TRANSIENT STABILITY SIMULATION OF COMBINED POWER PLANT DURING FAULTS ON 400 AND 110 KV TRANSMISSION LINES

Srete Nikolovski[1], Predrag Marić[1], Zoran Baus[2] Goran Slipac[3]

[1]J.J.Strossmayer University of Osijek, Faculty of Electrical Engineering
31000 Osijek, K. Trpimira 2B, Croatia
[2]SIEMENS d.d. 10000 Zagreb, Hainzelova 70a, Croatia
[3] HEP d.d. Sektor za razvoj
10000 Zagreb, Ul. Grada Vukovara 37, Croatia

pmaric@etfos.hr (Predrag Marić)

Abstract

The paper presents simulation of transient stability of a 56.25 MVA generator and two 22.5 MVA generators in the combined steam-gas power plant "TE-TO" Osijek synchronized with a 110 kV transmission network. This power plant is electrically very close to the recently reconstructed substation 400/110 kV Ernestinovo. Three phase and single-line-to-ground faults were simulated at 400 kV and 110 kV transmission lines using DIgSILENT software for electromagnetic transients (EMT) to simulate transient stability during the fault and switching process. All input data for transmission lines, transformers, synchronous machines and switching devices are obtained from HEP databases. The analysis of dynamic behavior of generators during the single-line-to-ground faults and three phase faults on the closest associated 110 kV line to the power plant and on 400 kV line associated to TS 400/110 kV.
Operational variables such as generator speed, electrical and mechanical power, excitation voltage, frequency, currents and voltages in transmission lines were observed. Modeling of the system components by considering a very large number of relevant parameters and constants, as well as using real operational values for each model has enabled the relative accuracy in representing of all the states. Furthermore, the control system together with the protection system protects the plant from hazardous states thus allowing safe, good and long-life operation of all the plant components. Waveforms of transients on the 400 kV and 110 kV transmission lines, generator speeds and rotor angles deviation caused by faults have also been presented.

Keywords: Transient stability, transmission network, synchronous generator, short circuits, computer simulation.

Presenting Author's biography

Predrag Marić was born on December 11, 1979 in Osijek. He obtained his diploma degree in 2004 in the field of Electrical Power Engineering from the Faculty of Electrical Engineering in Osijek. His graduation thesis was awarded two prizes: "Hrvoje Požar" of the Croatian Energy Institute as a specially noticed thesis in field of power engineering. He works as a research assistant in the Power System Department at the Faculty of Electrical Engineering in Osijek. His main interests are modeling, simulation and analysis of transient phenomena in power systems.

ISBN 978-3-901608-32-2

1 Generator Model

Model of a synchronous machine in TE-TO Osijek, which considers both transient and subtransient effects in the generator, is presented in Fig.1.

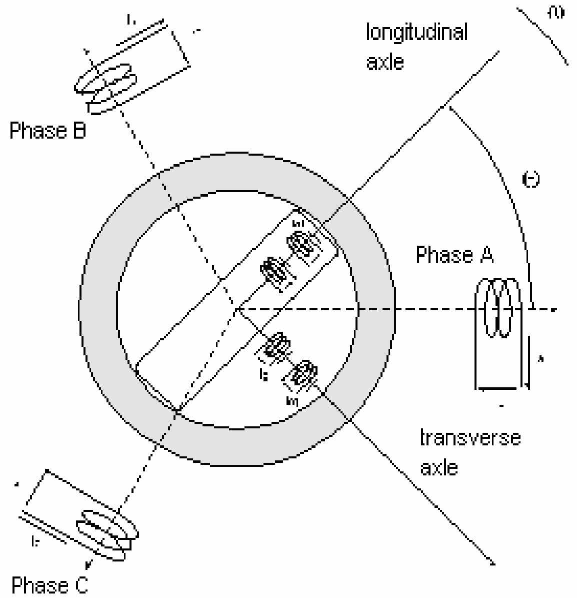

Fig. 1 A three phase synchronous machine model

Mechanical behavior of the synchronous generator is described by the following swing equations [1]:

$$2\,H\,d\omega/dt = T_m - T_e - K_D\,(\omega-\omega_0) \quad (1)$$

$$d\delta/dt=\Omega_0(\omega-\omega_0) \quad (2)$$

Electric power is calculated from the "d" and "q" component of the armature voltage and current as:

$$P_e=V_qI_q+V_dI_d \quad (3)$$

The value of generator power is obtained from the voltage and current axes. Because the transient and subtransient effects within the machine are considered in the model, the voltages on axes consist of several components that need to be considered. The following equations represent the values of field d and q components:

$$\tau'_{d0}dE'_q/dt=E_{fd}-E_q \quad (4)$$

$$E_{q2}=E'_q-E''_q-(x'_d-x_l)I_d \quad (5)$$

$$E_q=E'_q+\Delta E_q+(x_d-x'_d)I_d+(x_d-x'_d)(x'_d-''_d)/(x'_d-x_l)^2E_{q2} \quad (6)$$

$$\tau''_{d0}dE''_q/dt=E_{q2} \quad (7)$$

$$V_q=(x''_d-x_l)/(x'_d-x_l)E'_q+(x'_d-x''_d)/(x'_d-x_l)E''_q-x''_dI_d \quad (8)$$

$$\tau'_{q0}dE'_d/dt=-E'_d+(x_q-x'_q)I_q \quad (9)$$

$$\tau''_{q0}dE''_d/dt=-E''_d+E'_d-(x_q-x_l)I_q \quad (10)$$

$$V_d=-(x'_q-x''_q)/(x'_q-x_l)E''_d+(x''_q-x_l)/(x'_q-x_l)E'_d+x''_qI_q \quad (11)$$

The synchronous machine is modeled by two circuits, the first is in the direct axes (main field and a damped circuit) and the second circuit in the quadrilateral axes, respecting the machine axis orientation convention that positive „q" axis leads positive „d" axis by 90 degrees.

2 Excitation System Model

The generator excitation system is derived with a static thyristor system. The acquired values of the excitation voltage and current are determined automatically by a thyristor converter on the basis of the measured stator currents and voltages and the generator excitation current. An important characteristic of this excitation system is that the maximum excitation control voltage is proportional to the synchronous machine voltage; therefore it is not constant and is calculated as:

$$V_{r\,max}=K_pV_a \quad (12)$$

The excitation system has an automatic voltage regulation. During the fault on a power system component, the generator voltage is decreased and the excitation reacts to increase the excitation voltage, which in turn increases the generator voltage. Excitation control is also important during normal operation because the generator voltage and the reactive power are related. Equations describing the behavior of the excitation system are:

$$V_1=(K_R/\tau_R)V_t-(1/\tau_R)V_1 \quad (13)$$

$$V_3=(K_F/\tau_F)E_{FD}-(1/\tau_F)V_3 \quad (14)$$

$$E_{FD}=(K_A/\tau_A)V_e-(1/\tau_A)E_{FD} \quad (15)$$

where $V_{Rmin}<E_{FD}<V_{Rmax})$

$$V_e=V_{REF}+V_s-V_1-V_3 \quad (16)$$

3 Turbine Model

TE-TO Osijek has one steam turbine (ST) with regulated steam reduction for purposes of heating, and two gas turbines GT1 and GT2. It is possible to regulate the turbine mechanical power using the steam reduction control. During normal operation when load increases, the control of the turbine valve on the steam input reacts to release more steam in order to overcome the increased electrical torque and bring the state to balance. When a fault occurs on the transmission line, the electro-hydraulic control sharply decreases the steam input in order to decrease the output turbine power due to decrease of electric power during a fault. After the fault is cleared, the turbine gradually returns to steady operational regime.

4 Sample case

Simulation is performed by DIgSILENT Power Factory 13.1 software [4]. The first simulation is performed for the three phase to ground fault on the 400 kV transmission line Ernestinovo-Žerjavinec [2]. The fault is located at 10,2 km from the TS 400/110 kV Ernestinovo at time point t= 0.1 (s). The fault is successfully cleaned after t= 0.5 (s)

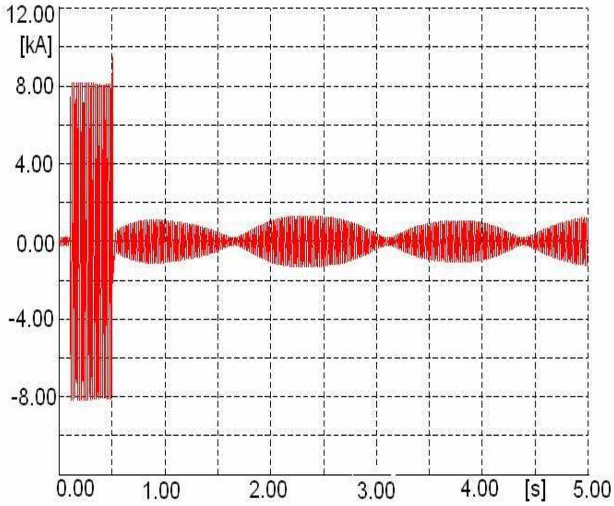

Fig. 2 RMS value of phase current at the 400 kV line during the 3FLG fault

The approximate value of 3FLG current is about 8 kA.

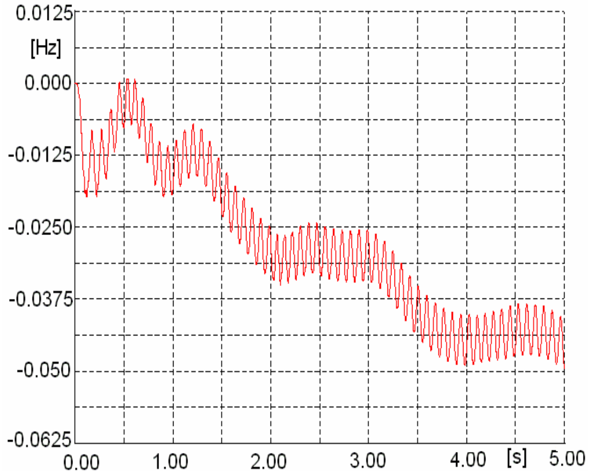

Fig. 3 Generator speed of steam turbine during the 3FLG fault at the 400 kV line

Because of the unbalance of input mechanical power and output electrical power during the 3FLG fault of the steam turbine driven generator, its synchronous speed increases [3].

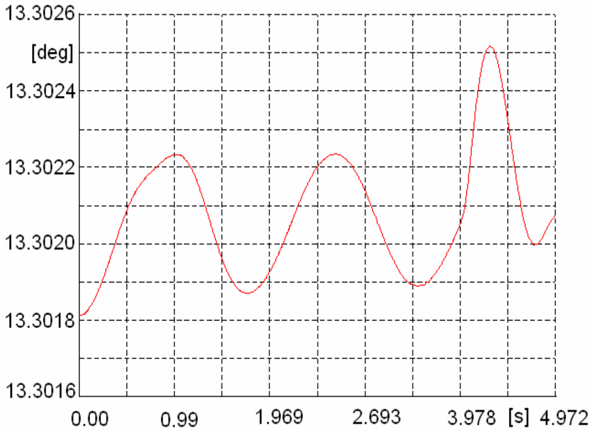

Fig. 4 Generator rotor angle deviation for steam turbine during the 3FLG fault at the 400 kV line

Due to complexity of the steam input control system (time delay on electrical and mechanical parts), the reaction of this system at the moment when a fault on transmission line appears is not possible. Decrease of electrical power with constant mechanical power results in generator speed and rotor angle increase presented in Fig. 4 and Fig. 5. Rotor angle oscillations may cause serious generator stability problems. Three phase to ground fault on the 400 kV line Ernestinovo-Žerjavinec is not critical for stability of generators in the power plant TE-TO Osijek because of the impact of other 110 kV and 400 kV lines and components connected to the TS 400/110 kV Ernestinovo.

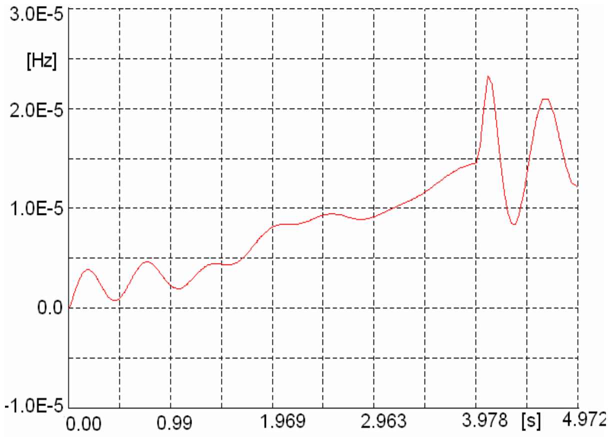

Fig. 5 Generator speed deviation for gas turbine during the 3FLG fault at the 400 kV line

The second simulation is performed for the three phase to ground fault on the 110 kV line Osijek 2 - Ernestinovo, the line that connects power plant TE-TO Osijek with the TS 400/110 kV Ernestinovo. The fault is located at 2,3 km from the power plant TE-TO Osijek at time point t= 0.1 (s). The fault is successfully cleaned after t= 0.5 (s).

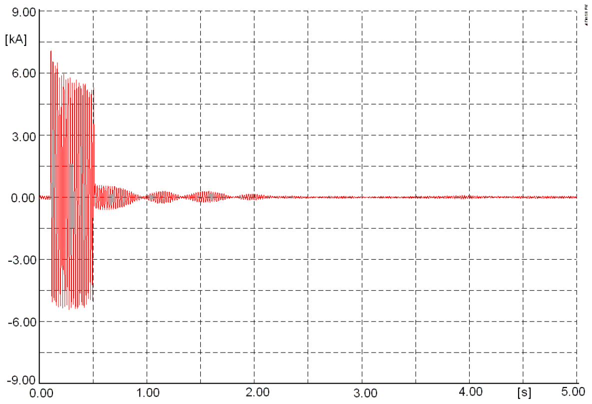

Fig. 6 RMS value of phase current at 110 kV line during the 3FLG fault

The highest RMS value of current during this fault is about 6 kA. The fault is electrically close to generators which results in voltage oscillations on generator terminals shown in Fig. 7 and Fig. 8.

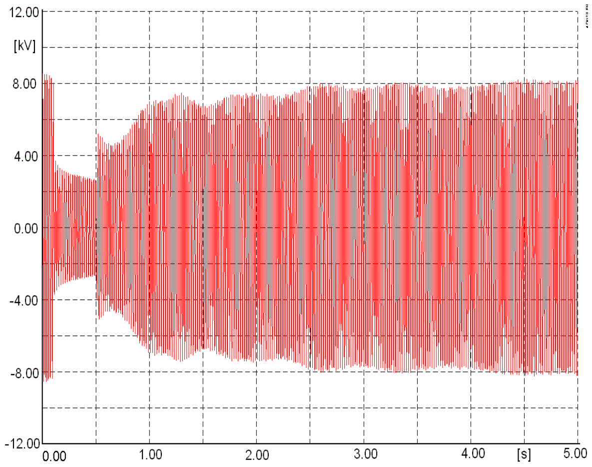

Fig. 7 Voltage at the 22.5 MVA generator terminals during the 3FLG fault at the110 kV line.

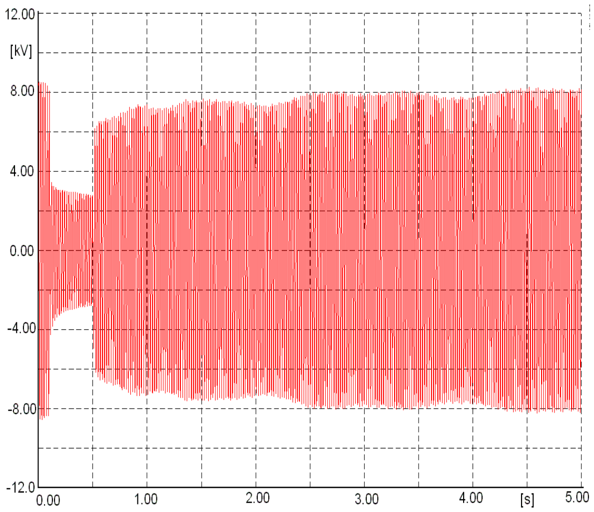

Fig. 8 Voltage at the 56.25 MVA generator terminals during the 3FLG fault at the 110 kV line.

The increases of generator speed and rotor angle during the fault are significantly higher at the 22.5 MVA generator due to smaller inertia of the 22.5 MVA generator than the 56.25 MVA generator presented in Fig. 9 and Fig. 10.

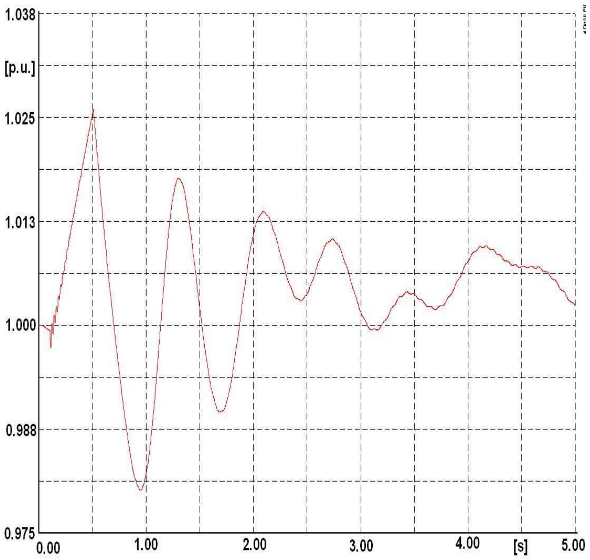

Fig. 9 Speed of the 22.5 MVA generator during the 3FLG fault at the 110 kV line.

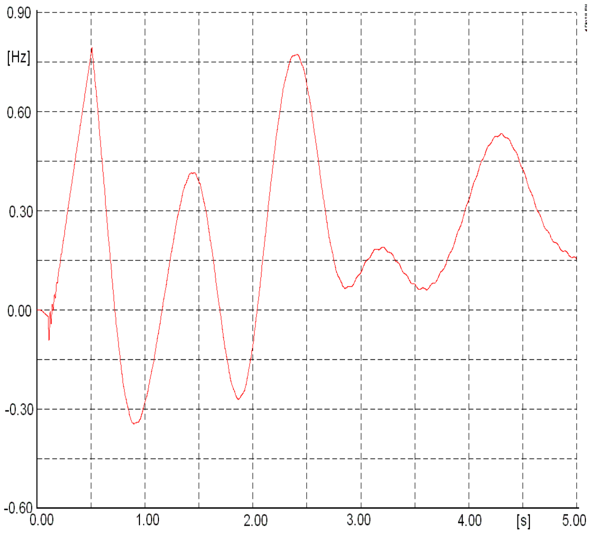

Fig. 10 Speed deviation of the 56.25 MVA generator during the 3FLG fault at the 110 kV line.

Basically, the stability of generator is not corrupted if the rotor angle during the transient process initiated by the fault on the transmission line does not exceed $180^0-\delta_0$, where δ_0 is rotor angle at the moment of fault beginning. Considering this criterion, the stability of generators is maintained, although the rotor angle at the 22.5 MVA generator almost reached the upper angle limit which can be seen in Fig. 11 and Fig. 12.

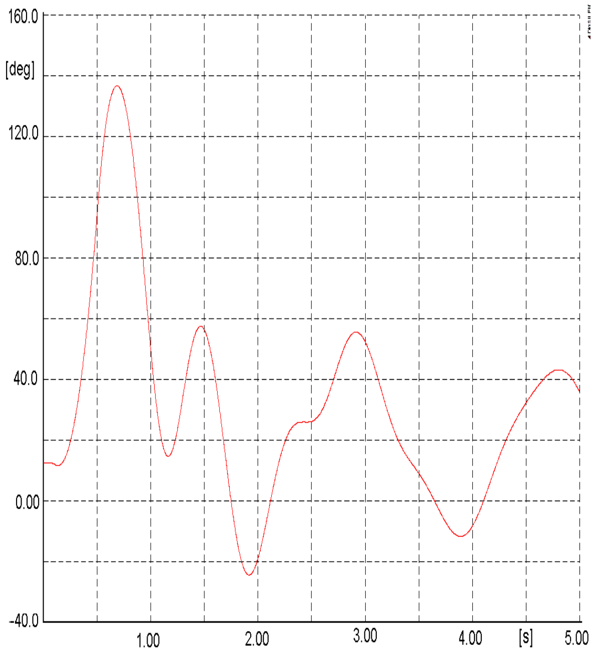

Fig. 11 The rotor angle of the 22.5 MVA generator during the 3FLG fault at the 110 kV line.

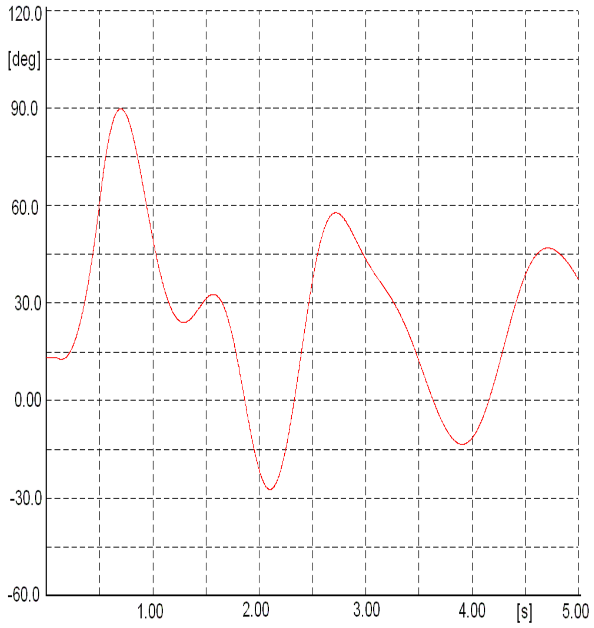

Fig. 12 The rotor angle of the 56.25 MVA generator during the 3FLG fault at the 110 kV line.

The third simulation is performed for the single phase to ground fault on the 110 kV line Osijek 2-Ernestinovo, the line that connects power plant TE-TO Osijek with the TS 400/110 kV Ernestinovo. The fault is located at 2,3 km from the power plant TE-TO Osijek at time point t= 0.1 (s). The fault is successfully cleaned after t= 0.5 (s)

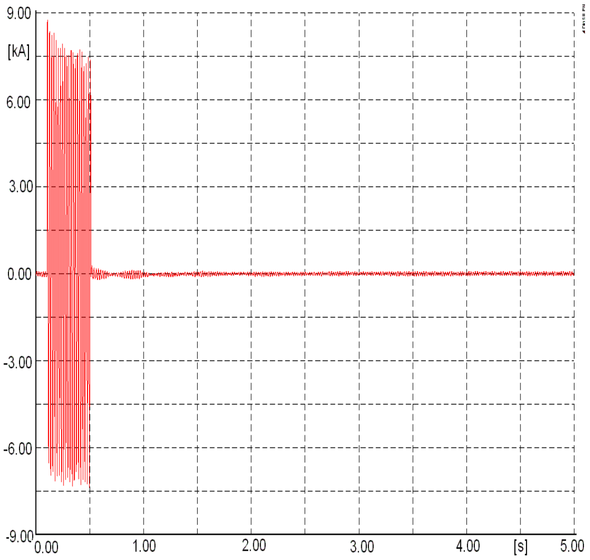

Fig. 13 RMS value of phase current at the 110 kV line during the SLG fault

The equivalent transfer reactance of transmission line affected with single phase to ground fault is greater than the equivalent transfer reactance of three phase to ground fault, so the single phase to ground fault is more convenient for the generator stability. The voltage oscillations on generator terminals are much lower now, Fig. 14.

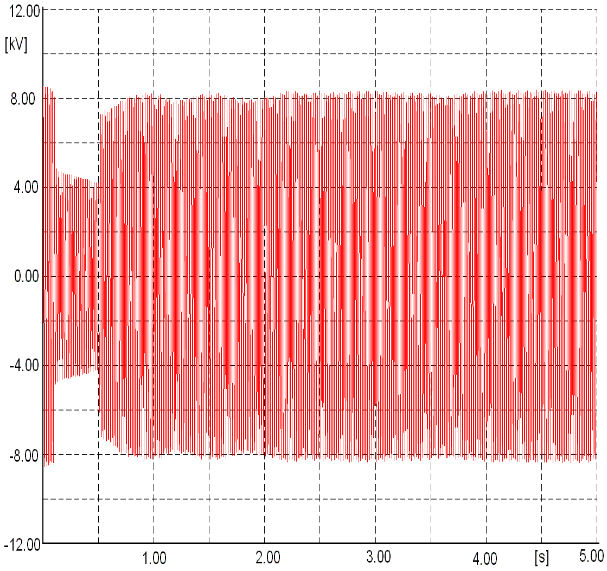

Fig. 14 Voltage at the 22.5 MVA generator terminals during the SLG fault at the110 kV line.

Transferable electrical power greater than in the case of three phase to ground fault and smaller difference in generator electrical and mechanical power result in smaller increase of generator speed and rotor angle, Fig. 15 and Fig 16.

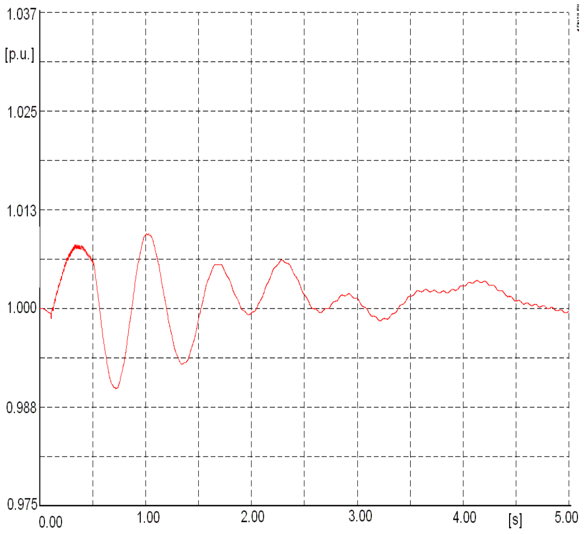

Fig. 15 Speed of the 22.5 MVA generator during the SLG fault at the 110 kV line.

Damped speed oscillations of the 22.5 MVA generator imply that even electrically closer (compared with three phase to ground fault on the 400 kV line), single phase to ground fault is less hazardous for generator stability.

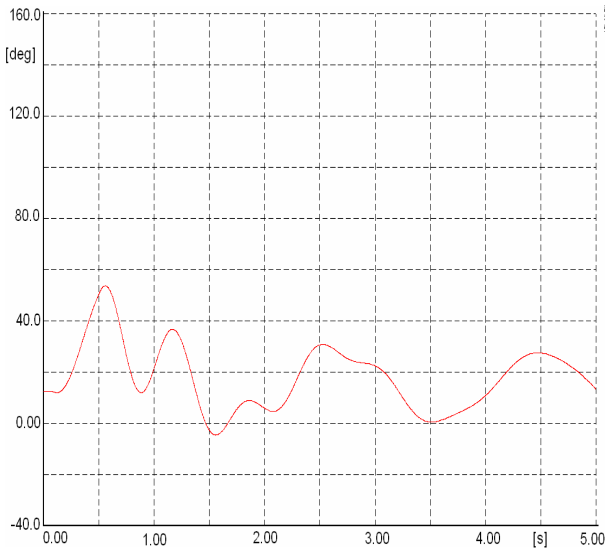

Fig. 16 Rotor angle deviation of the 22.5 MVA generator during the SLG fault at the 110 kV line.

5 Conclusion

The paper presents an EMT simulation of transients during the three phase to ground short circuit and single phase to ground short circuit on the 400 kV and 110 kV transmission lines that are electrically close to the power plant TE-TO Osijek. An analysis of dynamic behavior was performed for the steam driven generator of 56.25 MVA and the gas driven generator of 22.5 MVA. Waveforms of transients on the 400 kV and 110 kV transmission lines, generator speeds and rotor angles deviation caused by faults are obtained using the DIgSILENT EMT module. Simulations are performed on the assumption that switching and protective devices operate properly, and that all faults are cleaned within 0,5 seconds. Due to its own inertia, the 56.25 MVA block exhibited very good transient stability even in the worst case of a three phase line to ground fault on the closest 110 kV transmission line; there were no electrical and mechanical effects on the power plant components. The 22.5 MVA block also exhibited good transient stability in all analyzed cases, but in the case of three phase to ground fault on the closest 110 kV transmission line the rotor angle deviation was very close to unstable limit and if the fault clearing time had been greater than 0.5 seconds, the unstable state would have been achieved.

6 References

[1] P. Kundur. Power System stability and Control. McGraw Hill Publisher , 1994.

[2] S. Nikolovski, F. Jović, D. Tomić, D. Šljivac. Simulation Of Transient Stability of a Local Power Plant During Island and Parallel Conection With The Network. *XIII International Conference on Electromagnetic Disturbance*, Bialystok, 2003.

[3] S. Nikolovski. Power system protection (in Croatian), Faculty of Electrical Engineering Osijek, 2005.

[4] S. Nikolovski, P. Marić, I. Vicković. Simulation Tool for Coordination of Protective Relays in Distribution Networks, *Proceedings of the 14 th International Conference on Power System Protection, PSP 2004,* Faculty of Electrical Engineering, Ljubljana, 2004.

[5] DIgSIENT User's Manual, ver. 13.1, Gomaringen, 2006.

ISBN 978-3-901608-32-2