A Few Aspects Concerning the Technical Solutions Applied for Control of Excitation in Synchronous Generators across Romania

FLAVIU M. FRIGURA-ILIASA, MARIUS BIRIESCU, IOAN GRANDO, GHEORGHE MADESCU, MARTIAN MOT
1Power Systems Department, 2,3,4,5Electrical Machines, Drives, Lighting and Technologies Department
Politehnica University of Timisoara
2 V. Parvan Bvd. 300223, Timisoara
ROMANIA

Abstract: - The power quality is one of the main interests of producers, transporters and suppliers. In order to have a higher quality for the power produced by the synchronous hydro generators, using an adequate excitation system is essential. This paper shows a general overview of the main tasks which Romanian power producers have to accomplish today. It presents, also, some case studies concerning the existing technical solutions used for the excitation system of synchronous generators applied here, until now. The main goal of this paper is to present a general point of view regarding the actual situation in this area, to identify some solutions and tendencies concerning the updating of the existing generators, in order to accomplish all the European power standards and regulations. This study was made by the authors by taking in consideration opinions coming from the industrial environment.

Key-Words: - Excitation, Synchronous Generators, Romania

1 Introduction
The updating and the refurbishment of existing power generators located in the Romanian network is one of the most important tasks of power producers. It is extremely necessary in order to fulfill all European Power Quality requirements, due to the interconnection between the Romanian power system and the European one.

Inside the Romanian National Power System (NPS) we will find electrical generators located in thermal, hydro and nuclear power plants. All those power generators are inter-connected [1].

This inter-connection mainly involves:
- maintaining a constant rotation of the powering machine;
- maintaining a constant value of the voltage given by the generator;
- maintaining the constant phase between the generated voltage and the NPS voltage;
- maintaining all voltage variations that occur during transient conditions, inside the accepted limits.

In order to fulfill those inter-connection tasks, all power generators, no matter their type or size, must be equipped with [1], [2]:
- a control system for speed-frequency-active power;
- a control system for voltage - reactive power – power factor – excitation current;
- a control system for internal generator angle;
- a protection system for both generator and line.

Each of the first two systems must have the possibility to choose the controlled parameter and a manual - automatic mode switch. They must have limitation blocks and well defined speed limits for the executive element. These inter-connection tasks are demanded by the simple necessity of having a high stability power network [3].

Nowadays, in Romania, each power producer connected to the NPS must, of course, be certified as service supplier inside the network. This procedure gives him the access to the national energy market. This certification is issued by the Romanian Power Transport Company, Transelectrica S.A., which acts as a dispatcher of the National Power System, surveying the quality of all services inside the NPS.

At this national level, the NPS dispatcher must control mainly [3]:
- frequency stability;
- voltage stability;

Booth systems are with continuously act.

The first main function is realized by frequency/active power control systems and the second is done by voltage/reactive power control ones. All the adjustments needed are done under the co-ordination of the NPS dispatcher/operator, but control systems are located at the producers, on the transport lines and even at the final consumers.
The most efficient way to control those two parameters is by using flexible excitation systems, which can act with high efficiency.

Concerning the power synchronous generator, there are some extra-requirements [4]
- the excitation control system must act continuously, without any instability, on the whole functioning area of the generator, including abnormal regimes;
- the generator must offer the nominal active power, repeatedly, for each functional point, starting from a logging power angle having \( \cos \phi = 0.85 \) to a leading power angle having \( \cos \phi = 0.95 \), capacitive;
- the reactive power produced in a normal stable regime must be constant for voltage variations as \( \pm 5 \% \) for 400 kV lines and \( \pm 10 \% \) for 110 and 220 kV lines;
- to compensate the accidental voltage drop.

That’s why all these requirements impose an efficient and well-controlled excitation system [5].

2 Excitation Systems and Control

Excitation systems have evolved continuously. This evolution was necessary due to the bigger power demand and to the requirements imposed by the NPS, especially concerning system stability during transient regimes.

Concerning the main excitation systems used today in Romania, we noticed 3 main categories [3]:
- excitation systems made by using DC current machines functioning as generators (about 60% of the existing solutions);
- excitation systems made by using inverse synchronous machines, connected through a rotating rectifier at the main synchronous generator (about 20%);
- power electronic (static) excitation systems (about 20%).

Concerning the excitation connection solution, we can observe two situations [3]:
- connections made by two electrical wheel contacts, when excitation systems are not rotating;
- direct connections, when excitation systems are rotating together with the main rotor.

The main functions of the excitation system are:
- to insure the necessary current for maintaining a constant voltage on the generator outputs, in any regime, including transient one;
- to have a self-excitation by using a DC current pulse and residual voltage or a self excitation DC exciter;
- to produce an over-excitation when violent voltage variation appear;
- to have a rapid under-excitation when there is an increasing charge or an acceleration;
- to maintain constant, between the imposed limits, the output voltage, the reactive power and the power factor, depending on the control parameter;
- to allow switching between automatic and manual mode, even from local or remote equipment;
- to limit, instantaneously or delayed, all controlled parameters;
- to insure (automatically) synchronization for connect the generator to the NPS;
- to insure the redundancy of the control system, for all important components of the voltage control system;
- to realize a crash or incident recording, for a better analysis of the causes or data logger;
- to permit a rapid adjustment of parameters, for a flexible control (adaptive voltage control);
- to be sensible or insensible to certain parameters imposed by the NPS to correlate the range of insensibility in concordance with the demands of the NPS;
- to have a reactive power control.

Control systems, used for excitation systems in service across Romania are, today, based (as executive element) on [3]:
- electromechanical regulators (less than 5%);
- magnetic amplifiers having command made with classic equipment (less than 15%);
- magnetic amplifiers commanded by integrated electronic circuits (more than 60%);
- power electronic devices commanded by integrated electronic circuits (about 10%);
- power electronic devices commanded by PLC’s (about 10%).

The two last solutions are the most modern in service, especially when using dedicated controllers (such PLC’s) for implementing the command strategy [6]. All those solutions were applied by using equipment produced both by Romanian manufacturers as well as foreign ones. There is a huge variety of equipment in service, which is a problem for maintenance and personnel training.

3 Improved Excitation Systems

In Romania, most of the existing power generators are old, and modernization is necessary.

Table 1 shows us a comparison between the most used technical solutions described above.
Many hydro-generators used by the National Hydro Power Company, Hidroelectrica S.A. are more than 30 years old and their lifetime period is over-passed.

By consequent, all control equipment located on those generators is old, too, and their behavior is uncertain, especially during transient conditions [4].

Table 1. Comparison between different excitation systems applied in Romania

<table>
<thead>
<tr>
<th>Excitation and Command Type</th>
<th>DC excitation with electromechanical regulators</th>
<th>Inverse synchronous excitation with magnetic amplifiers having analog command</th>
<th>Inverse synchronous excitation with electronic (static) excitation and analog command</th>
<th>Electronic (static) excitation and digital command</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response time</td>
<td>very long</td>
<td>long</td>
<td>satisfactory</td>
<td>good</td>
</tr>
<tr>
<td>Dead time period</td>
<td>very long</td>
<td>long</td>
<td>satisfactory</td>
<td>very short</td>
</tr>
<tr>
<td>Complete regulating time period</td>
<td>long</td>
<td>long</td>
<td>satisfactory</td>
<td>short</td>
</tr>
<tr>
<td>Contribution to the NPS stability</td>
<td>small</td>
<td>small</td>
<td>satisfactory</td>
<td>good</td>
</tr>
<tr>
<td>SCADA inter-connection possibility</td>
<td>no</td>
<td>no</td>
<td>heavy</td>
<td>easy</td>
</tr>
<tr>
<td>Insensibility region</td>
<td>high</td>
<td>high</td>
<td>acceptable</td>
<td>reduced</td>
</tr>
<tr>
<td>Overload liability</td>
<td>very good</td>
<td>very good</td>
<td>good</td>
<td>satisfactory</td>
</tr>
<tr>
<td>Optimization possibilities</td>
<td>heavy</td>
<td>heavy</td>
<td>satisfactory</td>
<td>good</td>
</tr>
<tr>
<td>Behavior in case of abnormal regime</td>
<td>not allowed</td>
<td>not allowed</td>
<td>not allowed</td>
<td>partially allowed</td>
</tr>
<tr>
<td>Rapid des-excitation</td>
<td>long reaction time</td>
<td>long reaction time</td>
<td>long reaction time</td>
<td>short reaction time</td>
</tr>
<tr>
<td>Parameter adjustment possibilities</td>
<td>reduced</td>
<td>reduced</td>
<td>satisfactory</td>
<td>increased</td>
</tr>
<tr>
<td>Remote data and command transmission</td>
<td>not allowed</td>
<td>not allowed</td>
<td>allowed, but difficult</td>
<td>allowed</td>
</tr>
<tr>
<td>Power consumed for excitation</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>Small</td>
</tr>
<tr>
<td>Synchronization time</td>
<td>very long</td>
<td>very long</td>
<td>long</td>
<td>short</td>
</tr>
<tr>
<td>Control system</td>
<td>Electromechanical</td>
<td>Electronic, discrete</td>
<td>Analog, with integrated circuits</td>
<td>Digital</td>
</tr>
</tbody>
</table>

The Romanian NPS dispatcher is rapidly introducing IT techniques for control, efficiency, command, safety and recordings. This process involves special functions that actual excitation systems (and excitation control systems) could not perform [2], [5].

A few of the requirements, especially those related to the excitation control system, were already presented in Table 1, when speaking about the advantages and disadvantages of a certain excitation configuration and control. But one of the main tasks for power producers is increasing the efficiency of the whole generator system, and increasing unit power too. The digital excitation system is preferred today because of reducing the auxiliary consumption of the generator (and increasing its efficiency), too (without speaking about the other advantages) [2].

Speaking only about the existing situation in Romania, where, as we observed before, more than 80 % of existing excitation systems are made by using a DC machine or an inverse synchronous machine, all commanded by analog electronic devices or classic electrical apparatus, we notice some problems which appear during functioning of those old systems [1], [3]:

- generally, there is a higher power demand for the generator;
- maintenance is expensive and is often done;
- coal dust coming from the rotating contacts (brushes) of the excitation system is dangerous and overheats the generator;
- asbestos insulation system is old, un-efficient and not conform with the European safety requirements;
- there are driving problems with rotating machines which are not driven by the main axis of the generator;
- any spare part for these generators is hard to find, especially for the control system;
- there is a reduced possibility to connect these excitation systems to a SCADA control system;
- the response/reaction time is reduced, a major disadvantage when working in transitory regimes;
- the number of mechanical rotating joints is high;
- vibration of these generators is important;
- there are even gearboxes which reduces mechanical efficiency and involves maintenance, too;
- the recording of the events is not available;
- there are many electromechanical pieces involved, with a reduced liability and a constant maintenance.

Many of these disadvantages could be over-passed when using a static excitation system digitally controlled, the most modern and efficient existing solution.

The advantages of the digital static excitation system are [6]:

- a better limitation of over and under excitation, which helps preserve all wiring;
- this solution allows the transition from automatic mode to manual mode, in case of an incident on the automatic channel, without reactive power shocks;
- it insures a rapid automatic correlation between the generator voltage and the NPS;
- all excitation speeds could be programmed by using a dedicated software;
- there is a possibility to operate in two quadrants which is useful for positive or negative overloads;
- different control strategies could be applied, such as: voltage, reactive power, power factor or excitation current control;
- every parameter could be checked, and all incidents are easy to indicate and to record;
- it offers the possibility of creating a data base with all parameters and incidents;
- excitation control systems dedicated to high power special equipment have, at their basic level, the redundant control system, acting as a “hot reserve”;  
- generally, in order to inform the operator and, for a better command of all equipment, the excitation system has a simple human-machine interface, based mostly on touch-screen displays;
- the control system could be completed with an additional control of the rate between voltage and frequency, which has to be limited, in order to avoid the deterioration of the magnetic circuit;
- the system has stability reserves, which could allow the compensation of reactive power or voltage oscillations on the NPS, when connecting a high reactive energy consumer (such as large asynchronous engines);
- it could be connected to a SCADA (Supervisory Control And Data Acquisition) system, through a standard or a dedicated protocol (RS, USB etc.);
- all reaction times are reduced, and this could help to the stability of the NPS, during transitory regimes;
- all death work times are reduced, too;
- excitation could be initiated from the internal services or from the DC bus bars, by using a switching device and a resistor, for current limitation;
- when voltage reaches 70% of the nominal one, excitation will be insured directly from the generator, by using a dry transformer. This solution is applied mostly for systems operating in an isolate network;  
- this system allows a higher precision, which is situated around ± 2.5% of the nominal voltage;
- all parameters could be “on-line” modified;
- this system allows a rapid des-excitation by using combined methods in order to insure the commutation to inverter mode or by blocking impulses on the command deck after connecting a des-excitation resistor or another dedicated equipment;
- at last, but not at least, this digital control system applied to an electronic excitation system consumes far less energy then traditional ones.

Those are the advantages of using a digital excitation system. But, like any technical solution, it has disadvantages too, like [9]:
- the system must be equipped with supplementary protection devices, especially when there is a risk of accidental overloads;
- the inverse maximum voltage allowed by the power electronic commutation device (transistor, diode etc) must be well correlated with over voltages occurring to active or reactive power shifts;
- any rectifier equipment must be equipped with RC protection circuits for commutation;
- generally, this system is more sensible and fragile, when over voltages or overloads occur;
- cooling is essential for rectifiers especially. When a cooling fan drops, performances must be reduced;
- when contacts are made by using brushes, there is an increased risk of polluting the wiring of the generator with coal dust, with all possible bad consequences, such partial discharges;
- because the rectifier must work starting from the unload regime current to double the nominal value, it works mostly at low power angle, which needs reactive power compensation. This problem could be partially solved by using a passive rectifier connected to an active one. The first works up to 70 % of the nominal value, and the other offers the rest. This procedure is now standardized by the IEC;
- the good dynamic performances of the electronic excitation and command system are limited by high time constants belonging to the windings of the generator;

Despite these disadvantages, digitally controlled excitation systems are the most modern and functional technical solution applied today and their advantages are more important [10].
4 Technical Solutions for Digitally Controlled Electronic Excitation Systems

In this section we will present two technical solutions which could be (and which are already) used in modernized or new power plants across Romania [8].

4.1 Rotating Rectifier with Inverse Synchronous Excitation System Electronically Supplied

This technical solution is presented in Fig.1. It has, as possible supplying sources the internal services transformer (Services), the main contacts of the generator (GC) or the DC internal bar (connected to reserve batteries).

Fig.1. Schema of the excitation system with an inverse synchronous machine

The elements related to Fig.1 are:
- NPS – National Power System
- MS – Main Switch;
- SG – Synchronous Generator;
- RR – Rotating rectifier;
- ISE – Inverse Synchronous Excitation Machine
- ESEM – Excitation Source for the Excitation Machine;
- PLC – Programmable Logic Controller;
- VR – Voltage Regulator (independent);
- OP – Operational Panel;
- SCADA - Supervisory Control And Data Acquisition, system belonging to the plant or to the NPS;
- SVR – System Voltage Reaction;
- Vgen – generator voltage reaction;
- f – frequency reaction;
- Vexg – excitation voltage of the generator;

This solution could be applied to most of the existing hydropower generators which have to be modernized. It was used mostly to vertical position generators. It was demanded by foreign clients of the Romanian companies, too.

4.2 Static Excitation Electronically Supplied

This technical solution is presented in Fig.2. It has, as possible supplying sources the internal services transformer (Services), the main contacts of the generator (GC) or the DC internal bar (connected to reserve batteries).

Fig.2. Schema of the excitation system electronically supplied
The elements related to Fig.2 are:
- NPS – National Power System
- MS – Main Switch;
- SG – Synchronous Generator;
- ESG – Excitation Source of the Generator;
- PLC – Programmable Logic Controller;
- VR – Voltage Regulator (independent);
- OP – Operational Panel;
- SCADA - Supervisory Control And Data Acquisition, system belonging to the plant or to the NPS;
- SVR – System Voltage Reaction;
- Vgen – generator voltage reaction;
- f – frequency reaction;
- Vexg – excitation voltage of the generator;
- Iexg – excitation current of the generator;

This solution is applied mostly to Bulb hydropower generators, having a machine less then the one above. By consequent, all physical dimensions are reduced and the whole equipment is less expensive, easy to install, with a reduced excavation cost.

5 Conclusions
The requirements imposed by the inter-connection of the Romanian National Power System to the European one impose some important actions to the power producers inside the system. This study was made for hydro generators, because there are many individual solutions in this area. Power quality insurance could not be done with old generators, controlled by ancient systems and supplied from different uncontrolled sources. The main problems for these old pieces of equipment appear mostly when transitory regimes occur or when reactive power must be compensated or delivered. The whole reduced liability of those ancient systems imposes a rapid change or modernization of the generators by changing the excitation type and command. Modern excitation systems are less then 20 % in Romania.

The electronically supplied excitation systems, digitally controlled (in many cases by using PLCs), are the most modern and functional solution which could be applied (and is already applied) inside the Romanian National Power System, due to some important advantages. Their main disadvantage is their fragility when over voltages occur.

Two solutions for electronically supplied excitation systems, digitally controlled, are frequently applied in Romania. One is based on an inverse synchronous machine with a rotating rectifier and the other is a full digital excitation.

They are the most recommended solution, both for modernization of the existing generators as well as for new ones.

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References:
A Few Aspects Concerning the Modeling of Thermal Stability Control for a Low Voltage ZnO Varistor

FLAVIU M. FRIGURA-ILIASA¹, MIHAELA FRIGURA-ILIASA², LILIANA MATIU-IOVAN³, DORU VATAU⁴
¹,²,⁴Power Systems Department, ³Electronical and Optical Measurement Department
Politehnica University of Timisoara
2 V. Parvan Bvd. 300223, Timisoara
ROMANIA
¹flaviu.frigura@et.upt.ro, http://www.upt.ro

Abstract: ZnO based varistors are today the most common technical solution for making state of the art surge arresters for all voltage levels, due to some advantages like a high non-linearity coefficient and a high energy absorption capacity. Due to their thermal activated conduction, the control of heat dissipation inside that semiconductor device is crucial for its service. Heat dissipation control could be done only by modeling the thermal and electrical status of the varistor in case of some special and original configurations. The new configuration proposed in this paper consists in a disc varistor with an additional brass mass used for heat extraction and dissipation. This paper presents the finite-element model used for the direct control of heat dissipation, as well as some experimental results.

Key-Words: Thermal Stability Control Modeling, ZnO Varistor

1 Introduction
Modern surge-arresters are based on ZnO varistors. All electronic devices (including command and control equipment, industrial computers, PLCs etc.) are using low voltage varistors in order to protect those sensitive devices against any type of low voltage, mainly lightning strokes or induced overvoltages, both on power supply lines as well as on data lines.

ZnO varistors are essentially ceramic polycrystalline n – semiconductors. They are applied in modern technologies due to some important advantages such as: a high level of non-linearity for the current-voltage characteristic, a high energy absorption capacity and an excellent response time (less then 100 ns), which make them useful for protecting other sensible electronic devices.

Knowing the service limits for a certain varistor included into a protection, measuring or control equipment is important in order to obtain maximum performance and safety for a long term use of that protection equipment.

Another important aspect concerning ZnO varistors is improving their thermal behavior, by controlling the heat dissipation during permanent or shock regime.

2 Problem Formulation
Like many other semiconductor devices, the current passing through that varistor is thermally activated. So, for a high energy short time shock (like a violent lightning stroke) or for a long time over voltage (a technical incident), there is an increased risk of overheating [5].

As long as the temperature increases (even the environmental temperature increases), the passing through current increases too, due to the diminution of the electrical resistance. An avalanche phenomenon could occur any moment, with devastating consequences both for the surge arrester as well as for the protected equipment.

The heat produced inside the varistor is basically uncontrollable, during a heavy duty permanent regime or after an extremely violent shock.

That’s why, finding an efficient method to control heat dissipation or a technical solution to improve the thermal behavior by enlarging the safety stability reserve is very important.

As a consequence of the thermo-activated current, the thermal stability of a ZnO based varistor could be controlled and analyzed in two different regimes [3]:

- the permanent service regime, when the varistor is exposed to a long time accidentally over voltage, not very high, but destructive for the protected equipment;
- the shock (voltage impulse) regime, when the varistor is exposed to an extremely short time over voltage, but with a very high value (like a lightning stroke), obviously destructive for any protected equipment.