Güç Santrallerinde IEEE Güç Sistem Stabilizatörü tip PSS2B'nin Uygulanma ve Devreye Alınma Süreçleri

Implementation and commissioning process of IEEE Power System Stabilizer type PSS2B in power plants

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Özet

Güç sistemi stabilitesi, güvenilir ve esnek güç sistemlerinin ana bileşenlerinden birisidir. Ancak, sistemlerinin mekanik modlarının yetersiz sönümlenmesi ve yüksek hızlı otomatik voltaj regülatörlerinin kullanımı kombinasyonu nedeniyle doğabilecek düşük frekanslı salınımlar güç sisteminin salınımını bozabilir. Güç sistemi stabilizatör (PSS) ikaz kontrolü yoluyla söz konusu düşük frekans salınımlarını bastırmak için elektriksel tork momentini sağlamak üzere geliştirilmiştir. PSS'in karmaşıklığı sebebiyle devreye alma işlemi büyük bir mühendislik yeterliliği ve tecrübesi gerektirir. Makale KONCAR-INEM statik ikaz sistemlerinin otomatik voltaj regülatörlerinde uygulanan tip PSS2B IEEE PSS'nin standart ayarlama prosedürüne yönelik bilgi sağlamaktadır. Güç santrallerine uygulanan stabilizatörlerin performans değerlendirmesi makalede sunulmuştur.

Abstract

Power system stability is one of the key components of reliable and flexible power systems. However, low frequency electromechanical oscillations that can arise due to the combination of insufficient damping of the systems mechanical mode and usage of high-speed automatic voltage regulators can disrupt the stability of the power system. Power System Stabilizers (PSS) were developed to provide electrical torque to damp these low frequency oscillations through excitation control. Due to the complexity of the PSS, the tuning requires great proficiency and experience of the commissioning engineers. The article provides insight in the standard tuning procedure of the IEEE PSS type PSS2B implemented in Automatic Voltage Regulators of KONČAR-INEM static excitation systems. Performance evaluation of the implemented stabilizers in power plants is also presented in the article.

1. Introduction

Power system stability is defined as the ability of electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. [1] It is usually classified as presented in Fig 1. Stability of interest in this article is the rotor angle stability. While the synchronous generator is working in stationary state a balance of the mechanical torque transferred from the turbine to the generator and the electrical torque produced by the generator is present. The balance gets disrupted if a disturbance occurs in the system resulting in acceleration torque which speeds up or slows down the generator rotor i.e. it changes the rotor angle. Every generator in the system will produce two types of torque to regain stability during this transmission state: synchronization torque, dependent on the rotor angle shift of grid-connected generators, and damping torque produced in the damper windings of the rotor. If the amount of the mentioned torque is sufficient the electromechanical oscillations will be damped, in other case the rotor angle shift of the generator would continue to increase until one or even all generators drop out of the synchronism.

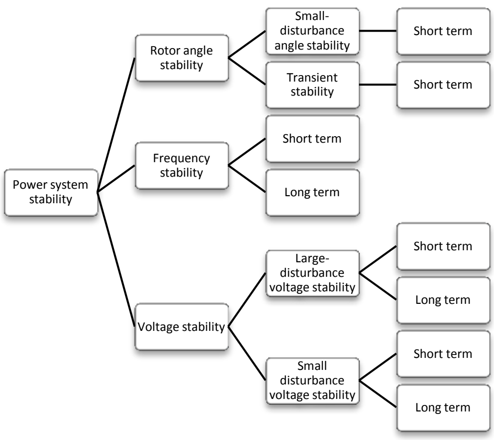

Figure 1.Power system stability classification [1]

Power system stabilizers (PSS) as supplementary excitation control subsystems were introduced to aid the generators in damping the low frequency oscillations in 0.1 - 4 Hz range [2 - 4]. As mentioned these oscillations can arise due to the lack of damping of the systems mechanical mode but are also additionally generated due to the usage of high gain fast-acting automatic voltage regulators (AVR). The AVRs have a negative contribution to the oscillation damping as they lower the amount of the needed damping torque to regain the generator stability. Basic function of the PSS is applying an additional signal to excitation system to create electrical torque that damps out abovementioned low frequency power oscillations. By dampening the occurring oscillations in distribution grid, stable, safe and reliable system work is ensured and in the same time range of international energy trade is increased.

According to the IEEE 421.5 standard the stabilizers are differed by the type of the stabilizer input signals in four groups: PSS1A, PSS2B, PSS3B and PSS4B. [5] Today the most used stabilizer types are PSS2B and PSS4B. In the following sections of the article the PSS2B stabilizer type structure and commissioning procedure are explained in detail. PSS parameter adjusting and commissioning procedure require great proficiency and experience of the commissioning engineers as a misadjusted stabilizer will have a negative effect on the generator and power system stability. Positive effects of the implemented PSS2B module in Končar's AVR system "DRN" in Yeniköy Thermal Power Plant and Aslancik Hydro Power Plant are presented graphically in the last section.

2. Excitation system with digital voltage regulator

2.1. Digital voltage regulator structure

Digital voltage regulator is based on the microprocessor system for the control and regulation of excitation systems type "DRN" [6], [7], Fig. 2. The microprocessor system is built around a programmable central processing unit (CPU) that enables real-time execution of control and regulation tasks. Modular hardware environment is based on MC68302 microprocessor [8] and industrial VMEbus system. Software environment is comprised of software for design and development of application program, system software support and software utilities.

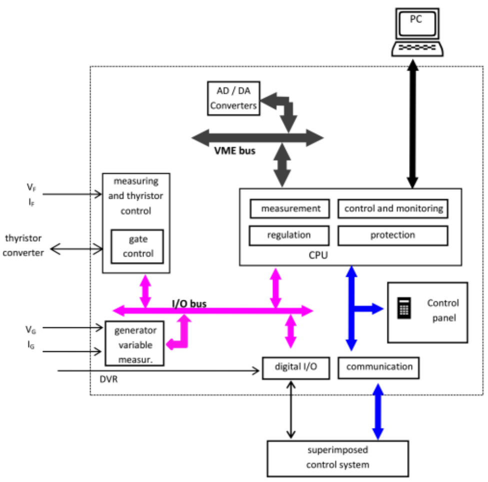

Figure 2. Block diagram of DRN structure [9]

Software for design and development of application program is based on graphical block-diagram oriented programming package. The system software consists of real-time kernel and system programs. Real-time kernel handles tasks according to the pre-emptive fixed priority-based scheduling policy [10], [11].

2.2. PSS2B structure and parameter adjusting

PSS2B structure implemented in Končar digital voltage regulator (DRN), presented on the Fig. 3, was built in accordance with the IEEE 421.5 standard. The stabilization signal is formed from two input signals: generator voltage frequency signal and generator active power signal. Input signals are first run through the input filters, then through the high pass wash-out filters (T_{W1}, T_{W2}) to remove the stationary value in the signals and after that the frequency signal is passed through the low pass filter (T_6) to remove the high frequency noise and the electrical power signal ΔP_e is passed through the integrator (T_7). Time constants for the high pass filters are typically set to 10 s. Filter time constant T_7 is adjusted to the value of 2H, where H represents the inertia constant of the synchronous machine. K_{S1} and K_{S2} gain values are usually set to 1 and are adjusted if needed during the commissioning to increase the contribution of the active power signal. Filtered frequency signal and integral of the power acceleration signal are summed up and led trough the ramp-tracking filter to remove the torsional oscillations from speed rotation signal (typical values: M = 5, N = 1 or M = 2, N = 4, T_8=M·T_9, T_9=0.125s). PSS signal phase compensation is provided by the three lead-lag blocks (T_1, T_2, T_3, T_4, T_{10}, T_{11}). Time constants of the lead-lag filters are selected to compensate system's phase lag at frequencies of interest (0.1 – 4 Hz). Lead-lag time constants along with the K_{S3} gain value are generally adjusted two times: before commissioning to get the initial values of the excitation system and then during the commissioning to ensure the needed oscillation damping effect. Output signal of the PSS module is usually limited to 0.05 of the rated generator voltage and then added to the input terminal of the AVR. PSS2B parameters typical value ranges are presented in Table 1.

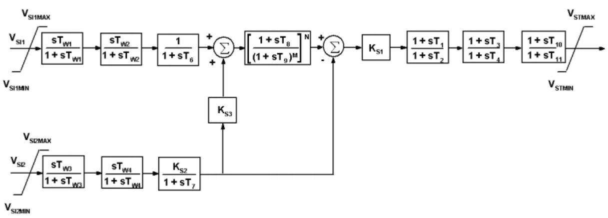

Figure 3. IEEE PSS2B structure [5]

Table 1. PSS2B parameters description and range [12]

Parameter	Unit	Description	Typical range
T_W	s	Filter time constant for elimination of stationary value	1 – 10
T_1-T_4, T_{10}, T_{11}	s	Derivation–integration filter time constants	0 – 2
T_6	s	Input filter time constant	0 – 2
T_7	s	Input filter time constant	0.5 – 10

T_8	s	Ramp-tracking filter time constant	0 – 2
T_9	s	Ramp-tracking filter time constant	0 – 2
N	integer	Ramp-tracking filter constant	1 – 6
M	integer	Ramp-tracking filter constant	1 – 5
K_{S1}	pu/pu	PSS output signal gain factor	0.2 – 20
K_{S2}	pu/pu	Gain factor	0.1 – 5
K_{S3}	pu/pu	Gain factor	0.1 – 5
V_{STMAX}	pu	Maximum output signal limit	0 – 0.2
V_{STMIN}	pu	Minimum output signal limit	-0.1 – 0

Linearized model of the grid connected generator is used for initial adjusting of PSS parameters. To adjust the simulation model the generator manufacturer must provide the values of the generator reactances and time constants, frequency of the local mode oscillation and system's phase lag characteristic. System's phase lag can be determined by recording the frequency response of transfer function between terminal voltage (V_T) and voltage reference (V_{REF}) and it depends on synchronous machine parameters, variation in loading condition and system parameters. Example of a system's phase lag characteristic for simulation model of the TPP Jertovec is presented on Fig. 4.

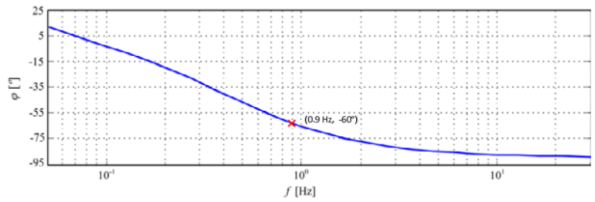

Figure 4. TPP Jertovec system phase lag characteristic with marked frequency of the local mode oscillation [13]

Time constants of the lead-lag filters, whose phase characteristic is presented on Fig. 5., were chosen to remove the phase lag in the interval around the frequency of the local mode oscillation [0.1 – 3 Hz].

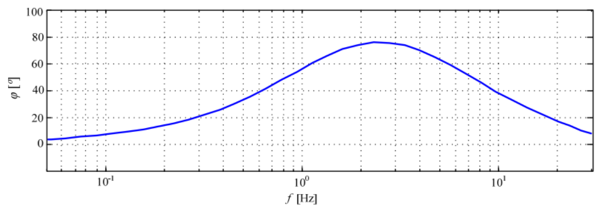

Figure 5. Phase characteristic of the lead-lag transfer function for TPP Jertovec [13]

2.3. PSS2B commissioning procedure

Before the commissioning of the PSS, the value of local mode oscillation frequency and the system's phase lag must be recorded to ensure their correlation with the simulation data. The frequency can be obtained from active power response signal to a small step voltage reference change in the AVR. If the measured frequency differs from the frequency specified by the generator manufacturer, parameter T_7 should be adjusted to the measured 2H value. Phase lag characteristic of the excitation system should be recorded while the generator is synchronized on the grid and its active power is higher than 0.5 pu and reactive power close to 0. If these conditions can't be met and the recording is done with generator in open-circuit mode, some adjustments must be made to the characteristic. In the frequency interval [0.1 – 0.6 Hz] phase lag of the PSS should then be set 10-30° higher and in the interval [0.6 – 4 Hz] the PSS lag should be set 20-40° lower than the absolute value of the recorded phase lag of the excitation system. [2] The peak of the phase characteristic must be set at the frequency 2.5 times higher than the frequency of the local mode oscillation. Examples of the PSS lead-lag filter phase responses for power plants with "DRN" digital voltage regulator are shown in Fig. 6.

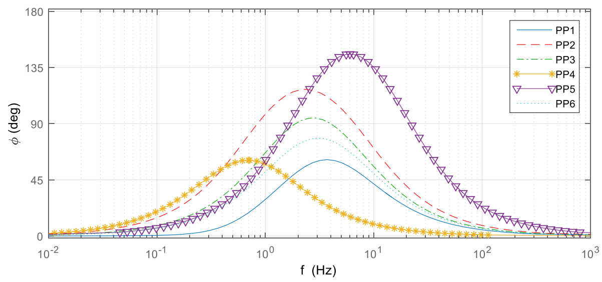

Figure 6. Example of the PSS lead-lag filter phase responses for power plants with "DRN" digital voltage regulator

To check if the lead-lag filter parameters are properly set the generator should be synchronized to the grid with deactivated PSS and the active power value between 50-100% of nominal active power. While the reference value of the voltage regulator is changed for 1-3% of the nominal voltage value, following signals should be recorded: active power, voltage frequency, acceleration power integral and output signal of the PSS. If the acceleration power integral signal is in phase with the generator voltage frequency signal and in the same time is preceding the active power signal for 90°, and if the PSS output signal is in antiphase (in ±20° borders) to the active power signal (P) the parameters of the lead-lag filters are correctly set. The last parameter of the PSS needed to be set is the gain value of the PSS (K_{S3}). In steps increase the value of the K_{S3} gain with activated PSS until the effect of the PSS is producing oscillations visible in the excitation current signal. The gain is then set to the 30-40% of the gain value that produced the oscillations. Described PSS evaluation procedure for power plants will be presented graphically in the last chapter of the article.

3. PSS2B performance evaluation

In 2010 the electric power system of Turkey has been connected to the ENTSO-E (European Network of Transmission System Operators) system with TEIAŞ (Türkiye Elektrik Iletim A.Ş.) obtaining the observer status in 2016. ENTSO-E experts proposed that all major power plants in the electric power system of Turkey should install PSSs to dampen the low frequency oscillations.[14] Effects of installed and tuned PSS2B stabilizers are presented on two power plants with Končar “DRN” digital voltage regulators: thermal power plant Yeniköy and hydro power plant Aslancik.

3.1. Power plant – basic information

TPP Yeniköy is situated in Bağdamları city in Muğla province, Fig 7. The thermal plant runs on lignite coal and has two 210 MW rated units with annual projected energy generation of 2 730 GWh. [15]

Figure 7. TPP Yeniköy, 2x210 MW [16]

HPP Aslancik located on Harşit River in province of Giresun is powered by two 60 MW Francis turbines which annually feed an amount of around 418 MWh of emission free electricity into the Turkish national grid, Fig 8. [15]

Figure 8. HPP Aslancik, 2x60 MW [17]

Both power plants have self-excitation systems with digital voltage regulators and fully-controlled thyristor converters. Nominal parameter values of generators are presented in Table 2.

Table 2. Generator parameters

Parameter	**Symbol**	**Yeniköy TPP**	**Aslancik HPP**
Rated apparent power	S_n	247 MVA	66,66 MVA
Rated active power	P_n	210 MW	60 MW
Rated voltage	U_n	15,75 kV	13,8 kV
Rated current	I_n	9056 A	2789 A
Rated frequency	f_n	50 Hz	50 Hz
Rated power factor	$cos\varphi$	0.85	0.9
Rated speed	n_n	3000 rpm	300 rpm
Generator type	-	turbo	hydro
Excitation type	-	self-excitation	self-excitation

3.2. PSS2B implementation results

Results of the PSS2B implemented in digital voltage regulators in power plants presented in previous section are shown in Fig 9-12. Signals are recorded in ZZT software in the following order:

- Ug, generator voltage [%] – VGACTINV
- Uf, field voltage - UFACT
- Q, reactive power [MVAr] – QACT
- P, active power [MW] - PACT
- PSS output signal - VPSS
- integral of acceleration power - PSS04

During recording, generator voltage reference is step changed for ±3%. The recording is first done with disabled PSS and then with fully tuned enabled PSS. As expected the step change in voltage reference when PSS is disabled will produce the unwanted oscillations in active power signal, Fig 9. and Fig 11. In case the PSS is enabled these oscillation are quickly damped as can be seen in Fig 10. and Fig 12. verifying that the implemented PSS is benefiting the generator stability and power system stability. Proof that the PSS is correctly tuned is also seen by comparing the phase shift of the active power signal and the PSS output signal. The two signals are in antiphase position meaning that the phase lag of the PSS is correctly set. Also the phase shift between the integral of acceleration signal and active power signal is around 90° which is also one of indicators for correctly tuned PSS as explained in section *2.3. PSS2B commissioning procedure*.

4. Conclusion

The article is describing the commissioning and tuning procedure of the IEEE type PSS2B stabilizer. Structure of the stabilizer is explained along with guidelines how to correctly chose stabilizer parameters and validate the influence of the PSS on the generator stability. Results of the stabilizer implementation in Končar digital voltage regulators type “DRN” were validated on two power plants in Turkey. Effects of the implementation were verified positive as the oscillations in active power signal caused by the change of generator voltage reference were quickly damped. Thereby the power transfer capability of the power system will not be lowered by the electromechanical oscillations which occurred by lack of damping of the systems mechanical mode or by usage of high gain fast-acting automatic voltage regulators.

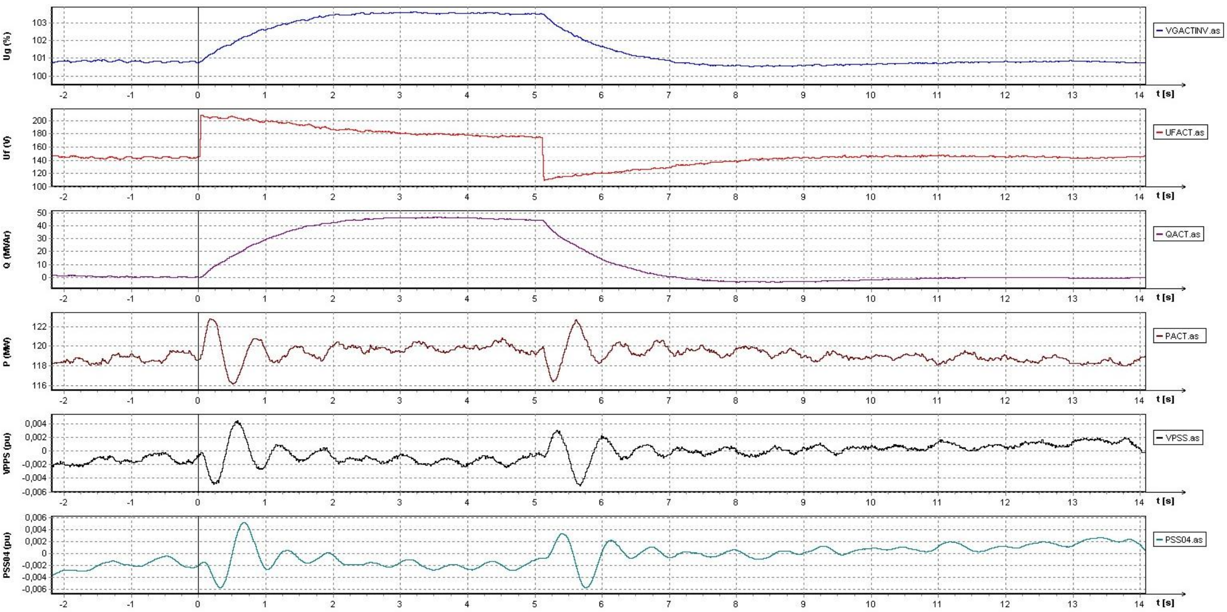

Figure 9. Generator voltage, field voltage, reactive power, active power, PSS output, integral of accelation power signal response to ΔVref=3%, PSS OFF, Unit 2 Yeniköy [18]

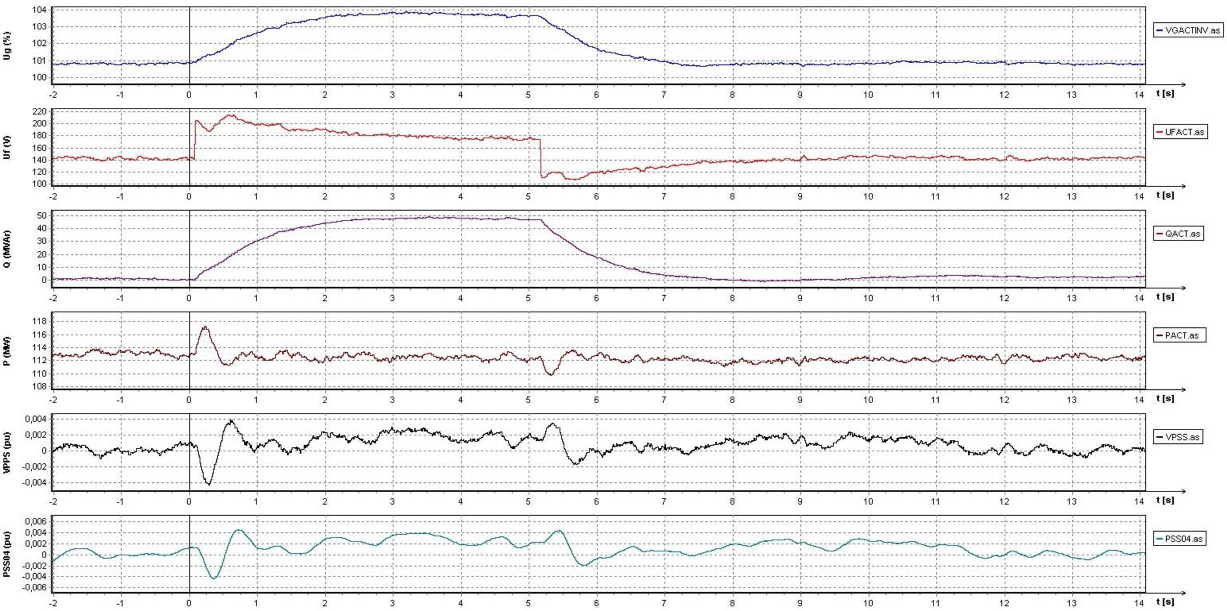

Figure 10. Generator voltage, field voltage, reactive power, active power, PSS output and integral of accelation power signal response to ΔVref=3%, PSS ON, Unit 2 Yeniköy[18]

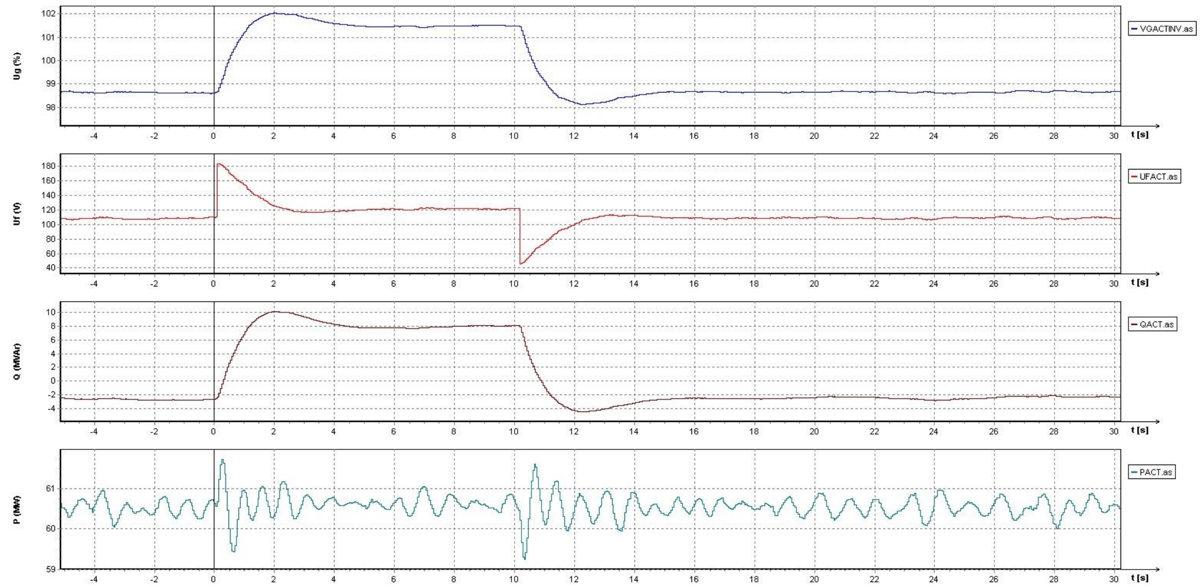

Figure 11. Generator voltage, field voltage, reactive power and active signal response to ΔVref=3%, PSS OFF, Unit 1 Aslancik [19]

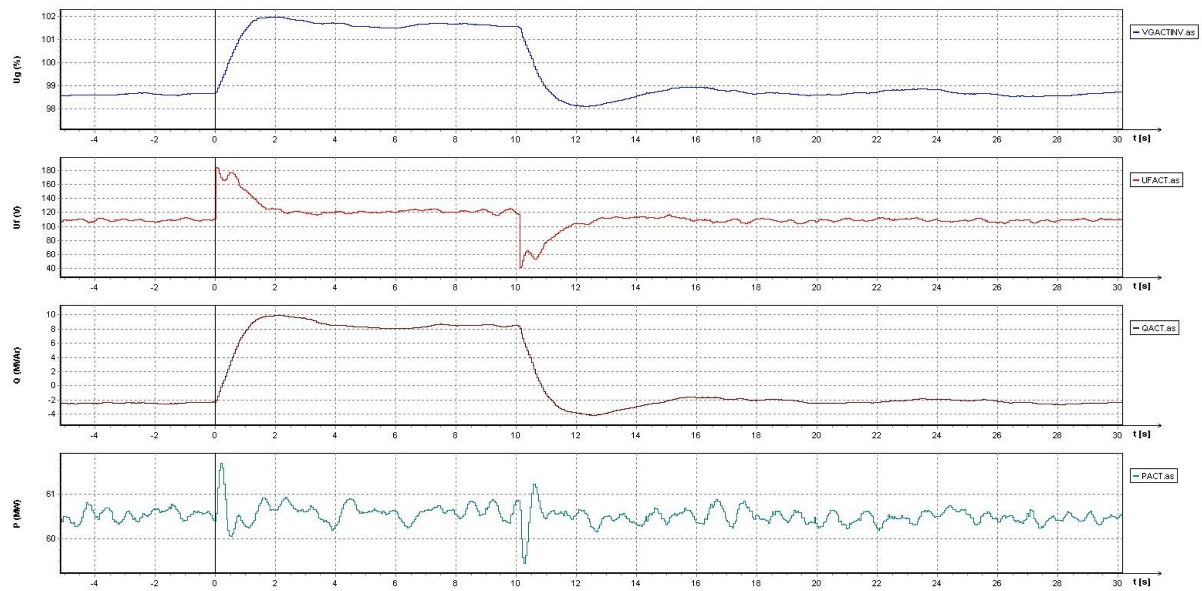

Figure 12. Generator voltage, field voltage, reactive power and active signal response to ΔVref=3%, PSS ON, Unit 1 Aslancik [19]

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