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Small power plant excitation system development combined with several upgrades for improved voltage output achievements

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SUMMARY

Despite their size small hydroelectric power plants can have a major role in grid voltage and frequency regulation. Many of these units are positioned in areas with low grid short-circuit power so their reactive power contribution can be quite noticeable. Some power plants are also capable of small island operation due to unpredicted grid failures.
Due to the markets supply and demand gap in the small excitation system domain (excitation current up to 100 A), a new model was developed in 2013 at our Power electronic laboratory. Since the first analogue and digital units, there has been a lot of improvement in the past few years, mainly in the voltage and output stability domain. Despite the improvements the regulator still holds on to its primary key features such as high reliability, stability and robustness. With its built-in functions the power plants are capable of parallel and small island operation and therefore meet the conditions required by the system operator (SONDO).

KEYWORDS

Excitation system, small power plant, voltage regulation

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1. THE EXCITATION SYSTEMS

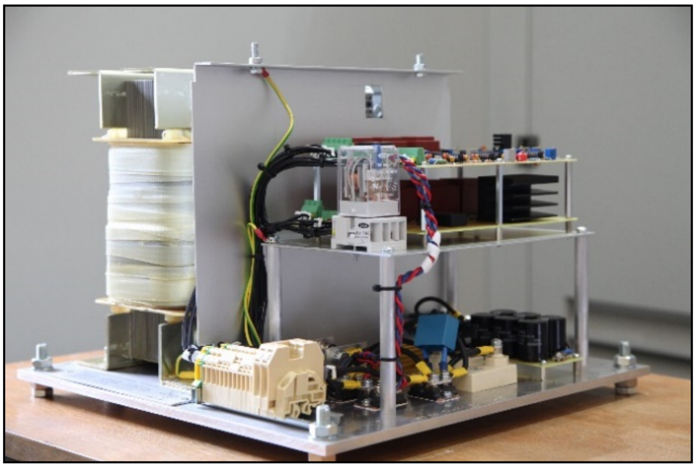
The developed analogue and digital excitation systems were made using the same approach – to achieve long life and high reliability. It is well known that most of the power plants main parts (such as generator, turbine, pipelines etc.) last for a long period of time, even 50 years and more. Consequently an extended life excitation system development was the main challenge for us. Special attention was paid to all main system building blocks and many of its components were oversized. Despite the power handling increase, the overall price remained close to other similar products on the market.
During the first few years of operation there have been no major interventions needed and the number of installed excitation systems is rapidly increasing.
Another key advantage is based in the highly skilled developing engineers and quick responded customer support for operating outage cost minimisation.

2. ANALOGUE EXCITATION SYSTEM

The first two analogue excitation systems were made for the Belica small hydroelectric power plant. The main function of the regulators was to maintain constant generator voltage output in accordance with the following equation:

$$0 = \frac{U_{REF} - U_{GEN}}{U_N} + \frac{Q_{GEN}}{S_N} \cdot u_{Q-DROOP} + \frac{P_{GEN}}{S_N} \cdot u_{P-DROOP} ,$$

U_{REF} … reference voltage
U_{GEN} … actual generator voltage
U_N … rated voltage
S_N … rated apparent power
Q_{GEN} … actual reactive power
$u_{Q-DROOP}$ … Q droop
P_{GEN} … actual real power
$u_{P-DROOP}$ … P droop



The MHE Belica analogue excitation system

<u>Power supply</u>
For achieving stable regulation the unit needs a stable power supply. Besides the main 230 V power supply that is connected directly to the generator voltage, the system has a redundant 24 V supply that enables so called black starts.

Digital voltage reference and limiting functions

The system uses a digital voltage reference for controlling the voltage output with simple up/down switching commands. The early versions already had a 10 % V-Hz (volt-hertz) limiter that lowered the output voltage if the frequency fell under 45 Hz.

For an unwanted start-up voltage overshooting a soft-start procedure was built in. During the start-up procedure the regulator gradually lifts the voltage to its nominal value. The regulator is galvanically separated from the measuring signals.

Power electronics and output

The output power circuit is built around two IGBT (Insulated Gate Bipolar Transistor) transistors with lower switching time characteristics compared to power thyristors.

Circuit thermal testing

3. ANALOGUE EXCIATION SYSTEM UPGRADES AND IMPROVEMENTS

The regulator improvements

Throughout the years some of the regulator building blocks were upgraded. Since the first units, there has been constant optimisation with many improvements.

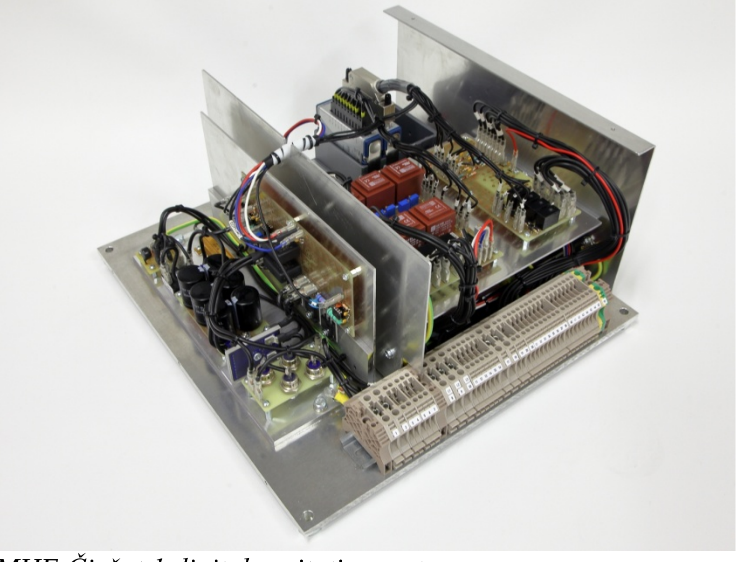
The soft-start procedure has been enhanced to achieve lower overshoot output characteristics. For better regulation achievement the shunt resistor excitation current measurement has been added to the system. Besides the up/down voltage reference changes, the new design also enables analogue signal voltage-reference output with optional visualisation. Although there weren't any overvoltage occurrences yet, we decided to install additional overvoltage protection to the systems measuring circuit as well as to the power supply. The measurement thermal drift was also lowered with a new double looped measuring approach.

Added liming and protection functions

During the last years of research a couple of analogue protection functions have been added to the regulator. The system has now a built-in excitation current and regulator failure protection with adjustable protection time from 0 to 30 seconds.

4. DIGITAL EXCITATION SYSTEM

As the project expanded the need of regulator adaptability also began to increase. A logic next step was to develop the next generation of excitation systems based on industrial stand-alone digital controllers. As most of the input-output circuits were already developed from the previous analogue excitation system, the new project needed some minor hardware adaptations and custom built software.



MHE Činžat 1 digital excitation system

The output circuitry as well as the power supply section remained unchanged compared to the analogue version. There was also no need for a digital reference and all the limiting and protection functions were software based.
With the extended flexibility of a digital controller its operating potential began to increase. Therefore new regulation modes were developed. Besides the primary voltage regulation equation, it was also possible to control other parameters such as reactive power, power factors, etc.

<u>Voltage regulation mode</u>

$$0 = \frac{U_{REF} - U_{GEN}}{U_N} + \frac{Q_{GEN}}{S_N} \cdot u_{Q-DROOP} + \frac{P_{GEN}}{S_N} \cdot u_{P-DROOP} \text{ ,}$$

U_{REF}	… reference voltage
U_{GEN}	… actual generator voltage
U_N	… rated voltage
S_N	… rated apparent power
Q_{GEN}	… actual reactive power
$u_{Q-DROOP}$	… Q droop
P_{GEN}	… actual real power
$u_{P-DROOP}$	… P droop

<u>Reactive power regulation mode</u>

$$Q_{REF} - Q_{GEN} = 0$$

Reactive power can be set between:

$$Q_{REF-min} \leq Q_{REF} \leq Q_{REF-max}$$

$$Q_{REF-min} \leq Q_{REF} \leq Q_{REF-max}$$

$$Q_{REF} - Q_{GEN} > 0 \rightarrow Increase\ U_{REF}$$

$$Q_{REF} - Q_{GEN} < 0 \rightarrow Decrease\ U_{REF}$$

U_{REF} … reference voltage
Q_{REF} … reactive power reference
Q_{GEN} … actual reactive power
$Q_{REF-min}$ … minimum reactive power reference
$Q_{REF-max}$ … maximum reactive power reference

<u>Power factor regulation mode</u>

Regulator function:

$$tan(\rho)_{REF} - \frac{Q_{GEN}}{|P_{GEN}|} = 0$$
$$tan(\rho) = \frac{Q_{GEN}}{P_{GEN}}$$

It is possible to set the power factor between:

$$tan(\rho)_{REF-min} \leq tan(\rho)_{REF} \leq tan(\rho)_{REF-max}$$

$$tan(\rho)_{REF} - \frac{Q_{GEN}}{|P_{GEN}|} > 0 \rightarrow Increase\ U_{REF}$$
$$tan(\rho)_{REF} - \frac{Q_{GEN}}{|P_{GEN}|} < 0 \rightarrow Decrease\ U_{REF}$$

U_{REF} … voltage reference
$tan(\rho)_{REF}$ … reference tangens
Q_{GEN} … actual reactive power
P_{GEN} … actual real power
$tan(\rho)_{REF-min}$ … minimal tangens set point
$tan(\rho)_{REF-max}$ … maximal tangens set point

<u>SODO regulation mode</u>

$$Q_{GEN-setpoint} = 0{,}75 \cdot P_{NG} \cdot \left[\frac{P_{GEN}}{psodo \cdot P_{NG}} + \frac{U_{CG} - U_D}{STAT \cdot U_N}\right]$$

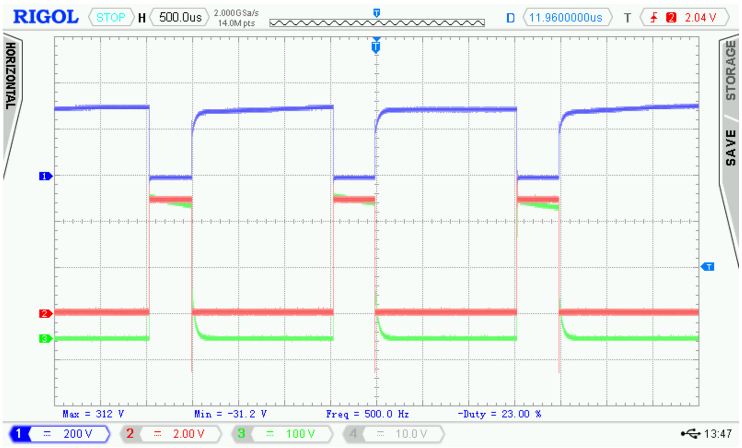
P_{NG} … generator rated real power
P_{GEN} … actual real power
U_{CG} … voltage reference set point
U_{GEN} … actual generator voltage
U_N … rated generator voltage

$psodo$ … real power factor
$STAT$ … droop

The SODO regulation mode enables the power plant to work in accordance with the grid operators demands.

Limiting and protection functions

Besides the operation modes the regulator includes a wide series of limiting and protection functions such as VHz limiter, minimum excitation current limiter, maximum excitation current limiter and protection, as well as regulator failure protection.



IGBT driver input signals during test procedures

5. DIGITAL EXCIATION SYSTEM UPGRADES AND IMPROVEMENTS

Regulator improvements

The whole digital regulator software was redesigned using so called D-TH (differential-time hysteresis) technology which results in better performance, increased speed, and lower voltage over shootings as well as better damping. Instead of using PWM (Pulse Width Modulation) the regulator has a built-in PDM (Pulse Density Modulation) unit for controlling its output section parameters.

6. FURTHER DEVELOPMENT

As it was seen in the field a lot of effort is put in turbine speed regulation with several difficulties in power plant synchronisation procedures. With a few hardware changes and new software our next step is to develop a turbine governor based on the D-TH approach. Due to its rapid and excellent response characteristics to higher order systems the regulator should be able to ease synchronisation procedures and perform much better during island operation of power plant

7. CONCLUSION

Our goal was to develop a robust and efficient excitation system capable of driving small power plants. One of its main advantages is most probably the systems adaptability and almost unlimited upgrade capabilities such as new protection designs, industrial standard communication, new software and hardware modules and much more.

8. BIBLIOGRAPHY

[1] Navodila za priključevanje in obratovanje elektrarn inštalirane moči do 10 MW, (Maribor, October 2008).
[2] Preverjanje pogojev za obratovanje razpršenih virov in vpliva njihovega obratovanja na kakovost dobavljene električne energije, študija EIMV, št.:1806, (Ljubljana, October 2007).
[3] Analogni vzbujalni system za male elektrarne, 12. konferenca slovenskih elektroenergetikov (Portorož, 2015).
[4] Razvoj digitalnega vzbujalnega sistema na osnovi FPGA tehnologije, 12. konferenca slovenskih elektroenergetikov (Portorož, 2015).