnetic field is the power supply from static or rotating exciter. Generator is described by the electrical and mechanical quantities. The electrical quantities which change during work are terminal voltage U_g, excitation current I_E and stator current I_S, active power P and reactive power Q. The mechanical quantities which change are mechanical torque T_M and angular velocity ω.

Draw power by recipients is changing all the time. At present we can store relatively low energy compared to the energy which is produced to provide for the needs of recipients. Therefore quantity of energy which is produced must be the same of quantity of energy drawn . This requirement may be fulfilled if input quantities are regulated.

2. Regulated physical quantities

Electrical energy comes from a very complicated technological process and is produced mainly in the power stations. In this process the thermal energy is produced in steam boiler and then in the turbine is converted into mechanical energy. Finally, mechanical energy is converted into electrical energy. An example of functional diagram is showed in Figure 1. This diagram does not include steam boiler.

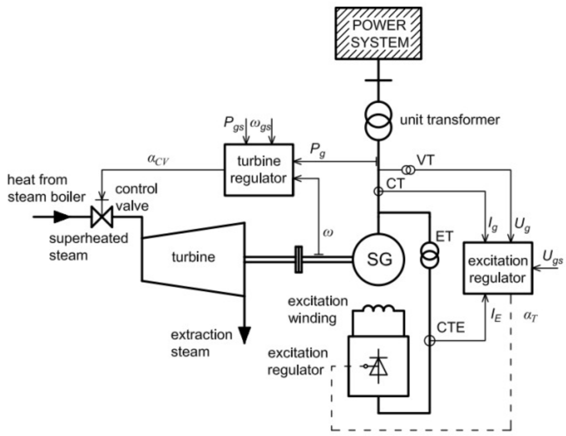

Fig. 1. Functional diagram of productive high electrical energy with static excitation system, where VT, CT – voltage and current transformer, ET – excitation transformer, CTE – current transformer excitation, α_{CV} – valve opening level, α_T – thyristor firing angle, index s – set value

Fig. 1. shows which parameters have direct impact on electricity output parameters such as value of active and reactive power, voltage and frequency. Reactive power and voltage depend on an excitation current. This dependence is nonlinear and it can be shown with open-circuit characteristics and V-curves.

Another parameter is superheated steam which comes direct from steam superheater but the first stage of production is steam boiler. Intensity of steam flow DT to turbine blade has an impact on mechanical power of turbine P_T. Besides steam flow, value of turbine power also depends on steam enthalpy at inlet i_o and at outlet i_k from turbine. At constant values of steam parameters , power of turbine can be described by formula 1:

$$P_T = D_T(i_o - i_k) \tag{1}$$

Taking into account losses accompanying transformation of mechanical energy to electrical energy, electrical power PE is given by formula 2:

$$P_E = P_T \eta_m \eta_e \tag{2}$$

Regulation of the turbine shaft power depends on changing steam flow which flows through control valve. A steam turbine is made up of low, medium and high-pressure stage. In all stages, compressed steam expands, giving the shaft driving torque. Medium-pressure stage is used in operating time of power unit and transient states, where rapid change of power is necessary. Under normal operating conditions high-pressure stage is used.

Compressed steam flows to the turbine, it is expanded in blades and mechanical torque is created on the turbine shaft. As a result of interaction of rotor and armature magnetic fields, electromagnetic torque is produced.. In steady state the mechanical torque is equal to the electromagnetic torque. However in unsteady state these torques are not the same. If mechanical torque TM is higher than electromagnetic torque, turbine shaft will accelerate. In an opposite situation, turbine shaft will slow down. The rate of these changes is a result of the rotor moment of inertia *J*.

$$T_M - T_E = J\frac{d\omega}{dt} \tag{3}$$

Synchronous generator is a machine which parameters can be controlled within acceptable limits, which are shown in Figure 2.

The first limits of the work areas are maximum and minimum mechanical power of the turbine. Straight lines AB and DE restrict the work area. Rated apparent power of turbogenerator is higher than maximum mechanical power of turbine in view of use fully the turbine power because of production cost of turbine which is several times bigger than turbogenerator. The second limit is maximum stator current. On the plane P-Q is plotted a circle and its radius is $U_g I_{S\_MAX}$. This radius draws the circle which describes work area with limits defined by allowable stator winding temperature.

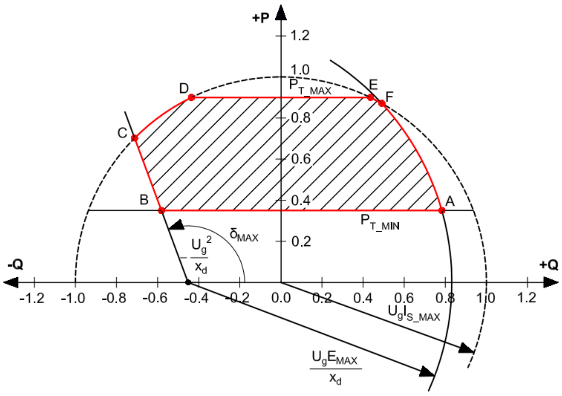

Fig. 2. Allowable work area of turbogenerator

The next limitation is maximum excitation current. This current has an impact on value of electromotive force E_e that is induced in the stator winding. Value of excitation current is calculated in view of rated apparent power and a power factor which are basic parameters in design process of the turbogenerator. During machine operation, the power factor is set to a fixed constant level. Reduction of this level would require increasing the excitation current above allowable limit for large load. Change in load type causes generator to draw inductive reactive power from power system to magnetize a stator core. It is an unwanted phenomenon and that is why direct current from exciter is used to magnetize stator core. Modern regulators of excitation current contain modules responsible for controlling constant value of power factor.

3. Flux to Simulink technology

Flux made by Cedrat is a finite element software application using for electromagnetic and thermal physics simulation. This software is suitable for designing, analyzing and optimizing synchronous generators [2]. Model of the turbogenerator was created in Flux software and it is based on field-circuit modeling. Using this tool it is possible to analyze physical phenomena occurring in synchronous generator. Synchronous generator is represented by two parts: field and circuit part. Electromagnetic field equations are solved in field part. During solving field equations parameters such as real physical characteristics of materials, configuration of windings, damper circuit and motion elements are taken into account. Electrical scheme is assigned to circuit part. Elements on

this scheme correspond with windings in the field model. During simulation coupled electromagnetic, circuit and motion equation are solved in every time step [3, 4].
Simulink is a part of numerical package Matlab from the MathWorks and it is used to perform computer simulations. Simulink allows building simulation models using the graphical interface. Simulations with discrete and continuous time can be performed using Simulink. It provides a customizable set of block libraries which can be used in design in simulation of time-varying systems [5].
Flux and Simulink are known well in their respective fields and are producing direct for systems simulation. It is possible to join these two software. Possibility to use input and output electrical and mechanical parameters from field-circuit model exists in the Simulink. The most important parameters used in presented simulation process are shown in Table 1.

Tab. 1. Electrical and mechanical parameters which can be used in modeling of turbogenerator regulation system

Electrical quantities	Mechanical quantities
current	angular velocity
voltage	load torque
resistance	moment of inertia
inductance	current angular position of rotor

The simulation time step, input and output parameters are introduced to Simulink's Block: *Coupling with Flux2d*, Fig. 3. Simulink environment provides the only opportunity to introduce additional input data and obtain results. The results in Simulink are only generated in suitable windows which must be declared before the simulation, but in the Flux all kind of results are available and their startup is the same like during the simulation using only Flux. That is why it is recommended to check the results in Flux environment and additional obtained results may be conveniently converted.

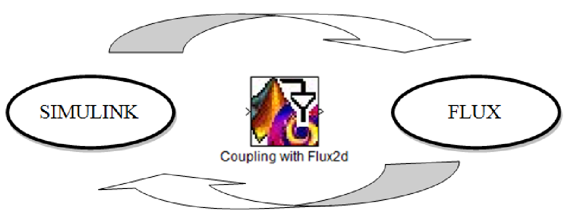

Fig. 3. Direct connection Flux and Simulink

4. Excication and turbine regulation

Excitation regulator acts on synchronous generator through the exciter. Voltage Ug and current Ig obtained by measurements are used in calculations of active, reactive power and power factor in the regulator. In the next step calculated parameters are compared with set values. Regulation signal is created. Example of excitation regulator is shown in Fig. 4, [7].

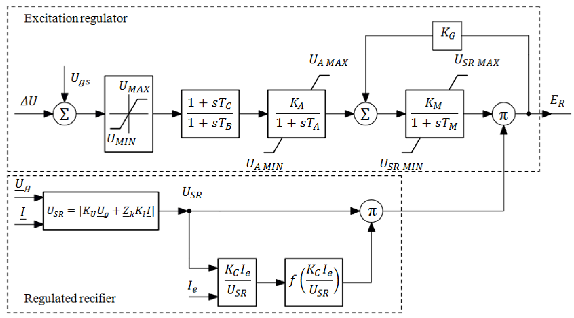

Fig. 4. Block diagram of excitation system and voltage regulation with static exciter

where: KA – voltage regulator gain, KC – rectifier loading factor proportional to commutating reactance, KG – feedback gain constant of the inner loop field regulator, KM – forward gain constant of the inner loop field regulator, TA, TB, TC – voltage regulator time constant, TM – forward time constant of inner loop field regulator, USR – power supply rectifier, ER – exciter output voltage, Zk – compensatory reactance

Fig.4. show direct current source in the form of controlled rectifier consisting of three-phase bridge rectifiers which are composed of six thyristors each.. Characteristics of such rectifier depend on the firing angle of the thyristors.
Turbine regulator is used to control frequency and output active power. Figure 5 presents the block diagram of steam turbine regulation system. This diagram is often used in transient stability studies programs.

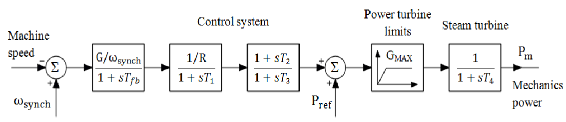

Fig. 5. Block diagram of steam turbine regulation system

where: Tfb – flyball time constant, G – flyball gain, T1, T2, T3 – first, second and third time constant for the control system, T4 – turbine time constant

Systems from Figs. 4 and 5 were used in creation of Simulink block diagram used in conjunction with Flux software. This is shown in Fig.6. Quantity such as angular velocity, terminal voltage, stator and excitation currents were obtained from Coupling with Flux2d Block when the filed-circuit model was working. For synchronizing process of turbine regulator block angular velocity from simulated machine is introduced and it is compared with synchronous angular velocity. During the simulation load torque may change and angular velocity vs. time may be recorded.. Output angular velocity from turbine regulator is introduced to Coupling with Flux2d Block as an imposed speed which determines turbine power PT, formula (4). Unsteady state will be last as long as value of electromagnetic torque will not be the same as turbine torque (3).

$$P_T = T_M \cdot \omega \tag{4}$$

To excitation regulator has inputs: terminal voltage, stator current, excitation current and set values: terminal voltage, reactive power or power factor. Last quantity is compared with measured values. Difference of these values forces precise course of excitation voltage. In this place it can be changed voltage on excitation current which can be powered directly excitation system. It depend on the circuit model in Flux.

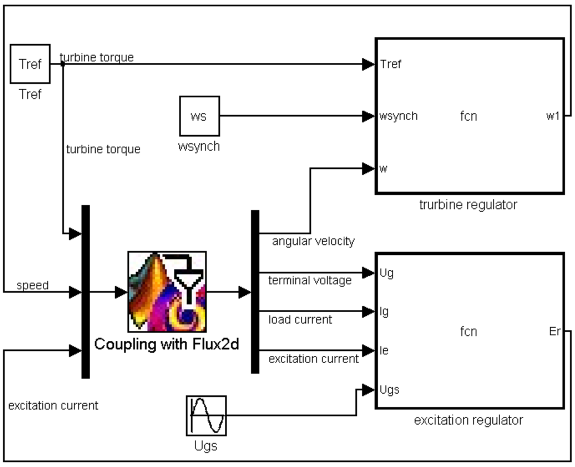

Fig. 6. Block diagram of Simulink with Flux connection to regulation system

5. Conclusion

Coupling Flux and Simulink programs in simulation is a useful tool in modeling of the turbogenerator regulation system.

Accuracy of the results is depends on number of mesh discretization connections. Steam boiler was omitted in the regulation system since its time constant would result in too long simulation time.

During the simulation limitation of quantities must be taken into consideration. Time constants should describe the real devices which was used in simulation.

6. References

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