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Impact of the Generator Operation at the Minimum Excitation Limit on the Power Plant Auxiliary

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Abstract: - In the contribution, we analyzed the possibilities of extending the regulation capacities of the electric block of the nuclear power plant in the region of underexcitation of generators, and the impact of such operation upon the block transformer, generator itself. The contribution analyzes also the impact of block operation at the minimum voltage level on the auxiliary system. Voltage conditions on 6 kV switching stations of the auxiliaries in the power plant block were checked. The objective was to ensure that the biggest machines in the auxiliaries start safely and the voltage on the busbars does not fall down below 0.7 p.u. of nominal voltage provided that the minimum level of the generator voltage is 0.95 p.u. of nominal voltage and the power is taken-off by the auxiliaries.

Key-Words: - Minimum Excitation Limit (MEL), Power Plant Auxiliary, Voltage Regulation.

1 Introduction

Change of the generator field current within permitted limits of an operating PQ diagram of the synchronous generator can be used for the voltage and the reactive power regulation in the power system. Limits of the PQ diagram are given:

- the positive value of generator reactive power is delimited by maximum value of stator and rotor current and by permitted value of terminal voltage of generator,
- the negative value of generator reactive power is delimited by minimum permitted value of generator terminal voltage and by reserve for generator stability.

Good realization and operation of voltage and reactive power regulation have benefits not only for transmission system operator in cost reduction of power transmission, maintenance and raise of operation safety, but also consumers have higher quality of supplied energy.

2 Technical Conditions of Operation of Generators and Block Transformers at the Nominal Frequency

According to the operating instruction the normal operation of generators is operation at the nominal values of generator electric parameters which are given by generator maker, also must be fulfilled the prescribed limits of cooling hydrogen and cooling condensate. Operation of generator is defined by the operating diagram PQ (fig. 1).

The limits of generator terminal voltage are ± 5 % of nominal voltage under full power of machine.

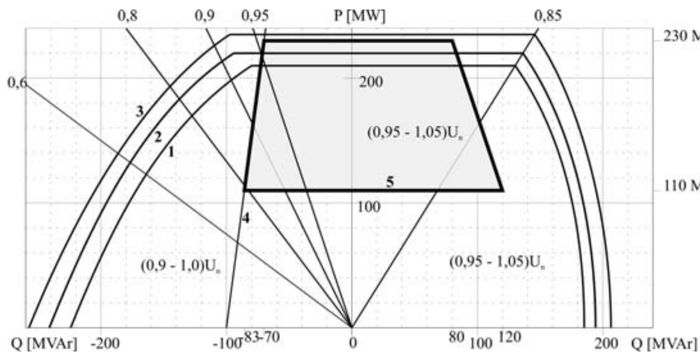

Fig.1.: Operation PQ Diagram of Synchronous Generator

1. Hydrogen pressure 300 kPa; 2. Hydrogen pressure 400 kPa, max. temperature of cooling water to hydrogen cooler 36°C, condensate 42°C; 3. Hydrogen pressure 400 kPa, max. temperature of cooling water to hydrogen cooler 33°C, condensate 39°C; 4. The setting of underexcitation guard; 5. The operation with remote control of voltage

In the operating instruction of block transformer are not any limits and conditions for its operation.

In regard to no existing limits and conditions in operating instruction of block transformer, we defined operating limits and conditions of block transformer according to the Slovak technical standards STN 35 1100 and STN IEC 354 (35 1106).

In terms of these standards the block transformers have to satisfy following conditions:

1. Transformers have to be able to supply nominal power with terminal voltage in limits ± 5 % of nominal voltage continuously.
2. Oil transformers have to be constructed for continuously current loading of windings with limits +5% of nominal current and with nominal voltage.
3. Transformers with voltage 110 kV and higher continuously allow operation with voltage 1.1 p.u. of nominal voltage on arbitrary tap, but voltage of any winding mustn't exceed the highest operating voltage by STN 33 0120.

3 Simulations of Operating States of the Electric Block of the Nuclear Power Plant

The power system of the Slovak Republic is divided into regulation zones. In each zone the voltage in one node only, so-called "a pilot node" is regulated. This node is selected in such way that a change of the voltage in this node be decisive for the trend of the voltage in the whole regulation zone.
The magnitudes of voltage in pilot nodes of the network 400 and 220 kV are set down for single months in the monthly preparation of the regimes of the power system on the basis of mode calculations of a steady operation of the network.
The analyzed power plant leads out on the one of the pilot nodes of power system - 400 kV substation (fig. 2).
For voltage and reactive power regulation in power system we can use the change of synchronous generators field current, i.e. change of generator reactive power with limits defined by operating diagram PQ. For voltage regulation in this 400 kV substation are used turbogenerators TG31 a TG32 of the power plant block.

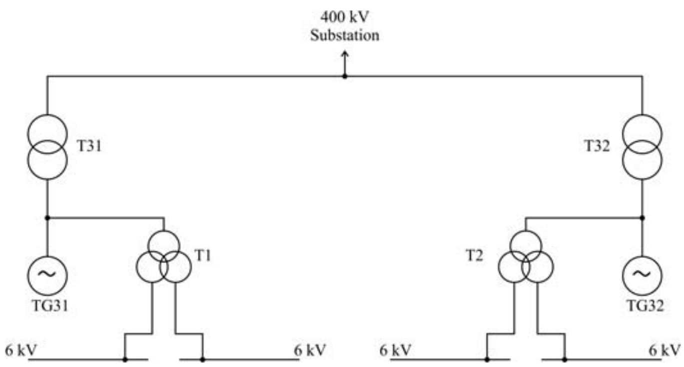

Fig.2.: Power of the Nuclear Power Plant – the block leading out

3.1 The First Simulated State

Description of simulation:

- TG31 and TG32 generate nominal real power 220 MW,
- voltage is regulated on 400 kV substation (required value 412 kV),
- block auxiliary system is supplied from transformers T1 and T2,
- reactive power of generator TG31 was changed in stages (from value -5 MVAr to minimum excitation limit (MEL) -70 MVAr),
- TG32 regulated its reactive power depends on voltage in 400 kV substation.

In the last but one simulation both generators operated with forced MEL (-70 MVAr). In this case voltage in substation was lower than required value 412 kV. In the last simulation both generators regulated their reactive power depends on voltage in 400 kV substation.
Currents of generators and block transformers and total watt loses of both block transformers didn't exceed nominal value. The lowest value of generators terminal voltage was 0.906 p.u. under forced MEL operation of both generators.

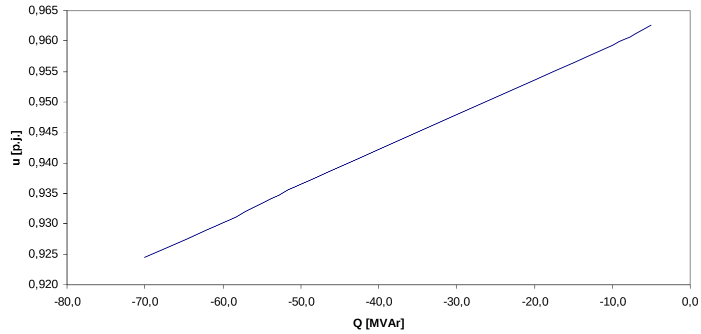

Fig.3.: Graphical representation of TG31 terminal voltage dependence on underexcitation

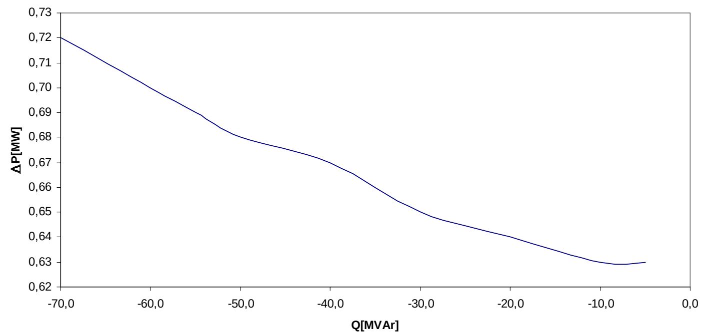

Fig.4.: Graphical representation of block transformer T31 watt loses dependence on underexcitation of TG31 with nominal real power 220 MW

3.2 The Second Simulated State

Description of simulation:

- TG31 and TG32 generate nominal real power 220 MW,
- voltage is regulated on 400 kV substation (required value 412 kV),

- block auxiliary system is supplied from reserved transformers, transformers T1 and T2 are switched off,
- reactive power of generator TG31 was changed in stages (from value -10 MVAr to MEL -70 MVAr),
- TG32 regulated its reactive power depends on voltage in 400 kV substation.

In the last but one simulation both generators operated with forced MEL (-70 MVAr). In this case voltage in substation was lower than required value 412 kV. In the last simulation both generators regulated their reactive power depends on voltage in 400 kV substation. Currents of generators and total watt loses of block transformers didn't exceed nominal value. The lowest value of generators terminal voltage was 0.914 p.u. under forced MEL operation of both generators. In this case currents of block transformers were exceed on side 15.75 kV and 400 kV too.

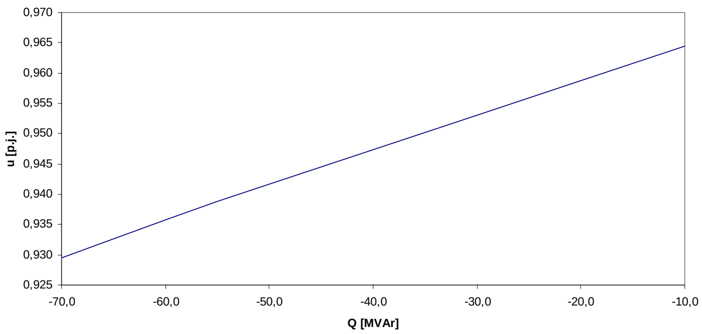

Fig.5.: Graphical representation of TG31 terminal voltage dependence on underexcitation

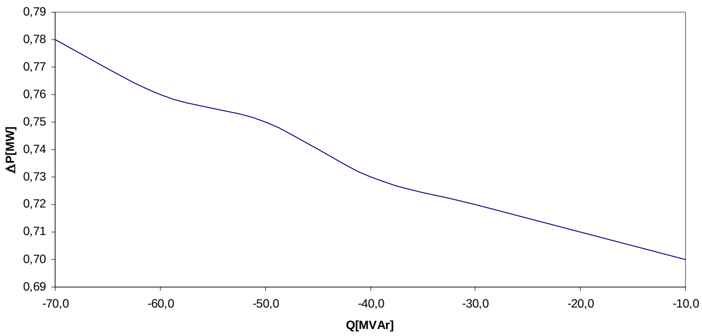

Fig.6.: Graphical representation of block transformer T31 watt loses dependence on underexcitation of TG31 with nominal real power 220 MW

3.3 The Third Simulated State

Description of simulation:

- TG31 and TG32 generate nominal real power 220 MW,
- voltage is regulated on generators terminals (required values from 0.95 p.u. to 0.9 p.u.),
- block auxiliary system is supplied from reserved transformers, transformers T1 and T2 are switched off.

Currents of generators and total watt loses of block transformers didn't exceed nominal value.

The lowest value of generators terminal voltage was 0.914 p.u. under MEL operation of both generators. In this case currents of block transformers were exceed on side 15.75 kV and 400 kV too.

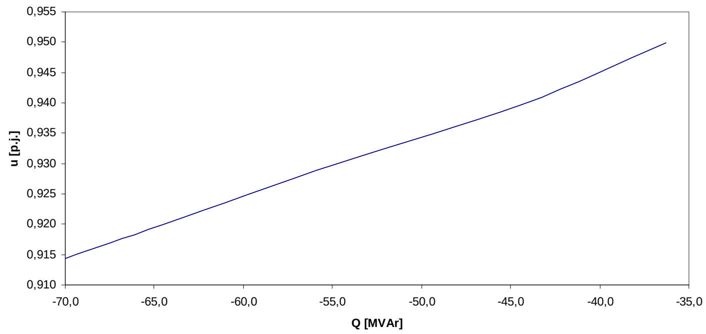

Fig.7.: Graphical representation of TG31 terminal voltage dependence on underexcitation

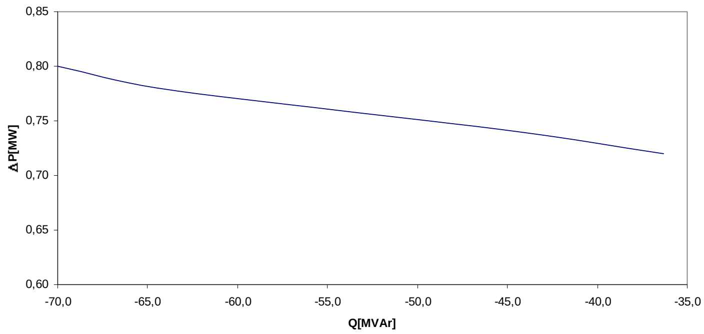

Fig.8.: Graphical representation of block transformer T31 watt loses dependence on underexcitation of TG31 with nominal real power 220 MW

3.4 The Fourth Simulated State

Description of simulation:

- TG31 and TG32 generate nominal real power 220 MW,
- voltage is regulated on generators terminals (required values from 0.95 to 0.9 p.u. of nominal voltage),
- block auxiliary system is supplied from transformers T1 and T2,
- simulated special state in power system with forced high value of voltage in system (compensating coils are switched off, the other generators in power system operates at overexcitation).

Currents of generators and block transformers and total watt loses of block transformers didn't exceed nominal value. The lowest value of generators terminal voltage was 0.918 p.u. under MEL operation of both generators.

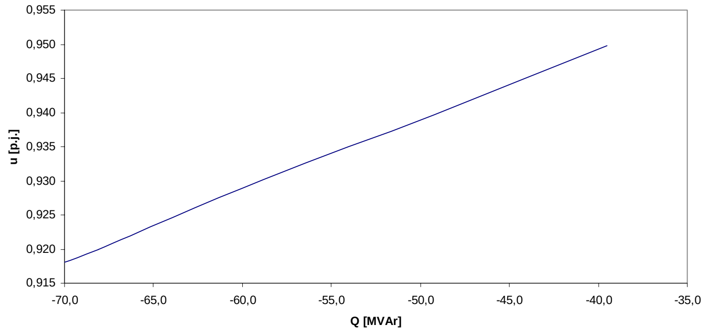

Fig.9.: Graphical representation of TG31 terminal voltage dependence on underexcitation

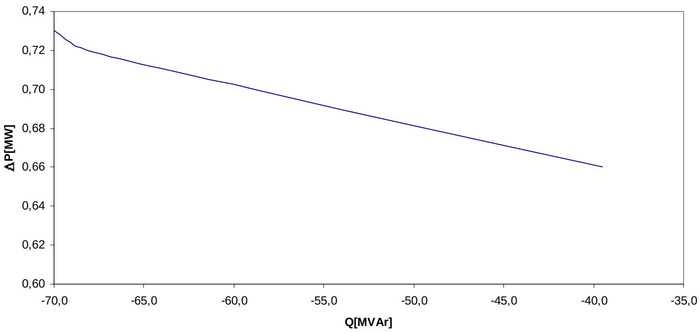

Fig.10.: Graphical representation of block transformer T31 watt loses dependence on underexcitation of TG31 with nominal real power 220 MW

3.5 The Fifth Simulated State

Description of simulation:

- TG31 generates real power 220 MW,
- TG32 – switched off,
- voltage is regulated on generator terminal (TG31) (required values from 0.95 p.u. to 0.9 p.u.),
- block auxiliary system is supplied from reserved transformers, transformers T1 and T2 are switched off.

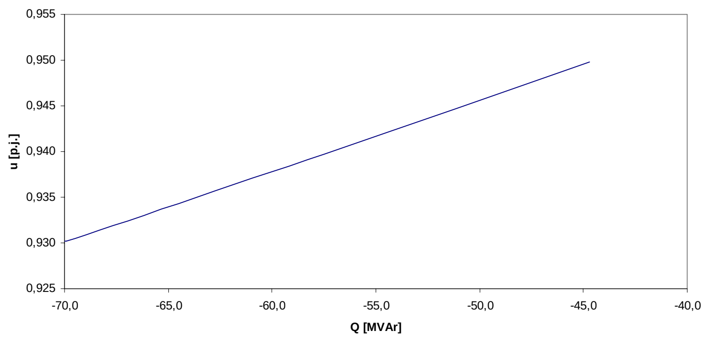

Fig.11.: Graphical representation of TG31 terminal voltage dependence on underexcitation

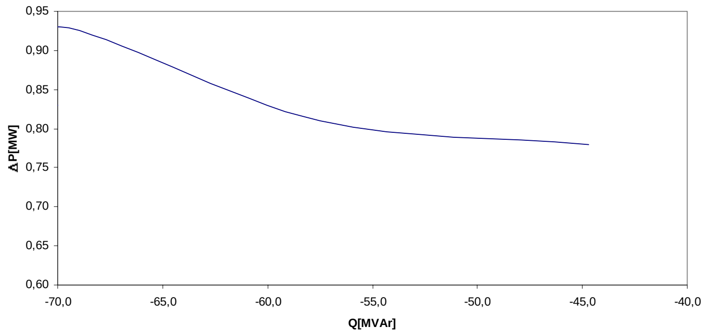

Fig.12.: Graphical representation of block transformer T31 watt loses dependence on underexcitation of TG31 with nominal real power 220 MW

Simulated states, when voltage was regulated on generator TG31 terminal from value 0.9 to 0.94 p.u., aren't acceptable in term of magnitudes of block transformer T31 currents and watt loses. Generator current didn't exceed nominal value.

The lowest value of generator terminal voltage was 0.93 p.u.

4 Check up of Impact of Block Operation at the Minimum Voltage Level upon the Auxiliary System

Voltage conditions on 6 kV switching stations of the auxiliaries in the power plant block were checked. The objective was to ensure that the biggest machines in the auxiliaries start safely and the voltage on the busbars does not fall down below 0.7 p.u. of nominal voltage provided that the minimum level of the generator voltage is 0.95 p.u. of nominal voltage and the power is taken-off by the auxiliaries.

For simulation we selected starting up of motor supplied from switching station 6 kV: pump of cooling water M1, feeding pump M2, main circulation pump M3).

During simulation the selected power drives were gradually started up. The first was started main circulated pump, the second feeding pump (in the 12th second) and the last was pump of cooling water (in the 16th second of simulation).

Results from simulation are in the following figures.

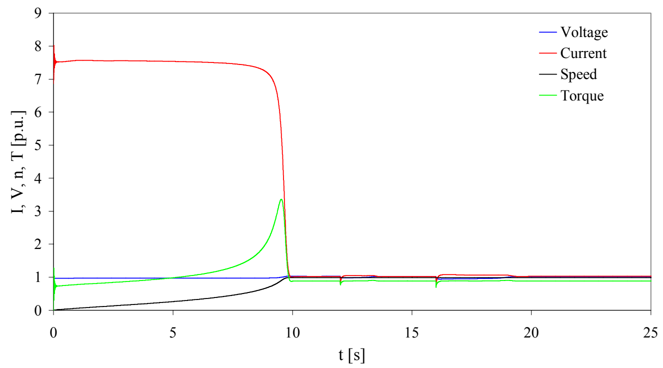

Fig. 13.: Time behaviors of voltage (V), current (I), operation speed (n) and torque (T) of motor M3 during simulation

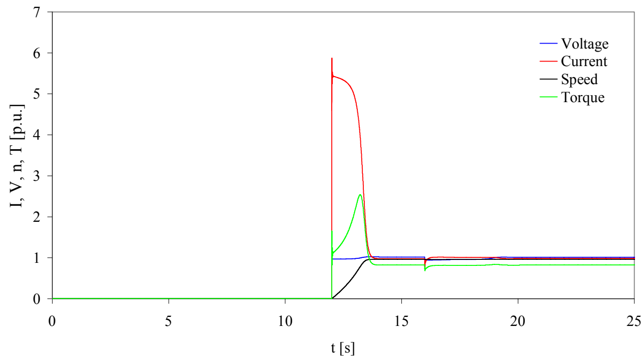

Fig. 14.: Time behaviors of voltage (V), current (I), operation speed (n) and torque (T) of motor M2 during simulation

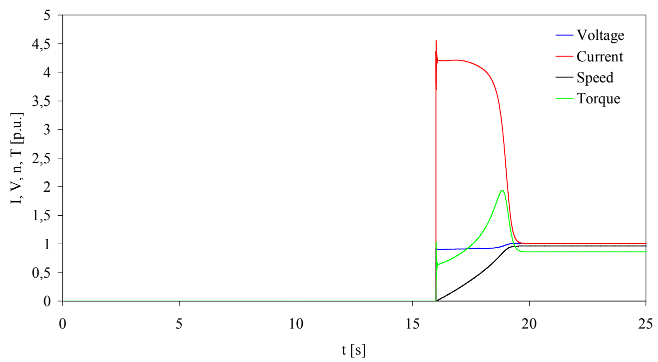

Fig. 15.: Time behaviors of voltage (V), current (I), operation speed (n) and torque (T) of motor M1 during simulation

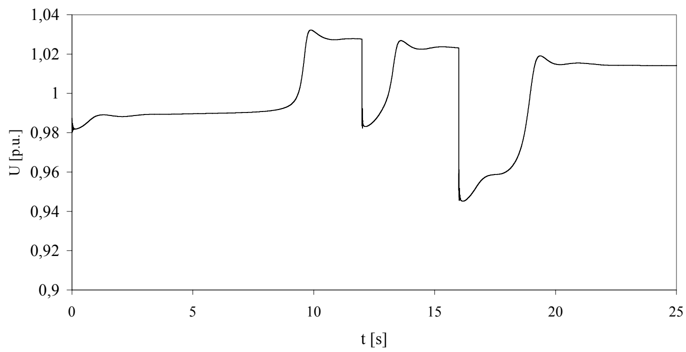

Fig. 16.: Voltage on 6 kV switching station during motors start-up

From time behaviors above is seen that voltage on auxiliary switching station of the block of nuclear power plant didn't fall down bellow 0.7 p.u. of nominal voltage during simulation of motors starts up.

5 Conclusion

In the contribution, we analyzed the possibilities of extending the regulation capacities of the electric block of the nuclear power plant in the region of underexcitation of generators, and the impact of such operation upon the block transformer, generator itself, and on the auxiliary system of the plant.
Results from performed experiments are that limiting criteria of power plant block operation in underexcited state with nominal frequency cannot be expressly only value of generator terminal voltage. Result from conclusions of experiments is that check up of generator and block transformer currents is needful.
In viewpoint of not exceeding of nominal values of generator and block transformer current and total watt loses, operation of power plant block with nominal real power 220 MW and auxiliary system supplied from transformer T1 and T2 is possible to operate even if generators work under MEL state. But in case of net configuration change (change in supplying of auxiliary, one of generator outage, heavy change of voltage proportion in power system) nominal value can be exceeded.
We simulated starts up of selected motors in generator operation with minimum terminal voltage. From time behaviors of voltage is seen that voltage on auxiliary switching station didn't fall down bellow 0.7 p.u. of nominal voltage during simulation of motors starts up.

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