
Develop a coupled-circuit phase-domain model of a 500-hp Induction Machine (book p. 244) in Simulink. You can use Matlab functions to implement the derivative function and output function, respectively, and integrator block from Simulink. Use a Matlab script file to store and load model parameters, as needed. The mechanical subsystem you can implement directly in Simulink. Implement a balanced 3-phase sinusoidal Voltage Source (VS) in Simulink with variable amplitude to supply the IM with the rated (nominal) voltages. Also, develop a qd-model of the same induction machine in Arbitrary Reference Frame using the conventional Simulink blocks, such that you can change the speed \( \omega \). Determine the eigenvalues of the coupled-circuit model and qd-model. Make your comments/conclusions whether the eigenvalues are the same or not, and whether the system is stiff or not.

1) Using both coupled-circuit and qd models, assume a short-circuited “squirrel-cage” rotor and synchronous reference frame \( \omega = \omega_c = \omega_h \). Implement a start-up transient assuming zero initial conditions and no mechanical load. Run the model up to 8 sec (to reach a steady state). Choose and state a variable-step ODE solver, tolerances, and step-size limits that you think are appropriate for your model. Plot variables: \( i_{as}, T_e, \omega_{rm} \), and time step \( h \), (all on one page using the subplot command). Compare the results and numerical efficiency of each model (e.g. #of steps and CPU time that it took). Explain your observations and conclusions.

2) For all subsequent studies, use your qd-model in Simulink. Implement the same start-up as in step 1). Use different speed for the reference frame: (a) Stationary Reference Frame \( \omega = 0 \); (b) Rotor Reference Frame \( \omega = \omega_r \); and (c) Synchronous Reference Frame \( \omega = \omega_e = \omega_h \). In each case, plot variables: \( v_{qds}, i_{qds}, i_{qdr}, i_{as}, \Psi_m \), and time step \( h \), (all on one page using the subplot command). Make observation about the frequency of currents, voltages, and flux as viewed in different frame of reference. Which reference frame resulted in the most numerically efficient solution in terms of the number of integration time steps?

3) Implement the following study: Start the model with the initial condition corresponding to the steady state at no load. Then, at \( t = 0.1 \text{sec.} \), a constant mechanical load of \( T_m = 1980 \text{N}\cdot\text{m} \) is applied. At \( t = 0.6 \text{sec.} \), the mechanical torque is reversed to \( T_m = -1980 \text{N}\cdot\text{m} \) and the model is continue to run till \( t = 1.2 \text{sec.} \). Plot variables: \( i_{as}, T_e, \omega_{rm}, \) slip frequency \( \omega_s \), as well as input real and reactive powers \( P_e \) and \( Q_e \) (book p. 118); and mechanical output power \( P_m \). Describe the results and the flow of real and reactive power.

4) Implement study in 3) using the model from Simscape Electric, verify your results, compare simulation speeds.

5) Use your own Simulink model, incorporate magnetic saturation using a method of your choice. Use Synchronous Reference Frame. Start model supplying the motor with 70% of the rated voltage. Then, at \( t = 3.5 \text{sec.} \), step up the voltage to 105% of the rated value and continue to run the model till \( t = 5 \text{sec.} \). Plot \( i_{as}, T_e, \omega_{rm}, \) and \( \omega_s \) for the same study with and without saturation. On the same plot, compare variables \( i_{qs} \) (with and without saturation) and \( i_{ds} \) (with and without saturation) for this study on the time interval from 3.45 to 3.65 sec. Compare the stator current \( i_{as} \) on the same time window with/without saturation. Make observations about the effect of saturation. Explain how does saturation affect the MMF wave (see Chap. 2.5) and its shape according to your model vs. the actual machine? Are the ac currents distorted due to saturation similar to what you saw in transformer? Explain why.

6) Assume that you have a wound-rotor machine and can insert variable resistors \( \Delta r_r \) into the rotor circuit. You know that it is possible to change the steady state torque-speed characteristic by adjusting the rotor resistance (see eq. 6.9-19 and Fig. 6.9-3). a) Determine the additional rotor resistance as a function of speed \( \Delta r_r(\omega_r) \) such that the motor can accelerate using maximum torque. Plot the resulting steady state torque-speed characteristic and compare/superimpose it with the original one. b) Repeat the start-up transient study of step 1) and compare/superimpose the results. Plot and compare stator current \( i_{as} \), speed \( \omega_{rm} \), instantaneous real power \( P_e \), and total energy spent during the entire transient \( \Delta E_{\text{start-up}} \). c) Assume that a motor like this can be realized using a double-cage rotor, NEMA class C. Sketch the corresponding qd equivalent circuit and explain how your model would be changed. Can you calculate the equivalent rotor parameters of this machine assuming two rotor windings?