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EXCITATION SYSTEM MODELS OF GENERATORS OF BALTI AND EESTI POWER PLANTS

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This paper describes the requirements for the generator's excitation system. Different parts of the excitation system are also presented. Two totally different types of excitation systems are installed in generators of both Eesti and Balti power plants. The one – fast static excitation system UNITROL5000 produced by ABB – was installed in 2005. The other is a rather slow excitation system – high-frequency AC machine – produced in Russia in the middle of the 70s. The paper presents main structures of those excitation systems and their control systems and also proposes models of control systems for dynamic calculations of those systems.

Introduction

Balti and Eesti power plants are two world's biggest power plants working on oil shale. With generation capacities of 765 MW and 1615 MW those plants produce approximately 95% of Estonia's power consumption. Renovation of one power unit at both power plant was completed in 2005. During the renovation new boilers were built, turbines and generators were renovated, and control systems of the power units were also renewed. The total capacity of the new units is 430 MW.

Excitation systems of generators in Balti and Eesti power plants were chosen for investigation because their work has the biggest impact on dynamic stability of the Estonian grid. Two totally different types of excitation systems are simultaneously used at Eesti and Balti power plants. A rather slow high-frequency AC machine excitation system (P-system) produced in Russia in the middle of the 70s is in use, and a fast static excitation system (PD-system) UNITROL5000 produced by ABB was installed in 2005. As the two excitation systems are used in both power plants, the models for dynamic calculations proposed in this paper can be

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used in both power plants as well. Both types of excitation systems have been investigated. The static excitation system UNITROL5000 produced by ABB and used in one 253-MVA generator of Balti Power Plant and in one 253-MVA generator of Eesti Power Plant was studied first followed by studies on the Russian type of high-frequency AC machine excitation system which is used in three 200-MVA generators of Balti Power Plant and in seven 200-MVA generators of Eesti Power Plant.

The basic function of an excitation system is to provide direct current to the field winding of the synchronous machine. The protective functions ensure that capability limits of the synchronous machine, excitation system, and other equipment are not exceeded.

The excitation system also performs control and protective functions important for satisfactory performance of the power system by controlling the field voltage and by that the field current. The control functions include the control over voltage and reactive power flow, and the enhancement of system stability.

Requirements for reliable performance of the excitation system have to be determined considering both the synchronous generator and the power system. The basic requirement is that the excitation system supplies and automatically adjusts field current of the synchronous generator to maintain terminal voltage as the output varies within the continuous capability of generator's U-curves. Margins for temperature variations, component failures, emergency overrating, etc. must be factored in when the steady-state power rating is determined. Usually, the exciter's rating varies from 2.0 to 3.5 kW/MVA generator's rating [2].

The excitation system must also be able to respond to transient disturbances by field forcing consistent with instantaneous and short-term capabilities of the generator. Considering this, there are many factors that limit generator capabilities: rotor insulation failure caused by high field voltage, rotor heating caused by high field current, stator heating due to high armature current loading, core end heating during under-excited operation, and heating caused by high excess flux (volts/Hz). There are time-dependent characteristics of thermal limits, and the short-term overload capability of generators that may be measured from 15 up to 60 seconds. To secure the best use of the excitation system, it should be able to meet the system requirements by taking full advantage of short-term capabilities of the generators without surpassing their limits.

As for the power system, effective control of voltage and enhancement of system stability should be supported by the excitation system. It should be able to respond rapidly to a disturbance improving transient stability modulating the generator field to improve small-signal stability. In addition to the error signal of terminal voltage, modern excitation systems are using auxiliary stabilizing signals (power system stabilizer) to control the field voltage to damp system oscillations. Modern excitation systems with high ceiling voltages are capable of providing practically instant response.

A substantial improvement of dynamic performance of the overall system can be achieved by combination of high field-forcing capability with the use of auxiliary stabilizing signals.

Exciter. It provides dc power to the field winding of the synchronous machine. Exciter can be either an AC machine, DC machine, or it is fed from generator's terminal switchgear through converter.

Regulator. It processes and amplifies input control signals to a level and form appropriate for control of the exciter. This includes both regulating and stabilizing the functions of the excitation system (rate feedback or lead-lag compensation).

Protective circuits and limiters. They include a wide range of control and protective functions to guarantee that the capability limits of exciters and synchronous generator are not exceeded. Limitation of maximum excitation, terminal voltage, field-current and underexcitation, regulation and protection of volts-per-hertz ratio are some of the principal functions. These circuits are usually distinct ones, and their output signals may be applied to the excitation system at different locations as a summing input or a gated input. In Fig. 1 they are grouped and shown as a single block for better consideration.

Load compensation and terminal voltage transducer. Terminal voltage transducer senses generator's terminal voltage, rectifies and filters it to dc quantity, and compares it with a reference which represents the desired terminal voltage. If it is desired to hold constant voltage at some point electrically remote from the generator's terminal, load (or line-drop, or reactive) compensation may be also provided. Load compensation function is optional, and at Eesti and Balti power plants it is used in UNITROL5000, but it is not used in the Russian high-frequency AC machine excitation system.

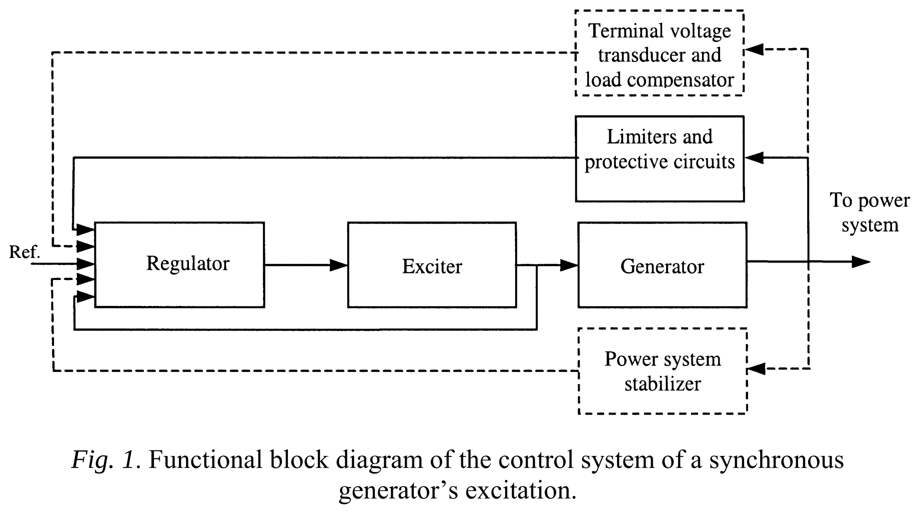

Fig. 1. Functional block diagram of the control system of a synchronous generator's excitation.

Power system stabilizer (PSS). Its function is optional as well. It is not used in the Russian high-frequency AC machine excitation system, but it is used in UNITROL5000. PSS is used to add modulation signal to the regulator to damp power system oscillations. Some commonly used input signals are rotor speed deviation, electrical or accelerating power and frequency deviation.

Methodology

The excitation system should be considered from the aspect of classical control methodology. A classical control methodology is based on feedback and error-driven control.

Simple systems are usually one-dimensional that means one input signal and one output signal. In that case the dependence of controlled object state on output is easily describable by a relatively simple function hence these systems could be successfully controlled by the output signal. The aim of regulation is automatic stabilization of the output, changing it by a given or by some unknown (stochastic, fuzzy) principle. These systems are called stabilizing and control systems.

Simple systems can be controlled by two principles. The first principle is that regulation action is dependent on regulation error, this action uses feedback for regulation, hence it is called feedback control. The second principle is that the regulation action is made in a way that compensates disturbance influences. Usually a combination of both principles is used, and in this case regulation action is a function of regulation error and disturbance compensation. Disturbance compensation principle is distinguishable from feedback principle only with some simplification, because generally measured disturbances can also be viewed as output of the controlled object, and feedback can also be used for regulation.

Controlled object is always of a specific structure. Technical and technological regulation objects are the objects consisting of controlled operation and measurement equipment. Measuring equipments give information about working of the controlled object. Regulator compares design state of the object with its actual state and makes regulation actions.

In the case of the excitation system, the generator is the controlled object, and controlled operation is the control of generator's acceleration. An excitation system uses both above-mentioned principles: regulation error and disturbance compensation. Representation of excitation systems by automation block diagrams is necessary for making accurate dynamic calculations and also in the case if the software model library used at calculations does not contain the required model. Software programs of dynamic calculations such as PSSE and PSCAD used at Estonian TSO and at Tallinn University of Technology do not contain the models of equipment produced in Russia.

PSSE and PSCAD offer the possibility to model excitation system by automation blocks.

Models of excitation systems

Static excitation system UNITROL5000, as mentioned above, is used in one 253-MVA generator of Balti Power Plant and in one 253-MVA machine of Eesti Power Plant. According to the information from ABB [9], static excitation system UNITROL5000 has the following functions:

- Voltage regulator with PID filter (AUTO operating mode);
- Field current regulator with PI filter (MAN operating mode);
- Reactive load and/or active load droop/compensation;
- Limiters for:
  - Maximum and minimum field current
  - Maximum stator current (lead/lag)
  - P/Q under excitation
  - Voltage-per-hertz characteristics.
- Power factor/reactive load regulation;
- Power system stabilizer (PSS)
  - conventional in accordance with IEEE-PSS2A
  - Adaptive power system stabilizer
  - Multiband power system stabilizer.

All components in these systems are static. The excitation power is supplied through a transformer from the station auxiliary bus, and it is regulated by a controlled rectifier. This type of the excitation system is also commonly known as a bus-fed or transformer-fed static system (see Fig. 2).

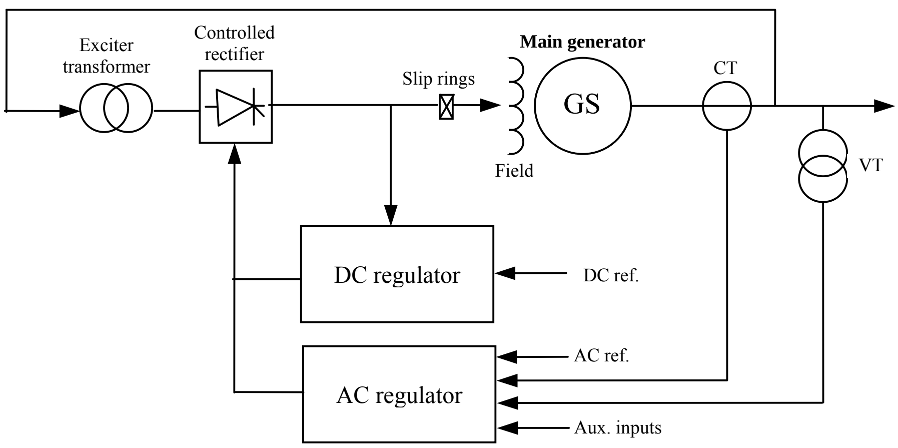

Fig. 2. Scheme of the static excitation system.

The inherent time constant in this system is very small. The maximum output voltage of the exciter (ceiling voltage) depends on the input ac voltage. It means that in system-fault conditions causing depressed terminal voltage of the generator, the available ceiling voltage of the exciter is reduced. This limitation of the excitation system is mainly offset by its virtually instant response and high post-fault field-forcing ability. Big generators that are using such type of the excitation system perform satisfactory when they are connected to a large power system. However, this excitation system is not performing as expected if the generator is connected to a small industrial network with long fault-clearing time. The automation block diagram of the exciter system UNITROL is shown in Fig. 3.

There are following marks in Fig. 3: KIR – compensation factor of reactive power, KIA – compensation factor of active power, KR – steady-state gain, TB1 – the first lag-time constant of controller, TB2 – the second lag-time constant of controller, TC1 – the first lead-time constant of controller, TC2 – the second lead-time constant of controller, Up+ , Up- – AVR positive and negative ceiling values of the output, respectively.

As one can see, the excitation system UNITROL5000 also includes the function of power system stabilizer (PSS). PSS is made in accordance with IEEE – PSS2A standard. The PSSE standard dynamic library contains this type of PSS models (see Fig. 4). In the PSSE model library this model is called Dual-Input Stabilizer model. PSS uses auxiliary stabilizing signals to add damping to the generator's rotor oscillation by controlling its excitation. Some commonly used input signals are rotor speed deviation, accelerating power and frequency deviation. It is an effective way to increase small signal stability performance.

There are following marks in Fig. 4: input signal V1 corresponds to the filtered value of deviation from rotor angular frequency $\Delta\omega$, V2 – filtered value of electric power at generator terminals, TW1-TW4 – wash-out time constants, Ks1 – PSS gain factor, Ks2 – compensation factor for calculation of integral of electric power, Ks3 – signal matching factor, T1 – T4 – lead-time constants of conditioning network, T7 – time constant for integral of electric power calculation, T8, T9 – time constant of ramp-tracing filter, M, N – degree of ramp-tracing filter, UST_{max}, UST_{min} – upper and lower limit of stabilizing signal, respectively.

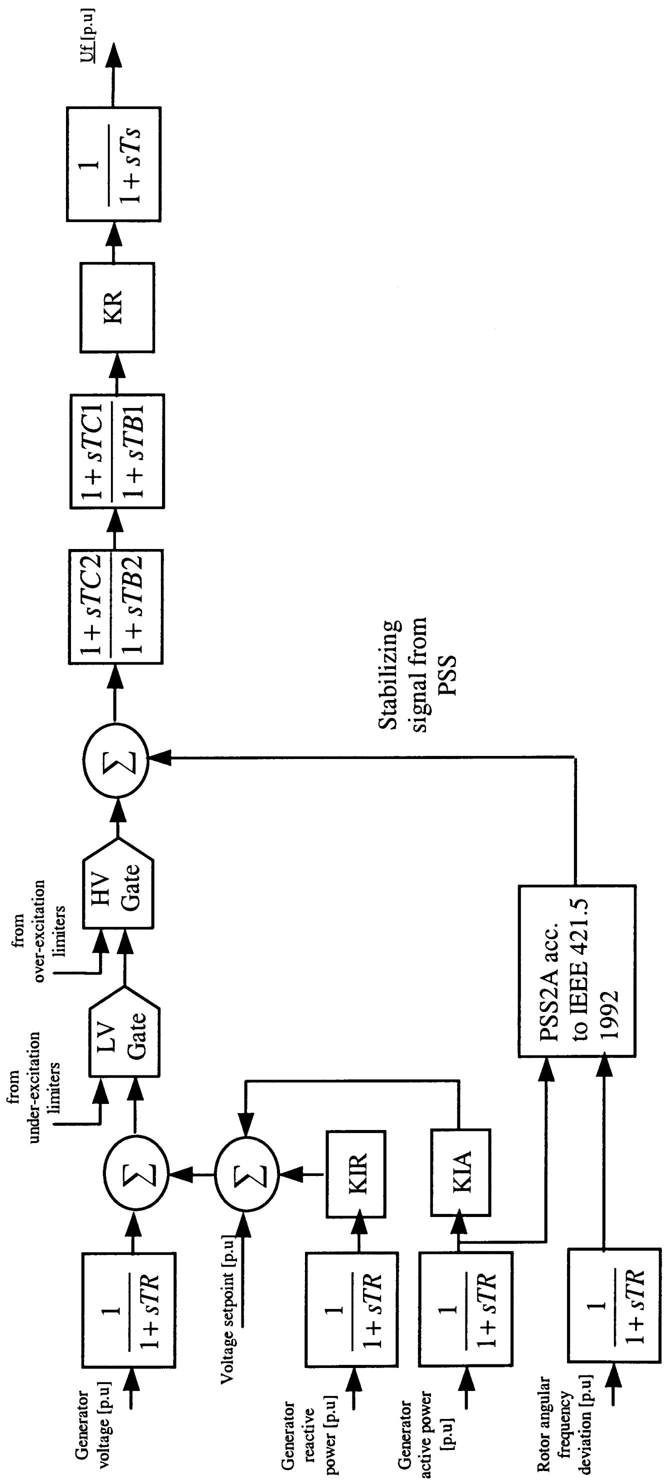

Fig. 3. Block diagram of automation of the exciter UNITROL5000 [9].

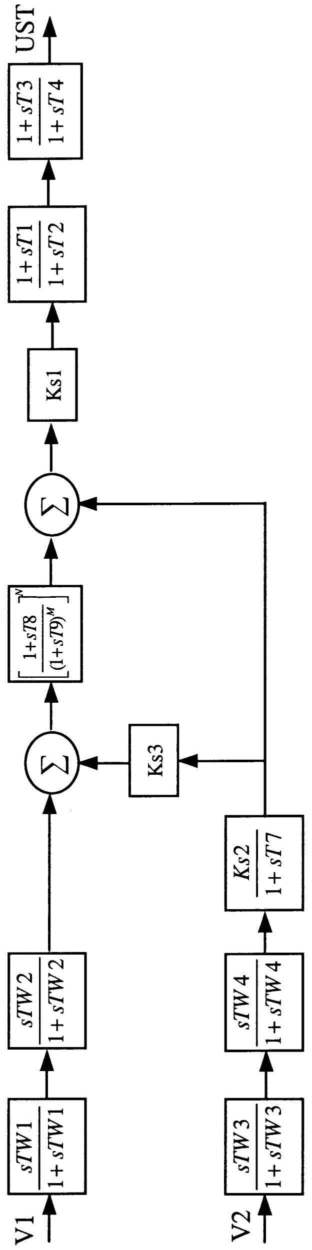

Fig. 4. Block diagram of automation of the power system stabilizer UNITROL5000 [9].

Russian type of high frequency AC machine excitation system

The other exciter type used at Eesti and Balti power plants is ВГТ-2700-500, and regulator type is ЭПА-325. It is an old version of the Russian excitation system. In this type of the excitation system the exciter is high-frequency (500 Hz) induction AC generator, which is placed in the same shaft with the main generator. The principle scheme of this exciter system is shown in Fig. 5.

The exciter has three windings: W1 is used as the main excitation winding and it is connected serially with generator's rotor winding, W2 is used to excite the forcing system, and W3 is used to give an additional excitation while the exciter is overexcited. The regulator has two electromagnetic magnifiers which are connected in series. The one is used to lead exciter's forcing winding, and the other to lead exciter's main winding. The structure of both magnifiers is similar, and they have three leading windings with the following functions:

1. Excitation-forcing limiter;
2. Magnifier core for additional pre-magnetization;
3. Flexible feedback, which gets its power from stabilizing transformer.

Block diagram of automation of the high-frequency AC machine excitation system is given in Fig. 6.

The exciter is lead by magnifiers, and because of that inherent time constant of the excitation system is rather big. Therefore these kinds of excitation systems are called slow-response excitation systems (P-system).

There are following marks in Fig. 6: TR – time constant of measuring filter, Te – gate control unit and time constant of converter, Tv – time constant of amplifier, Kv – amplification factor of amplifier, Ke – amplification factor of exciter, Te – time constant of exciter, Kffb – amplification factor of flexible feedback, Tffb – time constant of flexible feedback, Krfb – amplification factor of rigid feedback, Kf – amplification factor of winding W1, K – amplification factor.

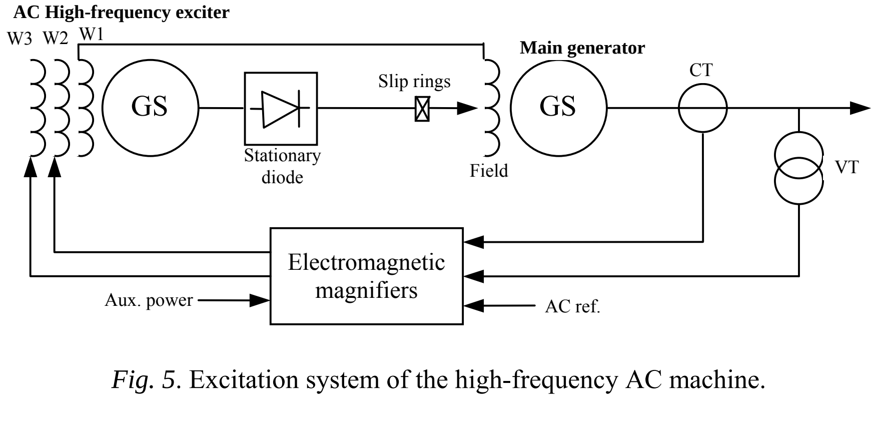

Fig. 5. Excitation system of the high-frequency AC machine.

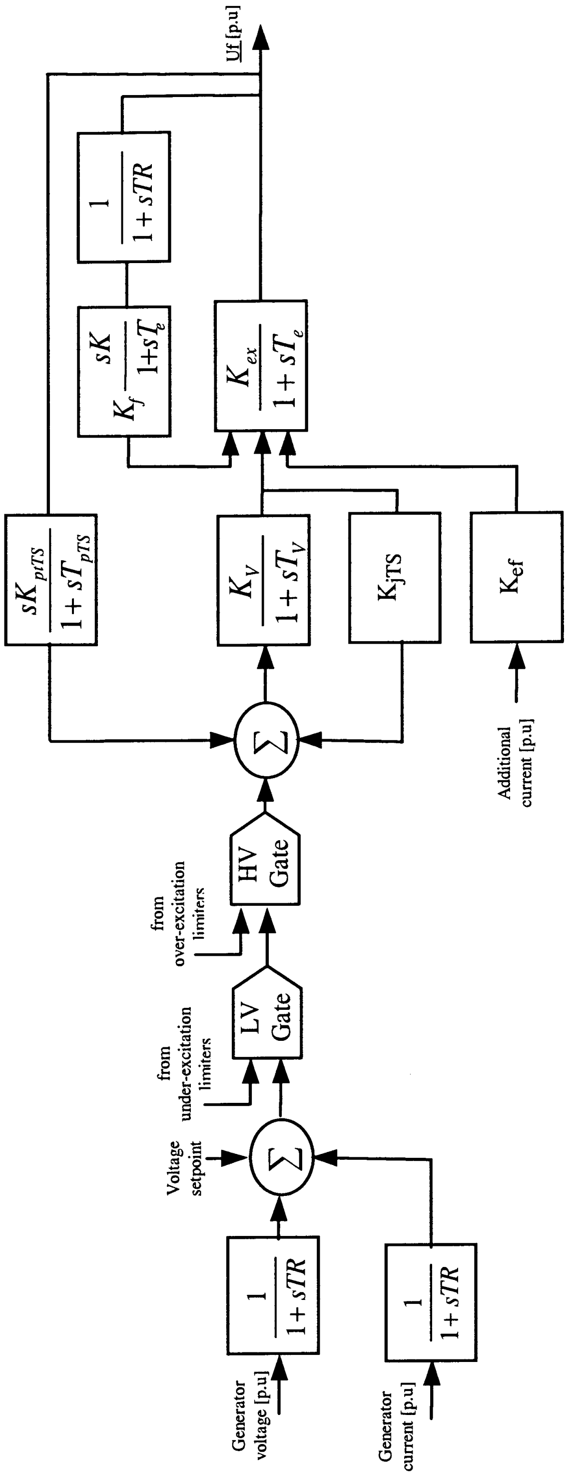

Fig. 6. Block diagram of automation of the high-frequency AC machine excitation system.

Conclusions

In this paper two totally different excitation systems have been investigated. One of them is an old Russian-type high-frequency AC machine excitation system which was developed in the 60s and installed in the 70s into two major power plants in Estonia. The other is a modern static excitation system, which was installed in 2005 only in two blocks of the above-mentioned power plants. This paper describes the requirements for the excitation system. Both systems satisfy the basic requirements, but because of their different structure their responses to grid disturbances are of different strength. Automation block diagrams needed for dynamic calculation programs are proposed.

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