Synchronous Machine Study 1

Methods of Initializing a Synchronous Machine

Motivation:

The objective of this application note is to familiarize the user with the synchronous machine model in PSCAD and demonstrate various methods of initializing the synchronous machine to reach a specific load flow steady state condition.

System Overview:

In order to investigate the effect of various phenomena such as faults etc in the system; it is crucial that the system is initialized properly and is under proper steady state load flow conditions.

In PSCAD the recommended method of initializing the machine is to start it as a fixed voltage source and use this mode of operation to determine exciter and governor input (or field voltage and mechanical torque) parameters needed to produce the desired steady state load flow condition.

Note: The synchronous machine model in PSCAD provides users with the option of running it as pure source. The model also provides the option of running it at a fixed speed of 1 PU (with the mechanical dynamics disabled).

Illustration # 1 – Machine model without controllers (exciter/governor)

Figure 1**Error! Reference source not found.** shows a very simple case to illustrate the load flow initialization of the network when a machine model is used in the simulation. For simplicity, machine controls such as exciters and governors are not included in this model.

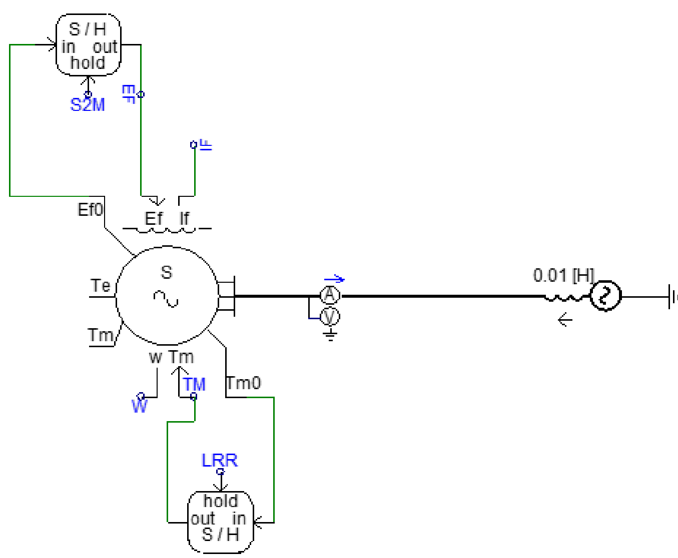

Figure 1: PSCAD model to study the initialization of synchronous machine (PSCAD case SM_study_01_A.pscx)

At time t = 0, machine is run as a pure source with its terminal voltage magnitude and phase specified by the user. To operate the machine as a pure source set the initial condition option in the parameter to 'none', as shown in Figure 2. By doing so the user can specify the terminal voltage conditions alone and properly initialize the machine and the network to a specific load flow.

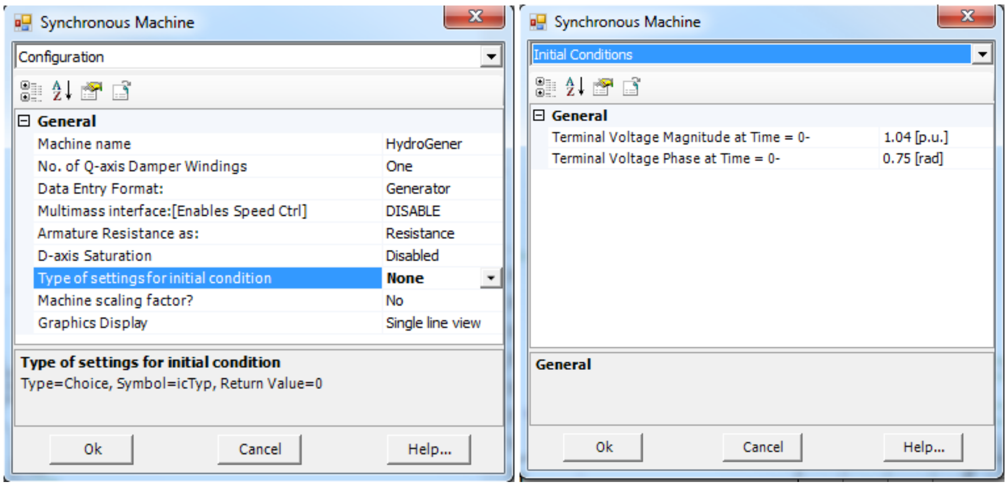

Figure 2: Initial condition option available in PSCAD

The variable initialization control (S2M) specifies the time at which the model transitions from source to a normal machine with all its electrical equations 'active'. To ensure that the machine is operating as a pure source, the 'variable initialization control (S2M) has to be set to '0' until the required steady state condition is attained. In this example, the signal 'S2M' is set to change its state from 0 to 1 at time t=2 s (Figure 3). At the instant the signal S2M switches from 0 to 1, the model acts as a normal synchronous machine but with the machine speed fixed at 1 PU. The output signal 'Ef0' is the 'initialized' field voltage of the machine that would be necessary to hold the machine's steady state operation. At the instant 'S2M' changes state, the value of 'Ef0' is sampled and is provided as a constant field voltage input to the machine's field winding.

If necessary, the user may run the simulation for a further duration at constant speed, allowing small transients that may occur at S2M transition to decay before 'releasing ' the rotor mechanical dynamics. In this example, the rotor dynamics are 'unlocked' at t=2.5 s where the signal LRR transitions from 0 to 1. The output signal 'Tm0' is the 'initialized' mechanical torque that would be necessary to hold the machine's steady state operation. At the instant LRR changes state, the value of 'Tm0' is sampled and is provided as a constant input to the machine's mechanical input field 'Tm'.

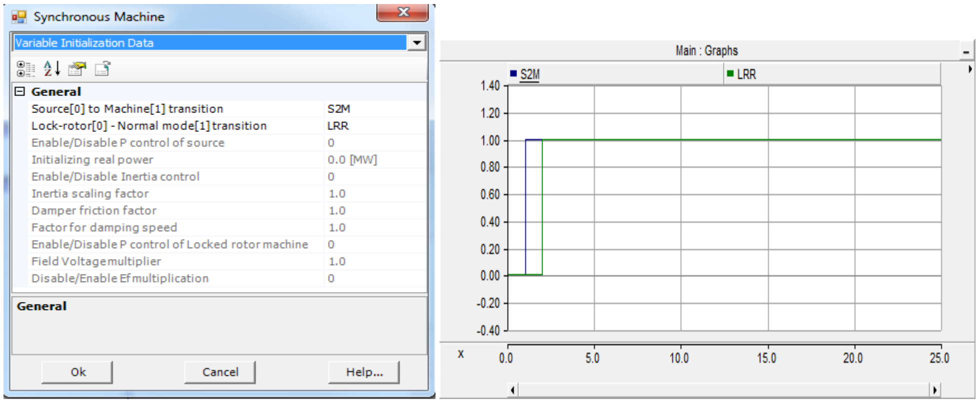

Figure 3: Switching from source mode to machine mode and enabling the rotor dynamics

Simulation Results

Figure 4 shows the variation of the machine parameters when it is switched from source to machine mode at t= 2sec and also when the rotor is released at t=2.5sec.

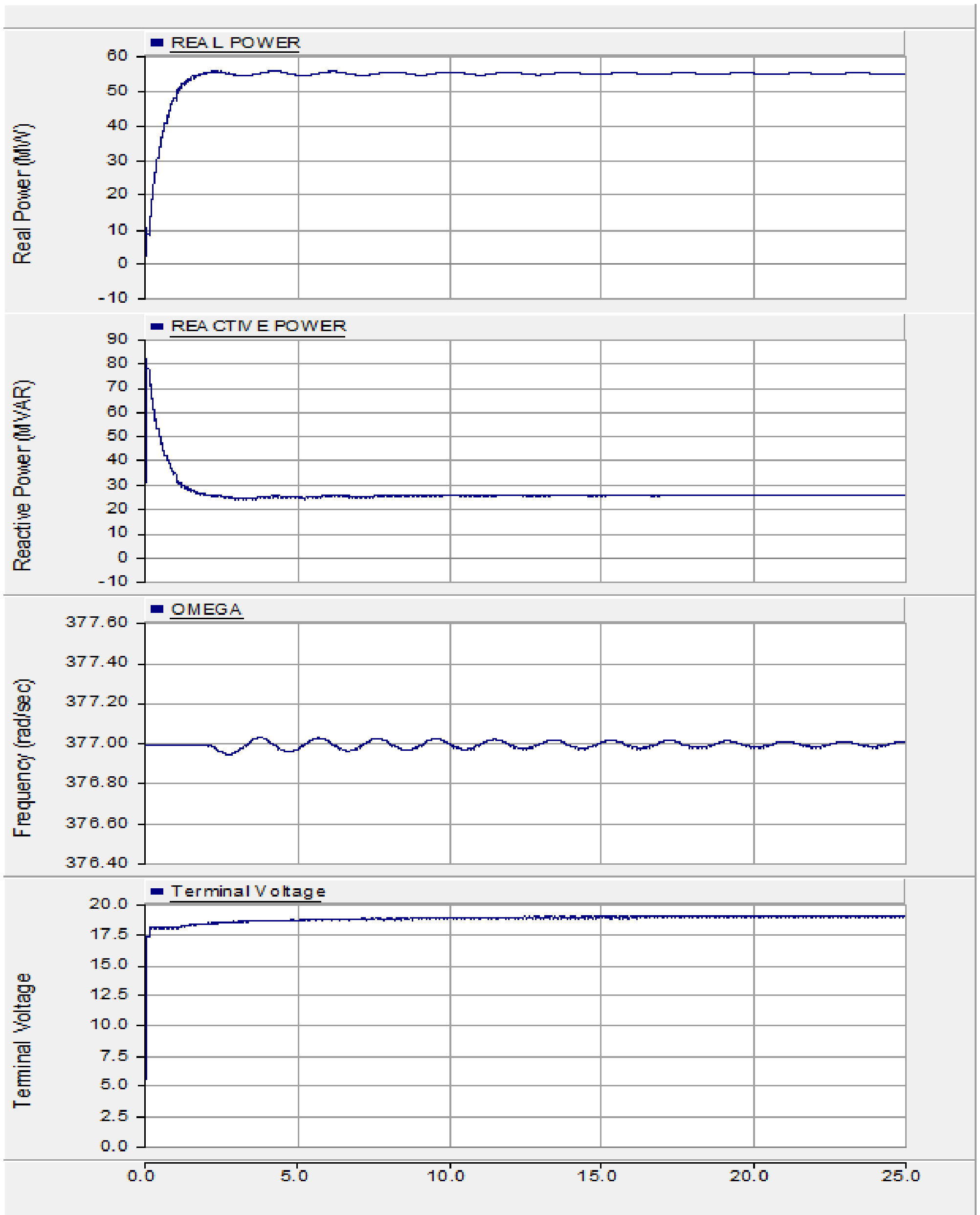

Figure 4: Simulation results

Illustration # 2 – Machine model with exciter, governor and turbine models in the simulation.

For a more realistic simulation, the exciters and governors and turbine models should be included in the simulation. Figure 5 shows the PSCAD model of synchronous machine with the exciter model in place.

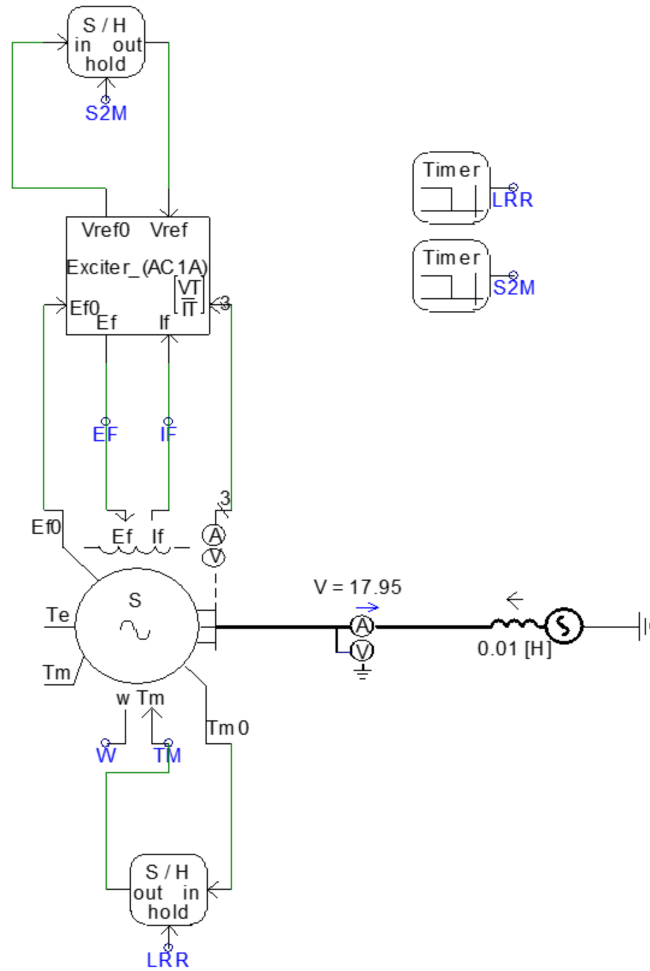

Figure 5: PSCAD model to demonstrate initialization with exciter

As explained in the previous case, set the initial terminal voltage magnitude and phase of the synchronous machine and operate it as a pure source. The terminal voltage magnitude and phase, set with respect to a 'reference bus' (equivalent voltage source) ensures the desired active and reactive power flow.

The exciter is initialized at the time instant when S2M changes state. This can be ensured by setting the output controller initialization variable (InitEx) (defined in the machine model) as shown in Figure 6. The same signal name is used inside the exciter model to define the instant that it should initialize its internal parameters and output the desired field voltage (Ef) value as given by Ef0.

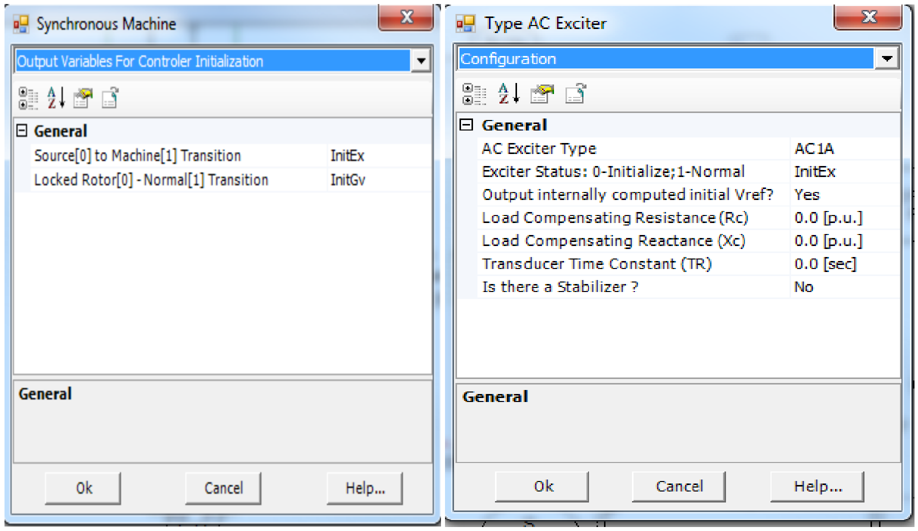

Figure 6: Controller initialization variable

Figure 7 shows the control signals to the synchronous machine and the exciter.

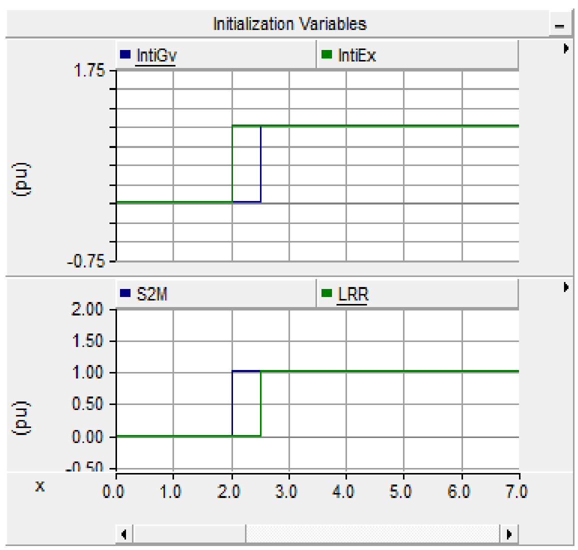

Figure 7: Control signals.

Note that, in addition to the desired output field voltage to the machine (Ef0), the field current (If) and the terminal voltage and current (VT/IT) are provided as inputs to the exciter model. PSCAD then calculates the initialized value of the reference voltage 'Vref0' need to maintain the steady state operating condition. Vref0 is the 'initialized' voltage set point to maintain the specified steady state terminal conditions. Once the system enters steady state, a sample and hold component can be used to hold this steady state reference voltage and feed the signal back to the exciter through input 'Vref'.

Note 1: During initialization the machine is operated as pure source.

Note 2: If the user needs to change the voltage reference point during the simulation, this can be achieved through an external (variable) input which is given a zero value initially, Figure 8.

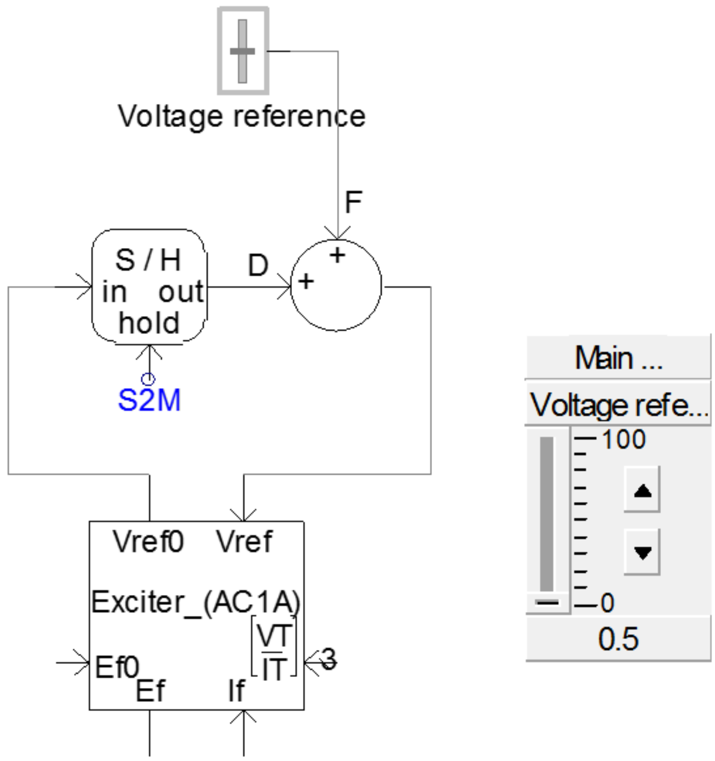

Figure 8: option for variable reference control

Governor and turbine initialization

After the initial transients have settled the machine mode was activated by switching S2M from 0 to 1. At this instant the rotor will be spinning at a constant speed as the machine is still in 'locked rotor' state. The governors and turbines can be initialized at the time instant when the rotor is unlocked i.e. when the signal LRR is switched to 1. Once this happens the mechanical dynamics, as defined by equation (1) is active.

$$T_m - T_e = J\frac{d\omega_m}{dt} + B\omega_m \qquad (1)$$

The simulation model with a governor/turbine model is shown in Figure 9. These models are 'initialized' in a manner similar to that used to initialize the exciter. Signal 'InitGv' (Figure 6) is the control signal used to activate the initialization of the governor

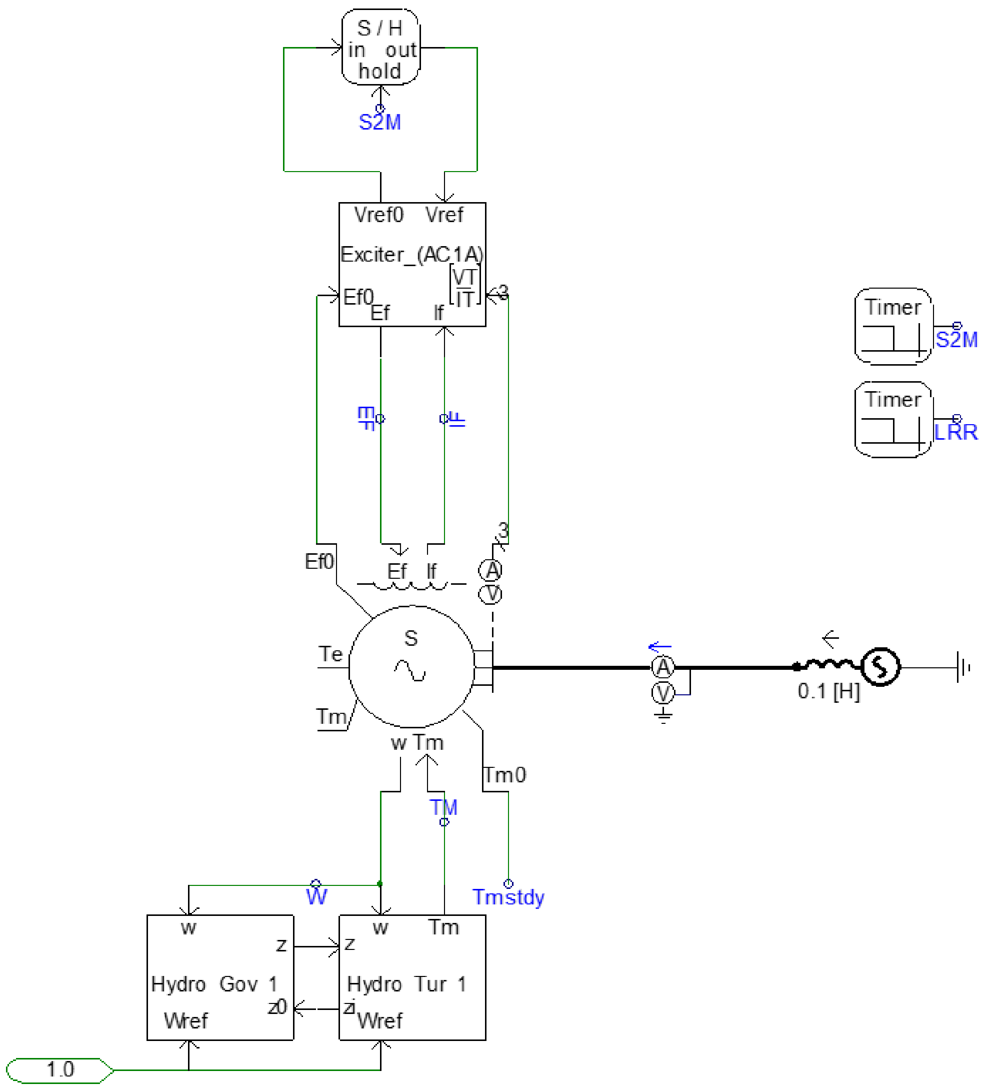

Figure 9: PSCAD model for synchronous machines with exciter, governor and turbines (PSCAD case SM_study_01_B.pscx)

Simulation results

The variation of the various machine parameters when it is switched from source to machine mode at t= 2sec and also when the rotor dynamics are activated at t=2.5sec in shown in Figure 10.

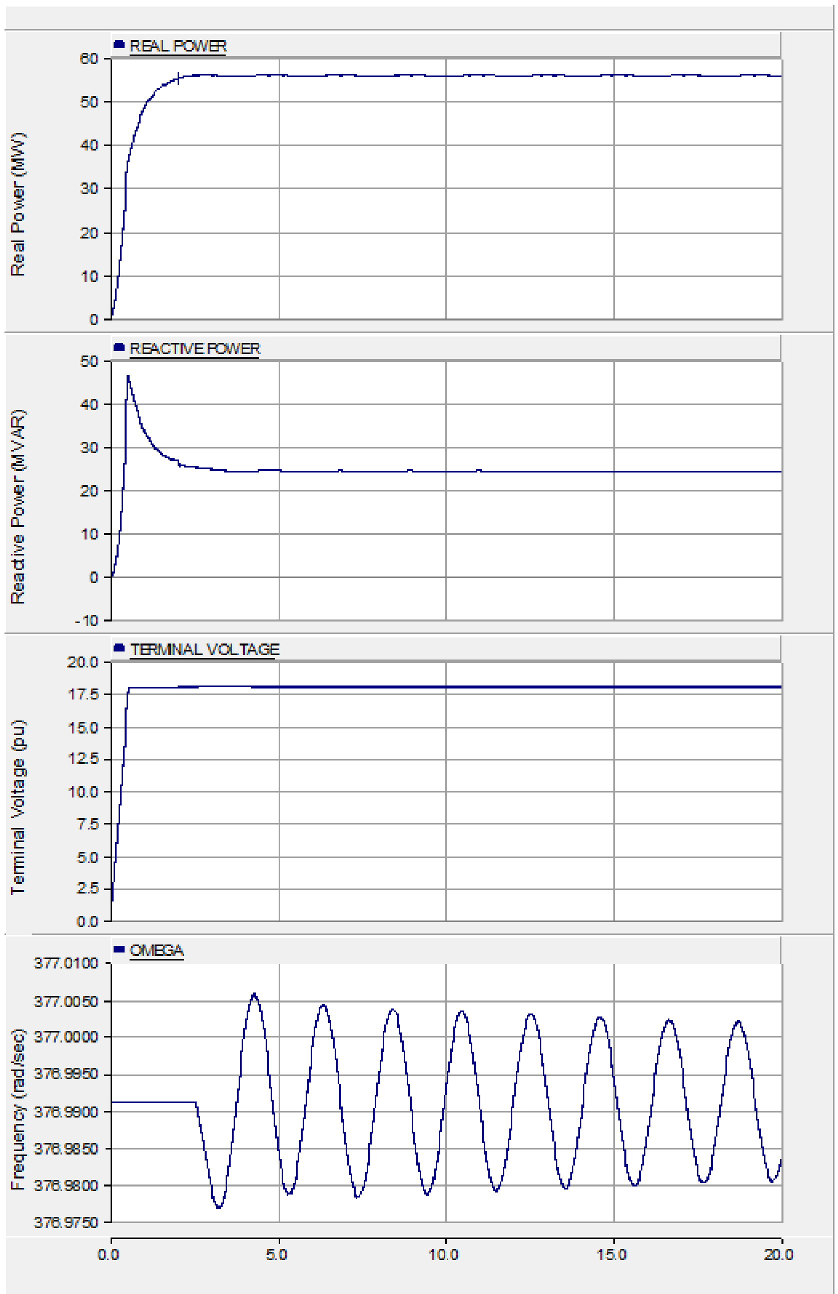

Figure 10: Simulation results using governor and exciter

At the point in time when the machines are running free and the excitation and governor systems are stable, a 'snapshot' can be taken. Faults and disturbances can be applied to the system with the start-up commencing from the 'snapshot file'.

PSCAD:

Refer to PSCAD case: SM_study_01_A.pscx and SM_study_01_B.pscx