Synchronous Machines Study 3

A Short Circuit Test on the Machine Model

Motivation:

This example demonstrates the classical short circuit test of a synchronous machine. The associated discussion of the simulation results serves as a validation of the PSCAD model.

System Overview:

The circuit diagram of this example is shown in Figure 1.

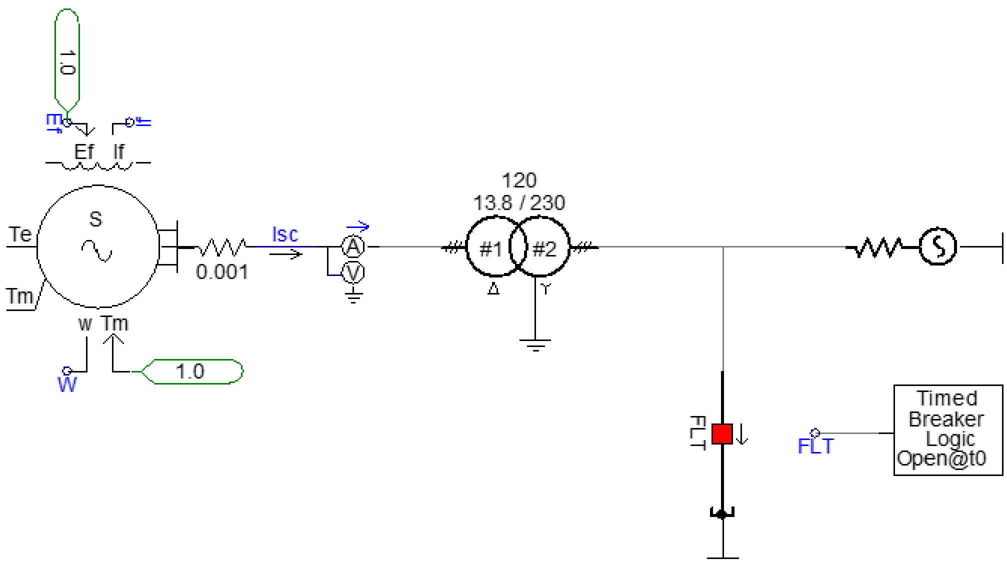

Figure 1: Short Circuit Test Set Up

To conduct the SC test, the machine has to be running in steady state in open circuit conditions. This is achieved by adjusting the phase angle and magnitude of the machine voltage with respect to the source voltage so that the current in the machine is zero (negligible) in steady state.

Voltage magnitude and phase of the infinite source is 230.0 kV and 0.0 degree, respectively. Same quantities for the machine are 13.8 kV and –31.08 degrees (includes phase shift by transformer and interface, Δt=50µs). Field voltage necessary to produce 1.0 PU terminal voltage on the open circuited machine is 1.0 PU. These initial conditions give open circuit condition for the machine.

The machine is run at constant speed by locking the rotor (Enab = 0) at synchronous speed. Thus, there are no prime mover dynamics involved. The exciter dynamics are also eliminated by feeding a constant voltage (E_f=1.0 PU) to the exciter. Machine saturation is disabled. The ideal transformer is simply a ratio changer with negligible leakage (0.005 PU) reactance and no saturation. These simplifications allow us to focus on the machine dynamics better.

The relevant section of the machine parameters is shown in Figure 2.

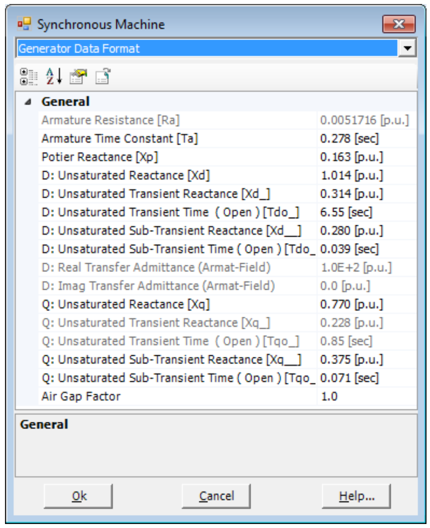

Figure 2: The 13.8 kV. 120 MVA Generator Parameters

A short circuit is applied at 0.5056 seconds (time 0.5056 seconds is chosen just for convenience so that the Phase A current does not have a DC component during the SC test).

Analysis and Simulation Results:

Let us validate the model by comparing the theoretical time constants for the given machine parameters with the time constants demonstrated by the simulation graphs. For details refer to [1].

Sub Transient time constant

The sub transient component of short circuit current should decay with the sub transient (or damper) time constant (Td”) given by the following equation,

$$Td'' = \left(\frac{Xd\_\_}{Xd\_}\right) \cdot Tdo\_\_ = \left(\frac{0.280}{0.314}\right) \cdot 0.039 = 34.7\ ms \qquad (1)$$

Thus, the sub transient effects will be seen for only about two cycles.

Transient time constant

The transient component should decay with the transient time constant (Td’)

$$Td' = \left(\frac{Xd\_}{Xd}\right) \cdot Tdo\_ = \left(\frac{0.314}{1.014}\right) \cdot 6.55 = 2.03\, s \qquad (2)$$

The subtransient and transient time constants can be seen from the expanded view of the Phase A fault current in Figure 4 below.

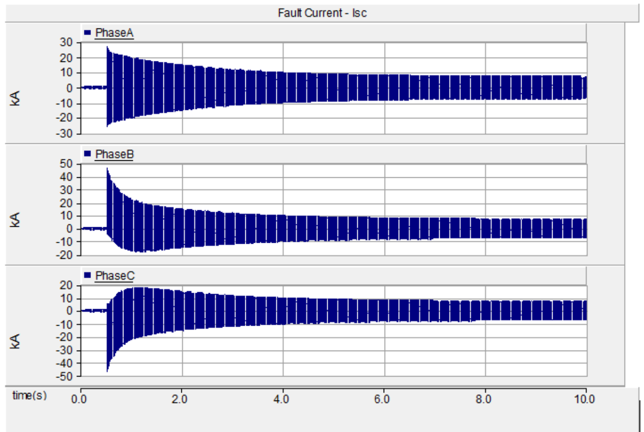

Figure 3: Fault Current (Isc)

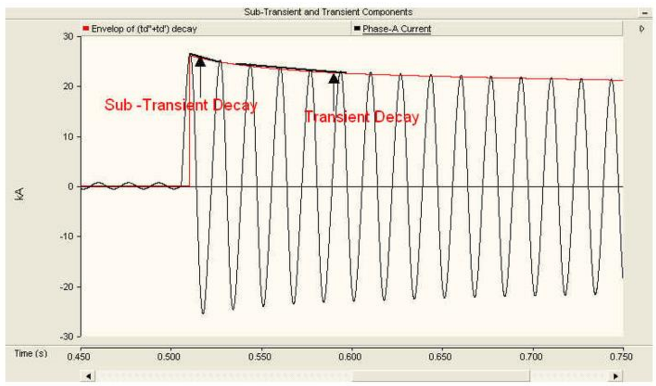

Figure 4: Decay of sub-transient and transient components of the Phase A fault current

Field current decay time constant

The time constant of the field current to decay to its pre–fault value is also Td” (if a constant field voltage, as we have applied in this case). This can be verified from the field current plot in Figure 5.

After the sub–transient effects have disappeared, but the transient component is still present, the magnitude of the field current is given by,

$$I'_{fo} = \left(\frac{Xd}{Xd\_}\right) \cdot I_{fo} = \left(\frac{1.014}{0.314}\right) \cdot 1 = 3.23\,PU \qquad (3)$$

The initial DC component of field current is approximately the midpoint of the first cycle which is about 3.2 PU as shown in Figure 5 and agrees with the above calculation. With a fixed field voltage, the field current will return to its pre–fault value in steady state. The decay of the field current during the transient period is given by,

$$I_f^{'} = I_{fo} + \left(I_{fo}^{'} - I_{fo}\right)\cdot e^{-t/T_d^{'}} = 1 + \left(3.23 - 1\right)\cdot e^{-t/T_d^{'}} \qquad (4)$$

Thus, after a time period equal to Td’, the field current will decay to around 37% of its initial value.

$$I_{f-Td'}^{'} = 1 + \left(3.23 - 1\right)\cdot 0.37 = 1.825\,PU$$

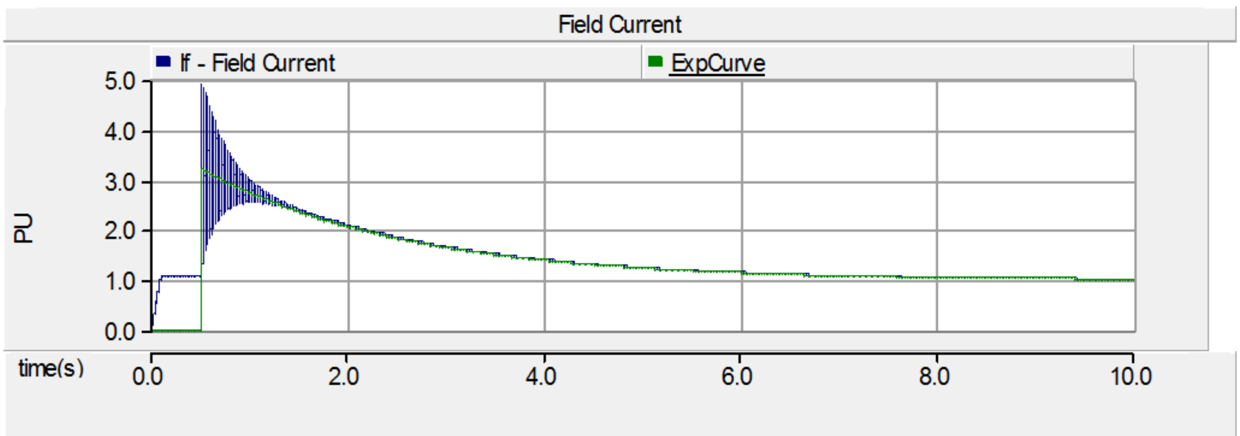

Figure 5: Field Current Response

From Figure 5, it can be seen that I_f reached approximately 1.825 PU after about 2.0 seconds from the fault inception. This agrees with the theoretical calculation of Td’. An exponential curve (ExpCurve) with a time constant of 2.03 seconds is superimposed on I_f to show that I_f indeed decays with this time constant. If SC is not ideal, but has a resistance (the fault resistance in our case can be considered negligible), this time constant could further be reduced.

Moreover, the transient and sub–transient components of current are only different by about 12% as shown below,

$$\frac{I_a^{''}}{I_a^{'}} = \left(\frac{Xd\_}{Xd\_\_}\right) = \left(\frac{0.314}{0.280}\right) = 1.12$$

With the fast decay rate of I_a”, this difference is difficult to observe. Hence, from Figure 4 it can be noticed that the sub–transient and transient currents are almost of the same magnitude (I_a" = 25.35 kA and I_a'= 22.6 kA).

Another calculation that can be verified is the ratio of the sub–transient component I_a'' to the steady state fault current I_a. Note that with constant field excitation, we have,

$$\frac{I_a''}{I_a} = \left(\frac{Xd}{Xd\_\_}\right) = \left(\frac{1.014}{0.280}\right) = 3.6$$

From the top plot of Figure 3 (Phase A fault current), we obtain a ratio value of 3.57 (= 25.0/7.0), which is close to the value calculated using the above equation.

The steady state I_a of 7.0 kA also exactly matches the calculated value as seen in Figure 6.

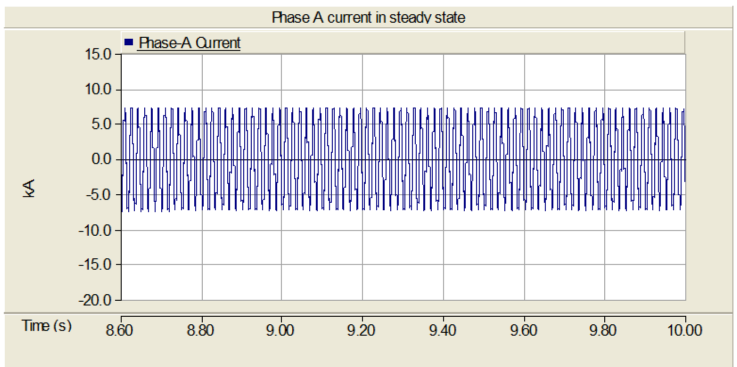

Figure 6: Steady State Fault Current

The armature time constant, Ta (0.278 s), is the decay time constant of the fundamental frequency component of I_f (on the stator side this is the time constant at which the DC component and the second harmonic component of stator current decay). This time constant is estimated in Figure 7. The initial peak–to–peak magnitude of the 60 Hz component after sub–transient influence disappeared is about 3.0 PU. The 60 Hz component reached 37% of this value (1.1 PU) in about 0.270 seconds. This value closely agrees with the given value for parameter Ta.

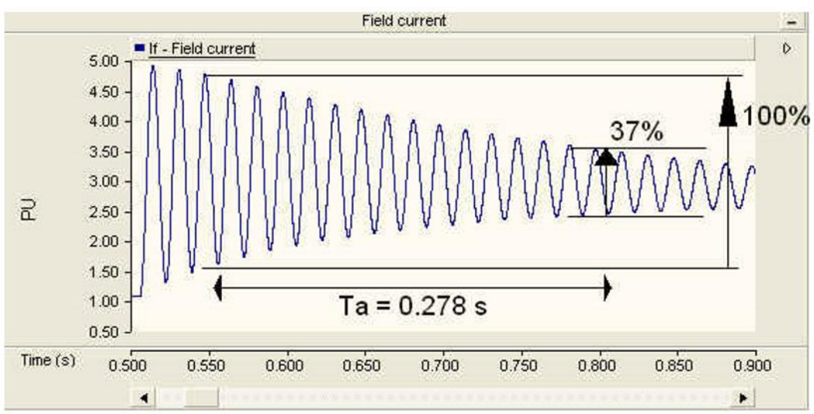

Figure 7: Decay of the fundamental frequency component in the field current

Discussion:

- The theoretical results and the simulation results are very close. Therefore, the model of the synchronous machine is accurately represented in PSCAD.

PSCAD:

Refer to PSACD case: SM_study_03.pscx

References:

[1] C.V. Jones, *The Unified Theory of Electrical Machines*, Plenum Press, N.Y., 1967, Chapter 20

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