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Vinko Ćesić, Mladen Kajari, Siniša Marijan, Zvonimir Jurin, Marin Kolić

Excitation System with Microprocessor Based Twin-channel Voltage Regulator for Synchronous Machines

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Professional paper

In this article a synchronous machine excitation system with microprocessor based twin-channel voltage regulator is presented. Block diagram of excitation system with digital voltage regulator and twin-channel voltage regulator are shown and the main parts of excitation system are briefly described. The responses of characteristic variables of excitation control system of synchronous generator in typical disturbances are presented.

Key words: generator excitation systems, real-time processing, control, converter control

1 INTRODUCTION

Excitation systems with microprocessor based voltage regulator type DVR are suitable for excitation of synchronous generators from few MW on. Voltage regulators are simply adaptable to different types of exciters: static exciter, AC exciter, DC exciter, and compound static exciter. The voltage regulator output amplifier is mainly a thyristor converter [4]. Here are solutions of voltage regulator from single channel AVR function to twin channel AVR.

The entire excitation system can be divided in three major function groups: excitation transformer and power converter unit, control electronics and field flashing and field suppression equipment. Equipment for electrical breaking of the generator can be added optionally. Excitation transformer adapts the supply voltage to the required input voltage for the converter. The power converter converts the AC current into controlled DC field current I_f. The control electronics is developed for power electronics applications in energy, industry and traction requiring high performance and reliable operation. It belongs to the DIREMK – GRASS technology (DIgital Regulation of Electrical Machines – KONČAR and Graphic Software Support).

2 EXCITATION SYSTEM

Excitation power is normally derived from synchronous machine terminals through excitation transformer and thyristor converter. The voltage regulator controls the thyristor converter via the pulse-triggering unit. The block diagram of the excitation system is given in Figure 1.

2.1 Excitation transformer

The excitation power is normally derived from machine terminals through excitation transformer. The task of the excitation transformer is to isolate the synchronous machine field winding from the MV (medium voltage) circuit of the stator winding and the grid and to adapt the secondary voltage to the required ceiling voltage of the thyristor converter. The maximum continuous machine field current determines the rated transformer current. The transformer is three-phase, two-winding, naturally cooled and either dry, cast-resin or oil- immersed.

2.2 Power converter

Power converter is usually three-phase thyristor converter in bridge connection. High availability of the thyristor converter is achieved by redundancy in configuration $(n-1)$ with $(n=3)$ or more parallel bridges, while $(n-1)$ bridge is capable of withstanding all continuous and short-time ratings or $(1+1)$ redundancy (rating 2×100 %). In the case of failure, the current-carrying bridge is blocked and changeover to second bridge is performed.

2.3 Control electronics

2.3.1 Strategy of synchronous machine control

Digital electronics is employed to perform all control and protection functions of excitation system. The use of digital techniques in voltage control enables implementation of sophisticated control functions that are not always possible with analog regulators [4]. The main objectives are control of terminal voltage on preset value with necessary accuracy,

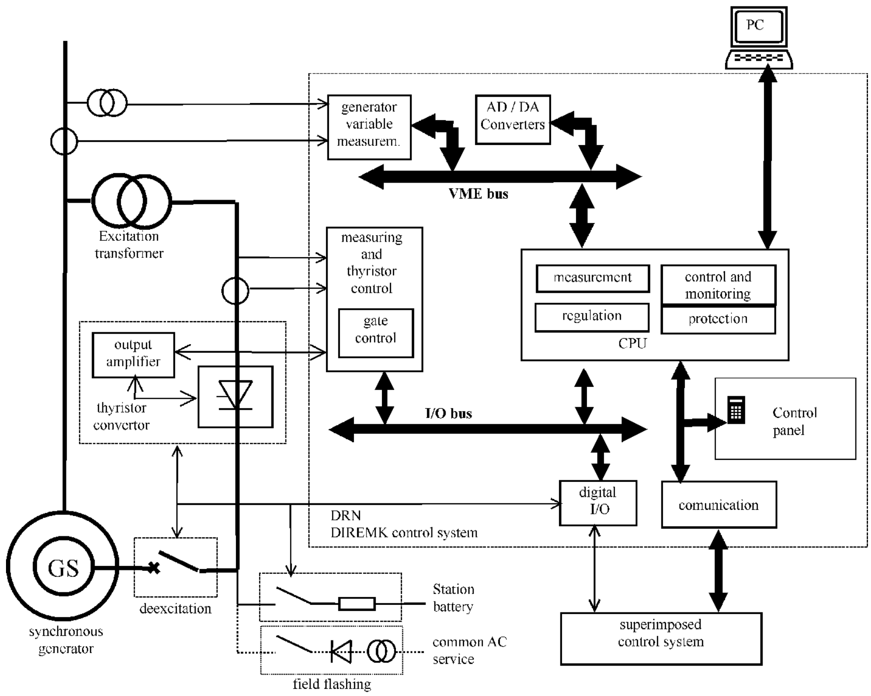

Fig. 1 Block diagram of the excitation system

ensuring stable operation with power system and keeping the machine within permissible operating range. Control functions are: voltage control, standby controller, logical and sequential control and communication.

Voltage control comprises the following functions: measurement and measured signals adaptation, forming the set point (reference) value, compensation of generator external characteristic in accordance with active and reactive current, frequency compensation of generator voltage during start-up (V/f compensation), forming the control error value, maximum and minimum selectors for the connection of the limiters proportional-integral controller (PI), limiters (instantaneous and time delayed field current limiter, time delayed stator current limiter in inductive region, instantaneous stator current limiter in capacitive region, under excitation limiter and minimum field current limiter), additional control functions (follow-up of the standby controller output value, reactive power unload, power system stabilizer) and superimposed control functions (reactive power controller and power factor controller).

Standby controller comprises the following functions: measurement and measured signals adaptation, forming the set point (reference) value of field current, forming the control error value and proportional-integral controller (PI). Pulse generating function is common for voltage control and standby controller.

Logical and sequential control monitors digital input signals, internal warning and fail signals, enables voltage control or standby controller and control of digital output. DIREMK system is based on proven hardware and software support (environment).

2.3.2 Programmable controller

Control of the excitation system is based on the KONČAR microprocessor system for the control and regulation of electrical machines – DIREMK (DIgital Regulation of Electrical Machines – KONČAR), adapted for static excitation systems [1, 2]. The system is built around powerful, programmable central processing unit (CPU) that enables real-time execution of complex control and regulation tasks together with high speed, accuracy and reliability.

2.3.3 Hardware

Modular hardware environment is based on the 16/32 bit microprocessor MC68XXX (for the time being 68302 running on 20 MHz clock) and industrial VMEbus system [7, 8]. The system comprises the following electronic modules [1, 2]: processor module, modules for adaptation, filtration and A/D conversion of generator variables, interface modules for adaptation of digital input and output signals, digital input and output modules, thyristor converter pulse triggering module (pulse generator), analogue/digital, digital/analogue conversion module and module for power supplies monitoring.

2.3.4 Software environment

DIREMK software environment comprises: software for design and development of application program, system software support and software utilities [1, 2].

Software for design and development of application program is based on the GRASS programming package (GRAphic Software Support). GRASS is a personal computer based programming package for design of control and regulation software functions. GRASS is user-oriented programming package that is used in graphical environment and supports a comprehensive library of already developed functional elements. GRASS elements library includes app. 160 functional elements such as: closed loop control elements (e.g. regulator of type PI, PID, integrator), arithmetic elements (e.g. multiplicator, divider, adder, subtractor, function generator), elements that support trigonometric functions, logic elements (e.g. AND, OR, NOR, EXOR, counter, oscillator), input/output elements for accessing the process peripherals, hardware monitoring and testing elements and elements for communication.

2.3.5 Twin-channel configuration

To implement the function of voltage control more reliably and availably, a twin-channel configuration is adopted. This means that two complete single channel digital voltage regulators are build into the system in a redundant configuration [3, 5, 6] with one channel in on-line operation and the other in a hot standby. Both channels have the same inputs and the same program. Both are monitoring their functions and the functions of the other channel. In the case of disturbance on on-line-channel, the standby-channel smoothly takes over complete functions without disturbing the generator operation.

2.3.6 Communication

Digital voltage regulator is provided with serial bus communication to the other control system in the plant.

2.3.7 Data recording

The program of digital voltage regulator has an element for recording up to 12 signals from the application program during the run-time. The program has also an element for storing changes of logical signals (alarm logger). It is possible to store up to 200 changes of signals. Recorded values can be viewed or transferred to PC.

2.3.8 Monitoring, self-monitoring and protection of the excitation system

Depending on the plant, some of the following standard protection functions can be implemented [1, 2, 4]: overcurrent protection of excitation transformer, DC short circuit protection, V/f protection, monitoring of voltage measurement circuits, field current monitoring, field flashing monitoring, monitoring of thyristor converter fuse failures, rotor overvoltage protection monitoring, ventilation monitoring, synchronization voltage monitoring, control system power supply monitoring, pulse monitoring, conduction monitoring, overcurrent, loss of excita-

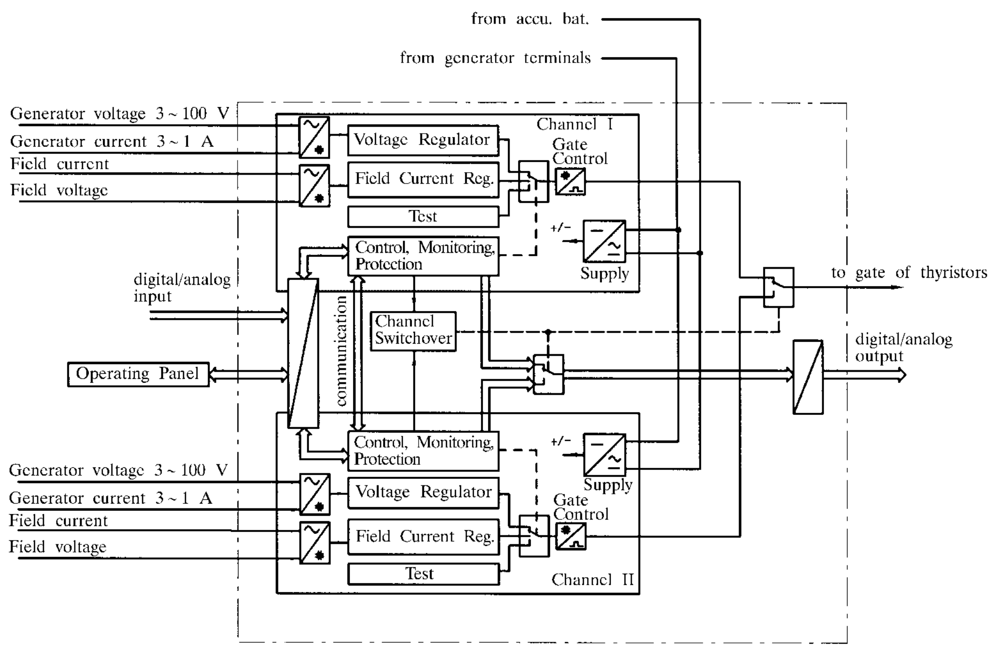

Fig. 2 Block diagram of twin-channel digital voltage regulator

tion, automatic supervision of proper control system operation (self-monitoring), A/D and D/A converters monitoring and rotor temperature monitoring.

Microprocessor control system is equipped with hardware and software support that enables detection of external and internal fault conditions and activates particular software switches or equipment in order to protect the excitation system from consequences of the above mentioned fault conditions.

2.4 Field flashing

Synchronous machines have generally very low remanent voltage. It is therefore necessary to feed the machine field with a smaller current for a few seconds to initiate the voltage built-up. About 10% of the no-load excitation current is fed through start excitation unit into the generator field until sufficient voltage appears on the machine terminals to supply the static exciter. The start-up energy is derived from an external D.C. supply, e.g. the station battery, and transfer from the external supply to the converter takes place automatically. Also the A.C. supply, from station auxiliary, can be used for field flashing. In this case the field flashing equipment comprises a transformer and a diode rectifier.

The same source can be used for boosting the excitation current in the case of severe and long disturbances on the transmission line.

2.5 Field suppression equipment

The thyristor converter is connected to synchronous machine field winding via a de-excitation D.C. breaker with a discharge contact and a discharge resistor (Figure 1). If a sustained electrical fault arises in the machine or inside the range of differential protection, the field should be suppressed as quickly as possible in order to limit fault current damage. It is also necessary to ensure safe de-excitation in the case of a fault in the exciter control circuit causing severe overexcitation. The voltage dependent or linear discharge resistor is used to achieve as rapid a field suppression as possible with regard to the highest permissible voltage across the field winding and the field breaker. It is also possible to implement static discharge using thyristors from the thyristors overvoltage protection (crow bar) and AC circuit breaker. The purpose of the overvoltage protections in the field circuit is to prevent the machine field and thyristor converter from being exposed to an excessive voltage induced in the machine field, which could otherwise arise during certain transient conditions such as improper synchronizing and loss of synchronism. The main circuit comprises the counter-parallel-connected thyristor (crow bar) and series resistor. The thyristors are fired by the overvoltage sensing trigger units with BOD (brakeover diode) elements, when the voltage exceeds the set protection level. The series resistor is intended to limit the current through the protection circuits.

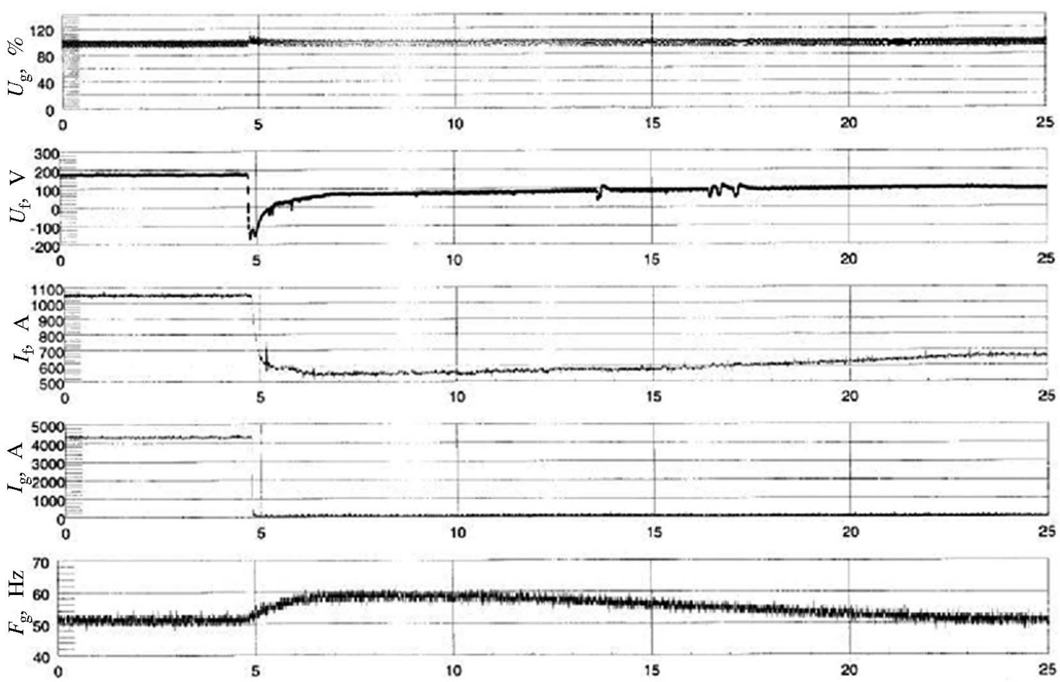

Fig. 3 The active/reactive power rejection on the 68 MW, 30.6 MVAr, 10,72 kV, 4066 A

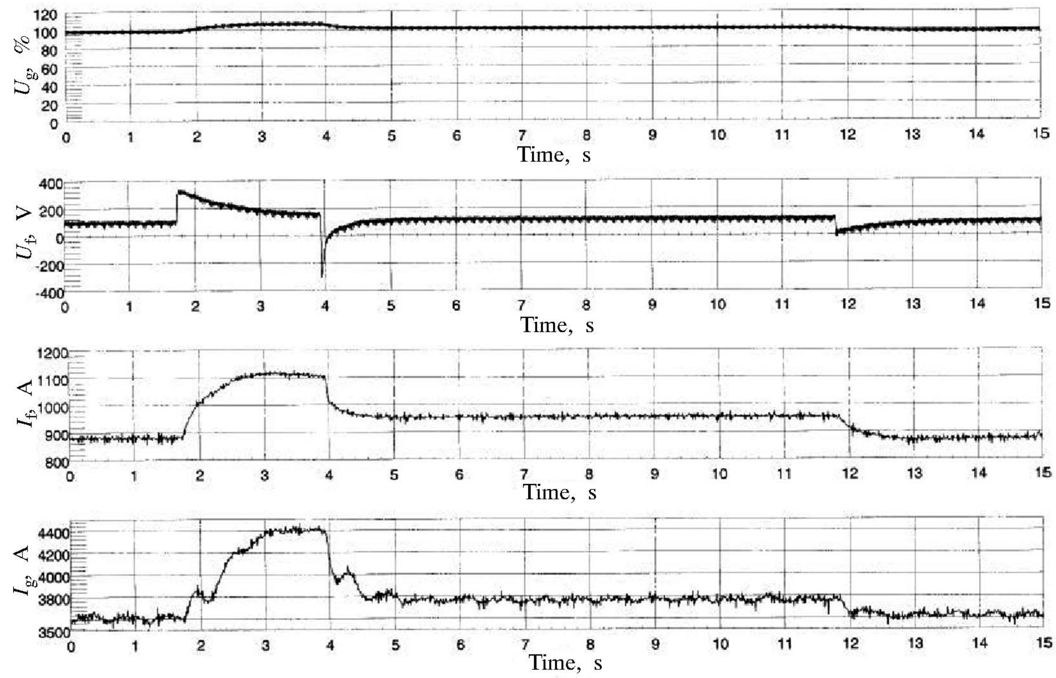

Fig. 4. Overexcitation limiter response (the values of limiter parameters are reduced)
$t = 1.8$ s change reference value of generator voltage from 100 % to 105 %
$t = 3.9$ s start of overexcitation limiter
$t = 11.8$ s change reference value of generator voltage from 105 % to 100 %
Nominal parameters of limiter are: $I_{max} = 2000\,A$, $I_{fMCR} = 1200\,A$, $I_{fn} = 1100\,A$, $T_{for} = 4s$
Reduced parameters of limiter are: $I_{max} = 1100\,A$, $I_{fMCR} = 1000\,A$, $I_{fn} = 900\,A$, $T_{for} = 4s$

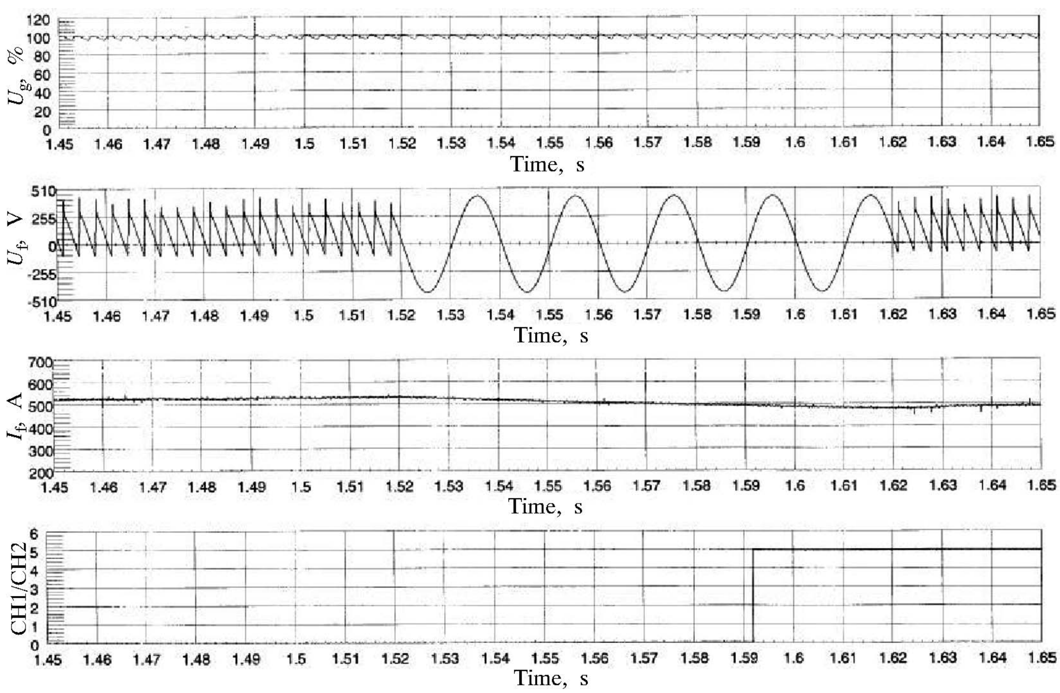

Fig. 5 Transfer Channel 1 to Channel 2 in parallel operation

3 REFERENCE LIST

In the last five years Končar-INEM has produced and commissioned 54 excitation systems with digital voltage regulators (45 systems with one channel digital voltage regulator and 9 systems with twin-channel digital voltage regulator). Excitation systems have been made for power plants in Slovenia (6 systems, 4 systems with twin channel digital voltage regulator and 2 systems with one-channel digital voltage regulator), Macedonia (11 systems with one--channel digital voltage regulator), Albania (6 systems with one-channel digital voltage regulator), Bosnia and Herzegovina (6 systems with one-channel digital voltage regulator), Columbia (2 systems with one-channel digital voltage regulator), India (4 systems with one-channel digital voltage regulator), Rwanda (1 system with one-channel digital voltage regulator) and Croatia (18 systems, 5 systems with twin-channel digital voltage regulator and 13 systems with one-channel digital voltage regulator).

At the moment 11 excitation systems (2 systems with twin-channel digital voltage regulator and 9 systems with one-channel digital voltage regulator) are at the initial stage of their respective projects. Excitation systems are made for power plants in Slovenia (7 systems, 2 systems with twin-digital voltage regulator and 5 systems with one-channel digital voltage regulator), Macedonia (2 systems with one-channel digital voltage regulator) and Croatia (2 systems with one-channel digital voltage regulator).

4 TEST RESULTS

The implementation of static excitation systems with twin-channel microprocessor based voltage regulator on big synchronous hydro- and thermal-generators has proven the good behaviour of the equipment in operation.

The characteristic responses of excitation control system in typical disturbances is shown in Figures 3 to 5.

Tests are made on a hydrogenerator with following parameters: $S_n = 80$ MVA, $\cos\varphi = 0.9$, $Q_n = 34.8$ MVAr, $U_{gn} = 10.5$ kV, $f_n = 50$ Hz, $U_{fn} = 177.1$ V, $n_n = 600$ rev^{-1}, $P_n = 72$ MW, $I_{fn} = 1100$ A.

5 CONCLUSION

The presented excitation system with microprocessor based twin-channel voltage regulator is suitable for big synchronous machines in power system. The excitation system is characterized with increased safety, reliability and availability.

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Sustav uzbude sinkronog generatora s dvokanalnim mikroprocesorskim regulatorom napona. U članku je prikazan sustav uzbude s dvokanalnim mikroprocesorskim regulatorom napona. Prikazane su blokovske sheme sustava uzbude s digitalnim regulatorom napona i dvokanalnog regulatora napona i ukratko su opisani glavni dijelovi sustava uzbude. Prikazani su odzivi karakterističnih veličina sustava regulacije uzbude sinkronog generatora na tipične poremećaje.

Ključne riječi: sustavi uzbude sinkronih generatora, sustavi za rad u realnom vremenu, upravljanje, upravljanje pretvaračima

AUTHORS' ADDRESSES:

Vinko Ćesić, B.Sc., E.E.
Mladen Kajari, B.Sc., E.E.
Siniša Marijan, B.Sc., E.E.
Končar – Institut za elektrotehniku, d.d.
Baštijanova bb, HR-10002,
Zagreb, CROATIA
Tel: ++385 1 3667 321, Fax: ++385 1 3667 309
vcesic@koncar-institut.hr
www.koncar-institut.hr

Zvonimir Jurin, B.Sc., E.E.
Marin Kolić, Eng.
Končar – Elektronika i informatika, d.d.
Baštijanova bb, HR-10002
Zagreb, CROATIA
Tel: ++385 1 3655 768, Fax: ++385 1 3655 550

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