POWER GENETATION, TRANSMISSION AND DISTRIBUTION

ABSTRACT

In this report, simulations regarding a fifth order synchronous generator will be ran in order to study then response under some circumstances such as torque steps and three-phase faults.

PROCEDURE

A 5th order dynamic model for a 50Hz synchronous generator with one pole pair, an inertia constant of 3.75 J/VA was simulated in Simulink.is implemented in Simulink. The model is created using integrators, sum blocks, gains, trigonometrical functions and some other required blocks available in Simulink library.

The Inverse Park transformation is also modeled in Simulink, receiving as input the dq currents (for inverse transformations).

The torque steps are modeled using a step block, that let to configure the time when the step occurs and the value of that step. The three-phase fault is simulated using also a step block, setting the nominal voltage as initial value and then using a step-down to zero.

RESULTS AND SIMULATIONS

Part a): Synchronous generator.

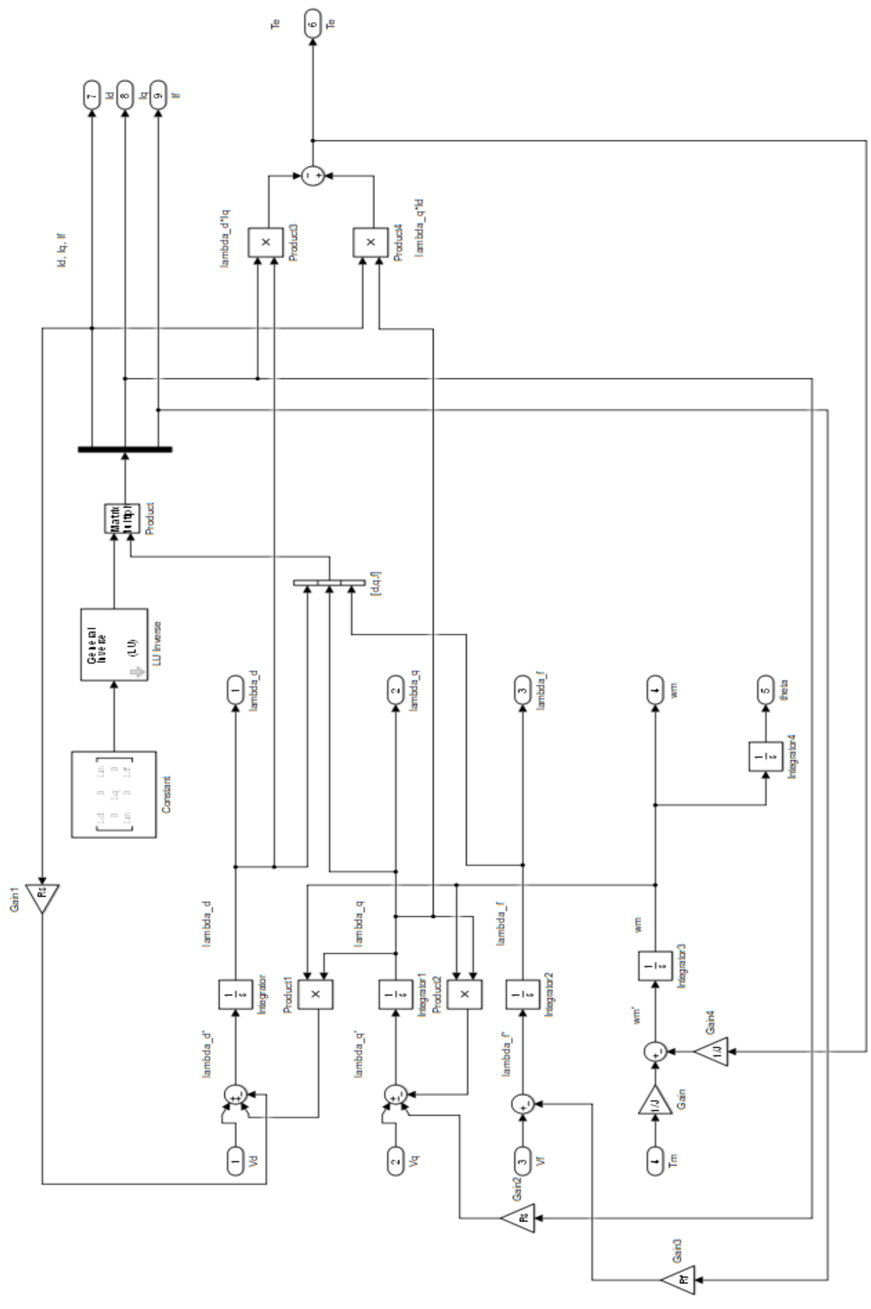


Figure 1. Synchronous Generator model created in Simulink.

To transform the V_{RMS} voltage to the dq axis, we can use the formulas depending of the load angle:

$$V_d = V_{RMS} * \sin(\delta)$$

$$V_q = V_{RMS} * \cos(\delta)$$

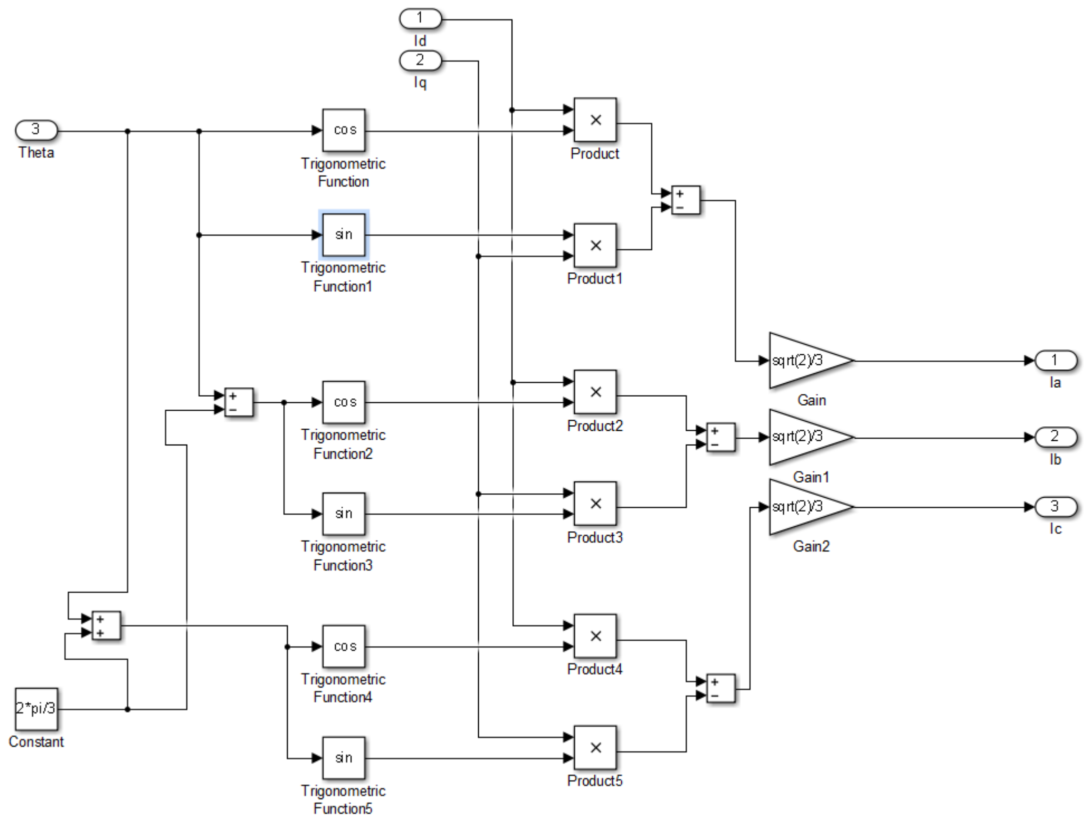


Figure 2. Inverse Park Transformation model created in Simulink.

b) Steady state calculations

The synchronous generator is connected to an infinite bus. It is also feeding a load of 370MVA at a power factor of 0.9. We obtain the active power demanded by the load by the following equation:

$$\frac{P}{S} = 0.9 \rightarrow P = S * 0.9 = 370 * 0.9 = 333MW$$

The phase-current delivered by the synchronous generator on steady-state is:

$$I = \frac{S}{V} = \frac{370MVA}{20kV} = 18500A$$

The synchronous generator speed at steady-state condition is:

$$w_m = 2 * \pi * 50 = 314.16\ \frac{rad}{sec} = 3000rpm$$

The power factor angle is obtained by the following equation:

$$\varphi = \cos^{-1}(PF) = \cos^{-1}(0.9) = 25.8419º$$

We can obtain tan $(\varphi + \delta)$ using the following formula:

$$\tan(\varphi + \delta) = \frac{Q - w_s * L_q * I.^2}{P - R_s * I^2} = 66.4278º$$

$$\delta = \tan^{-1}(\varphi + \delta) - \varphi = 40.5859^{o}$$

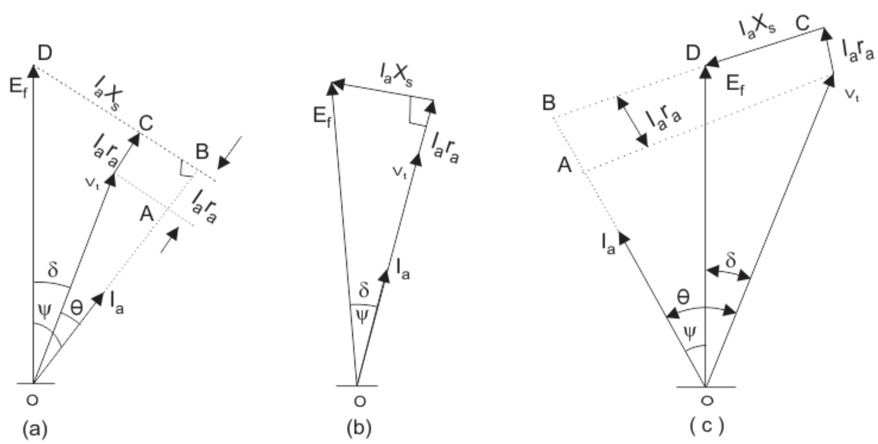


Figure 3. Representation of voltage vectors and angles.:

$$V_d = V_{RMS} * \sin(\delta) = 20kV * \sin(105.4743) = 13012kV$$

$$V_q = V_{RMS} * \cos(\delta) = 20kV * \cos(105.4743) = 15189kV$$

Form the following equations:

$$V_d * I_d + V_q * I_q = P$$

$$V_q * I_d - V_d * I_q = Q$$

We obtain:

$$I_d = -16959.3056\ A$$

$$I_q = -7398.2228\ A$$

Also, we have:

$$I_f = \frac{V_q - R_s * I_q - w_s * L_d * I_d}{w_s * L_m} = 25102\ A$$

$$V_f = I_f * R_f = 24.7254\ V$$

The linkage flux can be obtained by:

$$\varphi_d = L_d * I_d + L_m * I_f = 48.3846\ Wb$$

$$\varphi_q = L_q * I_q = -41.5042\ Wb$$

$$\varphi_f = L_m * I_d + L_f * I_f = 72.4918\ Wb$$

The torque delivered by the generator is:

$$T_e = \varphi_q * I_d - \varphi_d * I_q = 1.0617 MNm$$

The following table resumes all the values obtained.

Variable	**Value**
I_{phase}	18500 A
w_m	314.16 $\frac{rad}{sec}$ = 3000rpm
φ	25.8419º
δ	40.5859º

V_d	13012 kV
V_q	15189 kV
I_d	-16959.3056 A
I_q	-7398.2228 A
I_f	25102 A
V_f	247254 V
φ_f	72.4918 Wb
φ_d	48.3846 Wb
φ_q	-41.5042 Wb
T_e	1.0617 MNm

Part c): Torque steps response

Torque step of 20%

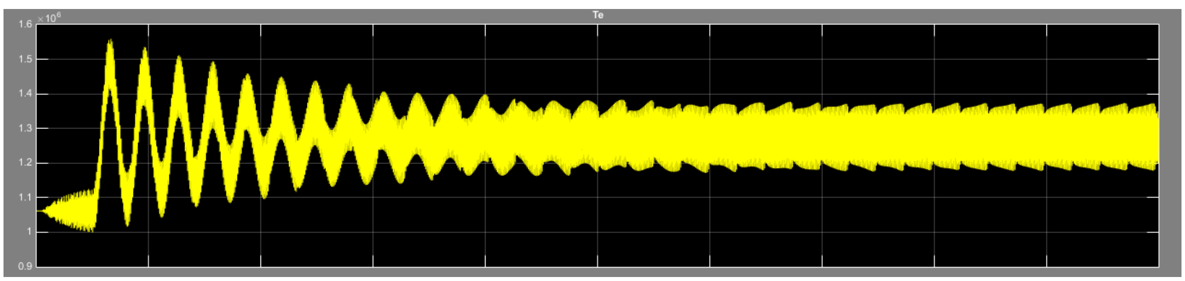


Figure 3. Generator speed when a torque step of 20% occurs.

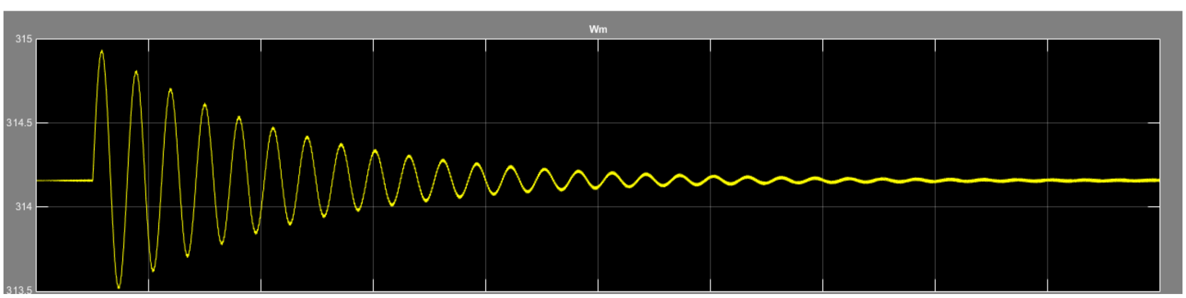


Figure 4. Generator speed when a torque step of 20% occurs.

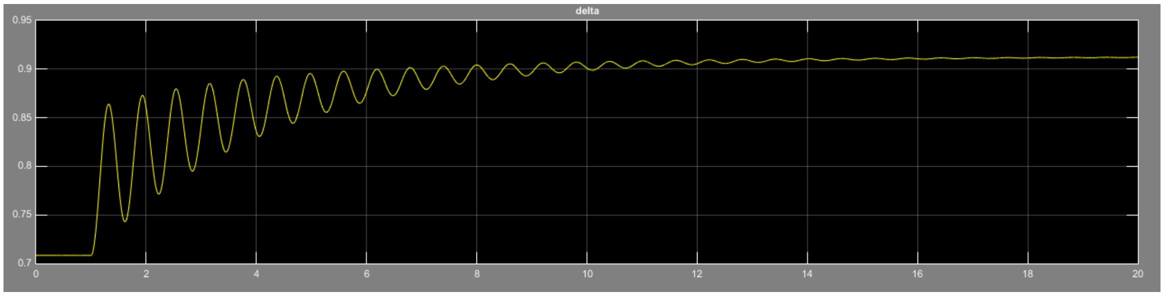


Figure 5. Load angle when a torque step of 20% occurs.

The machine speed increases and so the electric torque (due to the step). The system remains stable.

- Torque step of 70%

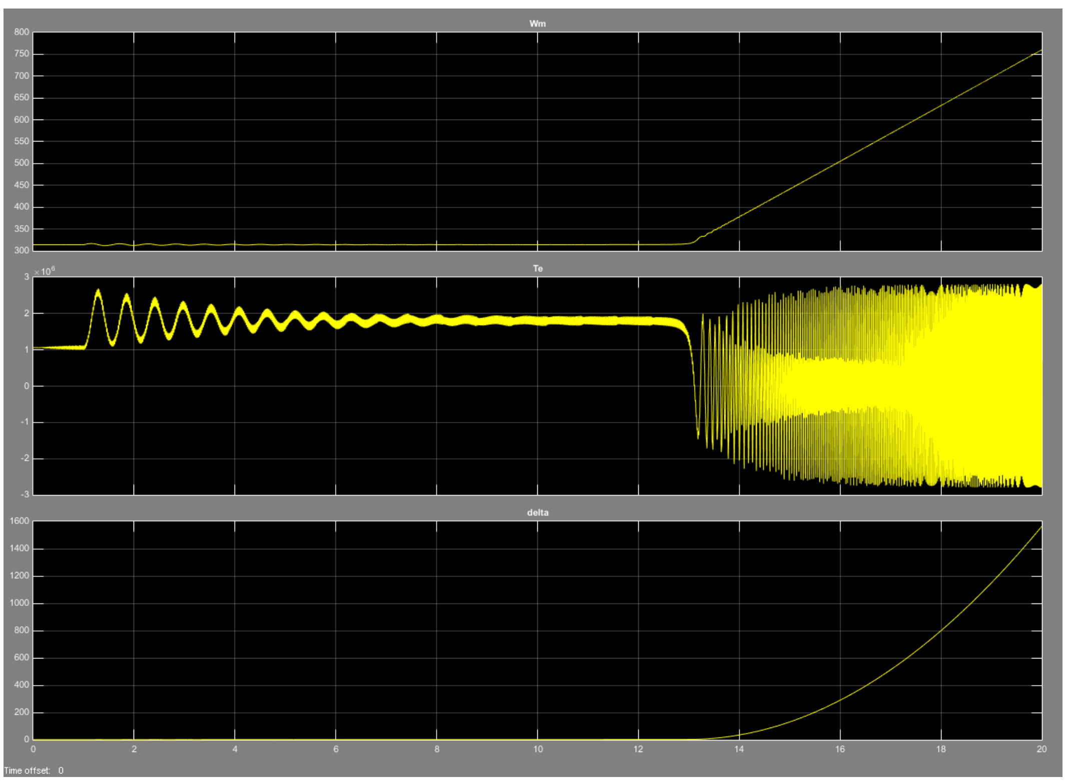


Figure 6. Generator speed, electrical torque and load angle when a torque step of 70% occurs.

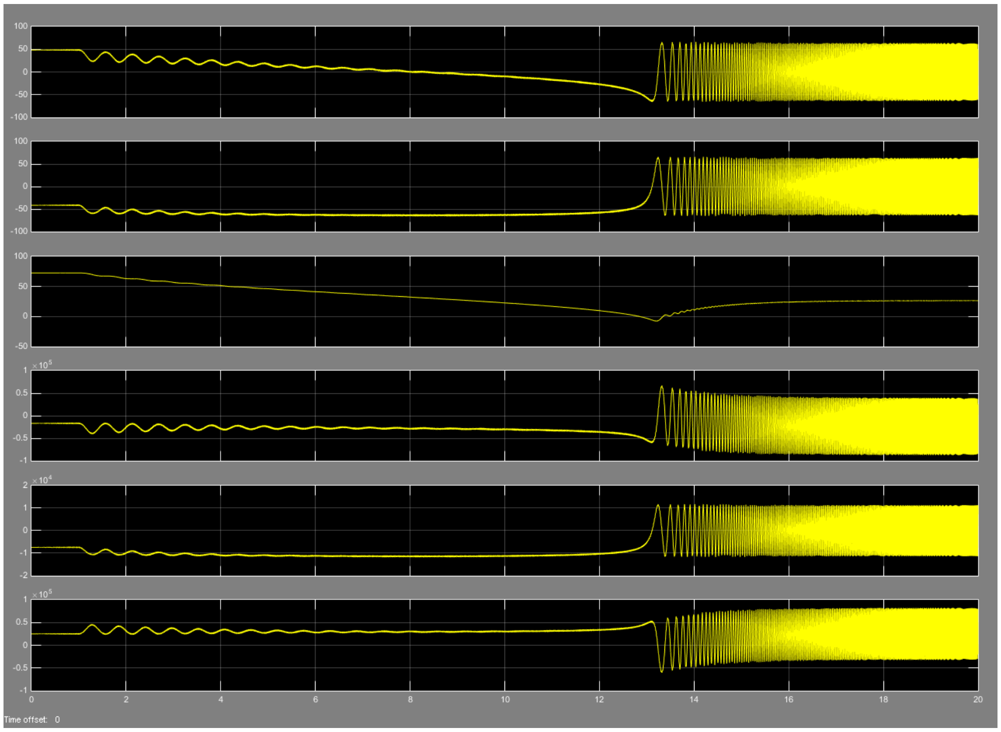
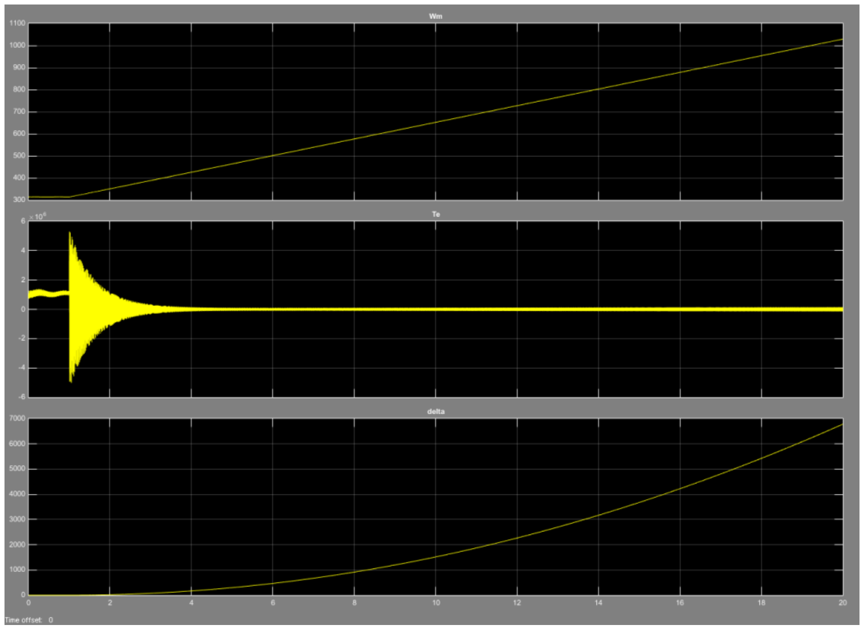


Figure 7. Phase currents when a torque step of 70% occurs.

As seem in Figure 6 and 7, the system becomes unstable. The machine keeps accelerating infinitely and it is not able to maintain the generation-load balance ($T_m \neq T_e$). In Figure 6 it is shown that the speed increases indifenitely..

Part d) Three-phase fault at generator terminals (symmetrical fault)

A three-phase fault is simulated at the terminals of the machine. This is done setting the voltage values to zero.



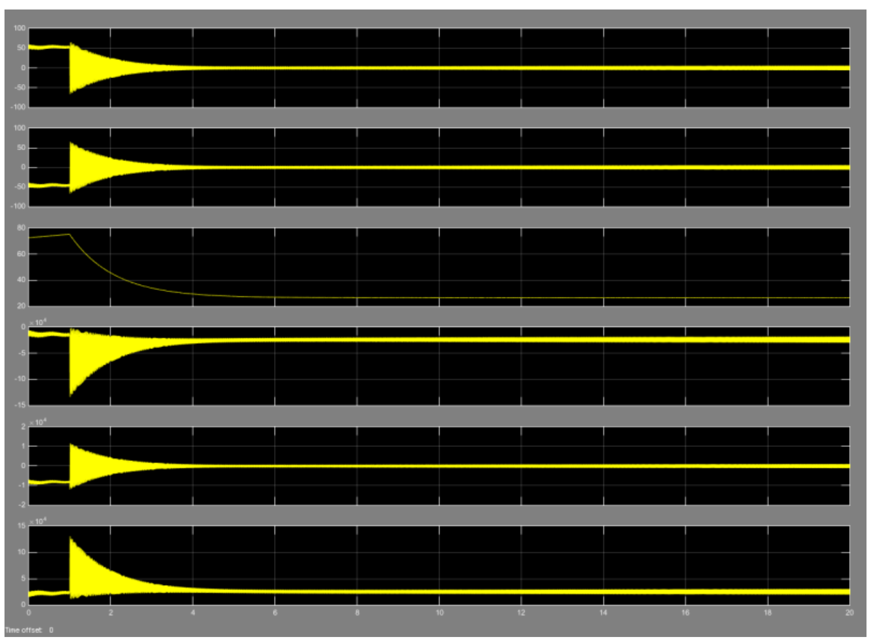


Figure 8. Mechanical variables (w_m, T_e, δ) , flux linkages and rotor and stator currents.

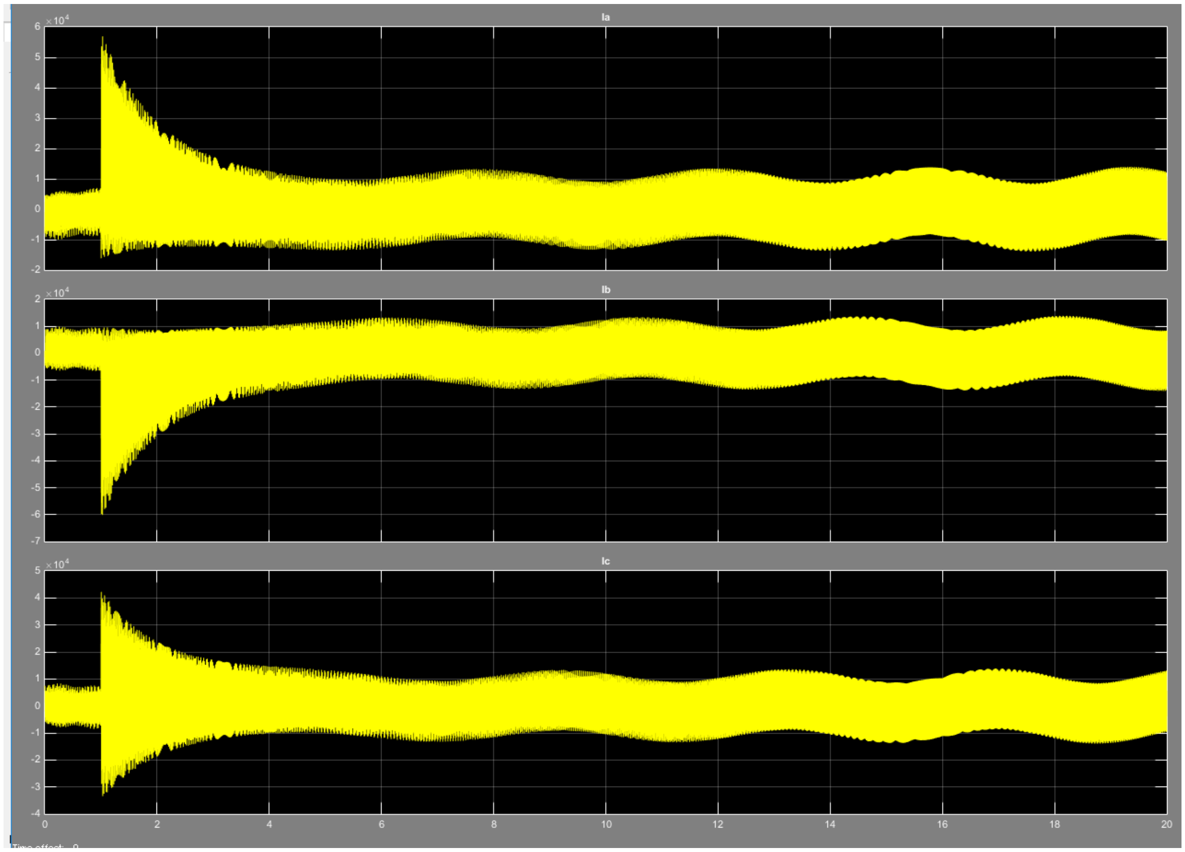


Figure 9. Phase currents under a three-phase fault.

CONCLUSION

In this paper, a synchronous generator was modeled in Simulink using the fifth order differential equations model, referred to the rotor axis. Step responses and three-phase faults were also simulated to study the response of the synchronous generator under these conditions.

The machine studied in this report is a 20kV, 370MVA machine connected to an infinite bus, feeding a load of the same rate apparent power, at a power factor of 0.9. The generator is able to maintain its stability under a 20% step-up torque, but when the 70% step-up torque occurs, the machine loses stability because is unable to maintain the generation-load balance.

The three-phase fault simulated in this report is a fixed fault. This means that the fault is never cleared so the generator will be accelerated infinitely. In a real case, the faults are cleared after some cycles so the generators are able to return to its initial speed. However, if a fault is not cleared at time, the generator will lose stability and begins to accelerate indefinitely, until the protections act and disconnect it from the system.