New Excitation Equipment for 220 MW Generators in Kozloduy Nuclear Power Plant

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Summary: Rehabilitation of the excitation equipment for Generator 5, Reactor Unit 3, in Kozloduy Nuclear Power Plant (NPP) was completed in November 2000. ABB's Static Excitation System based on UNITROL 5000 technology has been chosen by the Bulgarian National Utility and Kozloduy NPP to substitute the original Russian excitation system equipment with Electro-magnetic voltage regulators. This substitution is in a rehabilitation package of four excitation system equipment for Generators 5 and 6 of Reactor Unit 3 and Generators 7 and 8 of Reactor Unit 4. After a short overview of the original excitation system this paper describes the new Static Excitation System UNITROL 5000 including configuration with block diagram, its main features and merits such as modes of operation, limiters, special control functions and diagnostic facilities. Furthermore, new facilities, which are implemented in UNITROL 5000, such as dynamic current distribution among the thyristors working in parallel as well as the start-up from the residual magnetism are mentioned. Special functions including a so-called free-running mode of operation (originally called "выбег") and automatic change over sequence from new excitation system to the stand-by excitation system, which is a DC exciter machine, are described. Some records of the transient responses performed during the commissioning and a photograph of a manufactured system are provided.

1. Original excitation system

Most of the TBB type large turbo-generators in Bulgarian Thermal Power Plants including Kozloduy NPP with unit capacity between 150 and 220 MW were manufactured by "Elektrosila" - Russia. The units installed before 1985 were equipped with the so called "High Frequency" excitation systems, produced by the same factory as an integral part of the typical electrical design of the unit.

The "High frequency" excitation system, shown on Fig.1, consists of the following main parts (the original abbreviations and names are used):

- **VGT** - Rotating excitation generator, installed on the main generator's shaft, with a solid rotor - $P_{nom}/P_{ceiling}$ = 1230/2700 kW, $U_{nom}/U_{ceiling}$ = 370/676 V, f = 500 Hz;
- **VCP** - Auxiliary excitation generator, installed on the main generator's shaft, with permanent magnets - P_{nom} = 30 kW, U = 230 V, f = 400 Hz;
- **VUTG** - Diode rectifier - P = 6000 kW;
- **AVR** - Automatic Voltage Regulator - type ЭПА- 325В, consisting of passive measuring circuits, magnetic amplifiers and non-controlled rectifiers.

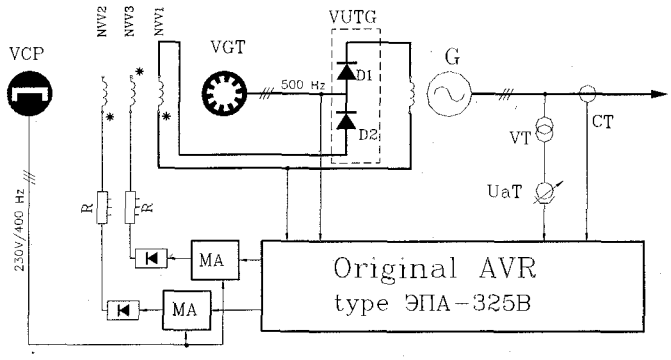

Fig.1: "High frequency" excitation system

More details about "High frequency" excitation systems and the problems encountered during their operation and maintenance are described in [1].

2. UNITROL 5000 - main features and parameters

The new system includes a fully redundant dual channel automatic voltage regulator (AVR), each with filed current and stator current limiters, P/Q-based under-excitation limiter and Power System Stabilizer (PSS). The PSS's control algorithm is based on IEEE Std.421-Type 2A. The stabilizing signal corresponds to the acceleration power signal resulting from a combination of the electrical power and rotor angular frequency input signals.

In addition, each channel provides facilities for reactive power regulation as well as MANUAL control for the field current regulation. Monitoring, protection and logic control functions such as the main field temperature monitoring are also implemented in the AVR's software.

The field current of the generator flows from its terminals through the high voltage disconnector, excitation transformer, ac-breaker with overcurrent protection, three thyristor converters and the field circuit breaker to the field winding. Alternatively, the field current may be supplied from the Stand-by Excitation System (SES), which is a DC exciter machine. This facility is described in Item 3, Special Functions. The main components of the employed system are shown on Figure 2.

Three thyristor bridges in a so-called n-1 configuration are provided to supply the necessary field current. They are simultaneously in operation and in case of a fault in a thyristor bridge, two remaining thyristor bridges take over its current and continue to operate without any restriction. The thyristor converter control in UNITROL 5000 systems is provided with a so-called dynamic current distribution facility, which takes care of an equal current distribution among the thyristors working in parallel. With this facility a current distribution factor of 0,97 has been achieved.

Furthermore, UNITROL 5000 is capable to start-up from the machine residual magnetism since a very low voltage is necessary for the normal operation of the gate control. A back-up field flashing circuit from the station battery is automatically switched on if the residual magnetism is lost during a long standstill period. In this case a small battery current (20 ...40 A) is supplied from the back-up field flashing circuit.

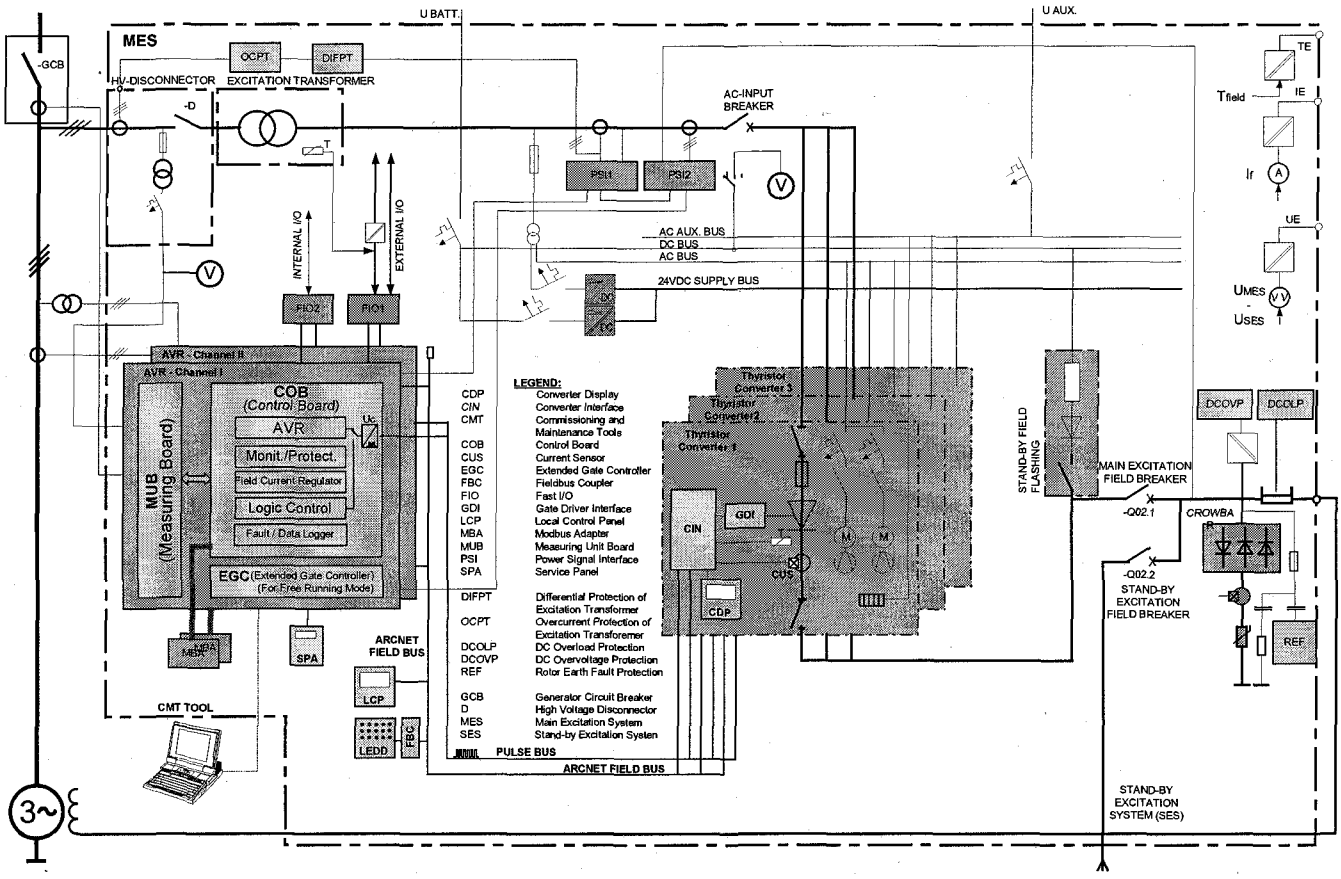

Fig. 2: Excitation system block diagram

The employed system is fault tolerant, i.e. the design concept ensures that each printed circuit board or component of the AVR as well as of the thyristor converter can be easily removed and replaced during operation. For the maintenance of the thyristor converters during operation a five-pole disconnector, one per each thyristor bridge, is used to disconnect the faulty thyristor bridge.

Main system parameters and control data:

- Rated system voltage UEN	:	357,5 V DC	- Free running mode up to	:	16.6 Hz
- Rated system current IEN	:	3025 A DC	- Firing of thyr. guaranteed for	:	< 5% Ug
- Positive ceiling voltage +Ucl	:	650 V DC	- Time to reach ceiling	:	20 ms
- Negative ceiling voltage –Ucl	:	-680 V DC	- Design ambient temperature	:	55°C
- Ceiling voltage guaranteed for	:	90% Ug	- Mechanical protection degree	:	IP54
- Ceiling current Icl	:	5'500 A DC	- Excitation transformer	:	IP23
- Applicable time for ceiling tcl	:	20 s	- Design life	:	30 years
- Control accuracy	:	± 0,5%			

3. Special Functions

A facility for ***change over from the main excitation system (MES) to stand-by excitation system (SES)*** and vice-versa is provided. The purpose of this facility is to enable the maintenance and inspection of the MES without interruption of the generator operation. An automatic change over control sequence is a part of the AVR's control software and enables the operator to perform a surge free change over. During the change over sequence from MES to SES the automatic control actuates the field rheostat of the DC exciter machine so that the output of the SES is adjusted to the value which a bit higher that the output of MES. After reaching that value a signal "Ready to transfer" is given to the operator. He can now switch on the breaker –Q02.2. Subsequently, the automatic control inverts the pulses to the thyristor converter and the SES takes over the supply of the field current. As soon as the field current from the MES has decayed to zero, the field breaker – Q02.1 is switched off. Now, the high voltage disconnector –D can be opened and the maintenance of MES can take place. The change over sequence from SES to MES is proceeded automatically in a similar way. In order to protect the generator field circuit during the operation of SES a separate set of the over-load and over-voltage protection relays is provided.

In some emergency cases the main close valves of the turbine should be activated without switching off of the synchronous machine (SM) from the network. The SM operates than as a synchronous motor supplying the 6 kV sections of the power plant during following 160 seconds. Subsequently, the SM is disconnected from the network and it continuous to operate in a so-called ***"free-running mode"***. In this mode the speed of the machine is slowly reduced for the following 180 seconds. At the end of that period the speed reduces from 3000 rpm to 1000 rpm and the generator voltage reduces from 15,75 kV to 8000 V approximately. Afterwards, the machine is switched off. The task of the excitation system is to keep the generator voltage above 8000 V. To achieve this a special controller, a so-called "Extended Gate Controller", which can correctly generate the triggering pulses for very low frequencies, is employed.

4. Diagnostic facilities

A special attention was given to the diagnostic facilities in design of the new system. The local control panel (LCP) is equipped with a local control display for measuring and alarming purposes. The alarms are displayed in clear text in Bulgarian Language. Furthermore, the local control is equipped with a conventional Local Alarm Display with 24 LEDs.

CMT-Tools (Commissioning and Maintenance Tools) are provided in a package with a personal computer for the commissioning, maintenance and diagnostic purposes. The tools include the following facilities: local control with an image of the control panel on the PC screen, trending function, uploading of the data logger (transient recorder) and the fault logger, displaying of software diagrams, parameter setting etc.

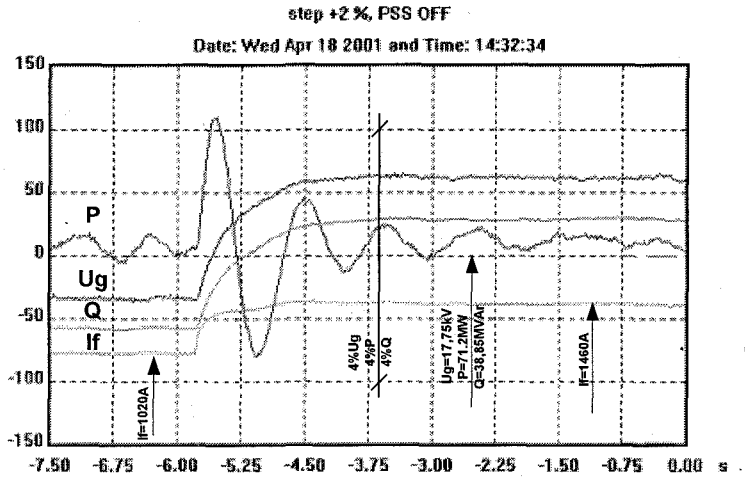

Figure 3: Step response test with PSS OFF

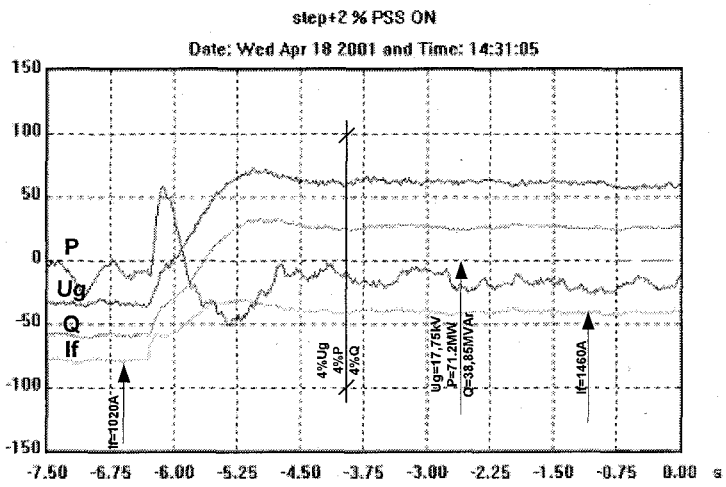

Figure 4: Step response test with PSS ON

The CMT-Tools package can be extended with a facility for remote diagnostic via a public telephone network.

5. Commissioning Experience

During the commissioning the new excitation system equipment was thoroughly tested to prove the operational requirements and guaranteed data. Excellent transient responses were achieved and recorded during the dynamic performance tests. Figure 4 and 5 show the response on 2% step signal with PSS OFF and ON.

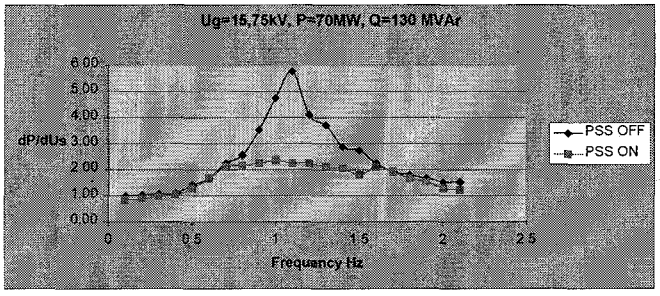

Figure 5: Plot of the frequency response test.

The frequency response test was carried out to verify the impact of PSS to the power swings between 0,5 Hz and 2 Hz. Figure 5 shows that PSS significantly reduces the amplitude of the power swings. dP/dUs represents a ratio between the produced power swing amplitude and the amplitude of the injected signal from the function generator versus frequency.

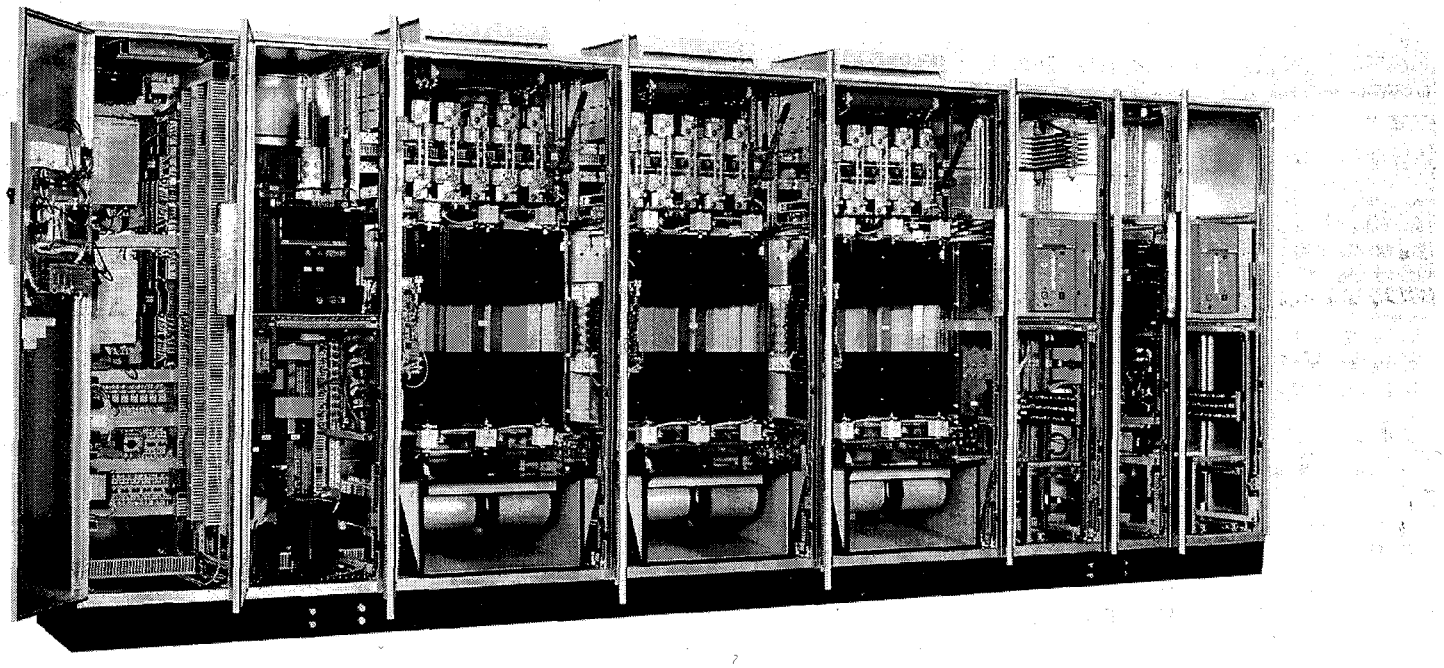

Figure 4: Photograph of UNITROL 5000 excitation system panels for KOZLODUY NPP after the shop-test

REFERENCES:

[1] Plants Plamen Popov, NEK; Davor Tomerlin, ABB Industrie AG - Upgrading of Automatic Voltage Regulators in Bulgarian Thermal Power