

ELEC-E8407

Electromechanics

Assignment:

Induction Machine Equivalent Circuit

1. Background

The equivalent circuit of an induction machine is an excellent model to investigate the performances of the machine under steady-state. The model can also be used to optimize the parameters of the machine for some given specification before making the preliminary design, e.g. the starting torque, the pull-out torque and the no-load current, among others. For these purposes, the equivalent circuit should be solved for a huge number of operation points and with several values of its parameters. Such a task obviously requires a systematic way of parametrizing and solving the circuit equation as well as plotting the required quantities

In this assignment, we will use MATLAB as a platform and implement the equivalent circuit equation of an induction machine. We will plot the performance characteristic of the machine and investigate the effect of some parameters on these performances. We will also discuss how the simulations agree with the theoretical consideration and approximations from the course lectures. The learning outcome of this assignment are the same as for the lectures on electrical machines. Furthermore, by doing this assignment, the students will familiarize with MATLAB, and learn how to put the theories they learnt in practice and how to analyse the results of the simulations.

After the implementation and simulations, the students are required to draft a report with the required plots and discussion. The implemented MATLAB code should be in report also as an appendix.

2. Machine data

The machine under study is a cage induction machine that has been designed for general industrial purpose. The equivalent circuit of the machine is shown in Fig. 1 and the corresponding parameters are given in Table I. Note that all the parameters are already referred to the stator side. This means that the turn ratio a in Fig. 1 is not needed at any steps of the assignment.

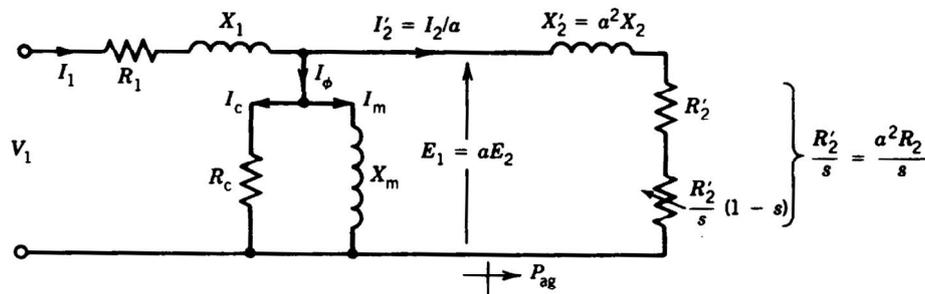


Figure 1. Equivalent circuit of the cage induction machine under study.

Table I: Parameters of the equivalent circuit of Fig.1

Quantity	Symbol	Value	Unit	Comment
number of phases	m	3		needed to compute total powers from equivalent circuit
number of poles-pairs	P	2		needed to calculate the speed. Not to confuse with the number of poles p !
Line-to-Line voltage	$V1$	380	V	use the phase voltage for the equivalent circuit, assuming star connection
Supply frequency	f	50	Hz	needed to calculate the synchronous speed
Stator resistance	$R1$	0.9466	Ω	per phase
Stator leakage reactance	$X1$	3.3929	Ω	per phase
Magnetizing reactance	Xm	73.6067	Ω	referred to the stator side

Core loss resistance	R _c	1357.2	Ω	referred to the stator side
Rotor resistance	R _{2_p}	0.8000	Ω	referred to the stator side
Rotor leakage reactance	X _{2_p}	1.6336	Ω	referred to the stator side
Slip	s	0 .. 1		used as a variable

3. Tasks

The task of the assignment is to implement the equivalent circuit equations of the machine in a MATLAB script and investigate the performances of the machine based on the equivalent circuit model, as well as the effect of the voltage, the rotor resistance and the stator and rotor reactance on these performances. The quantities to monitor are the torque-speed characteristic, the stator current, the power factor, and the motor efficiency under different slips. For this purpose, you need to follow the next steps (if you are very familiar with MATLAB, you can do otherwise provided you present the same results).

Implementation steps

1. Open MATLAB and start a new script, call it "IM.m", the final script should be attached to the assignment report as an appendix.
2. Start the script with the command "clear all" and enter the needed parameters (m=3; p=2; etc.).
3. Write your equation for the stator impedance and the impedance of the magnetizing branch as function of the main parameters.
4. Define an array for the speed ($n=f/P*[0:0.1:60]$;). You can do this in a different way if you like, e.g. in a for-loop.
5. Write the equations for the slip, the rotor impedance, and the total impedance as function of the previously defined quantities. Note that in MATLAB you need to use element-wise operation when you are dealing with arrays (.*, ./, .^, e.g. a=b.*c./d;)
6. Write similarly the equations for the stator current, the induced voltage E₁, and the rotor current (phasors)
7. Write the equation for the output power as function of the rotor current, the rotor resistance and the slip
8. Write the equations for the stator copper loss, the rotor copper loss, and the iron losses
9. Write the equations for the power factor, the efficiency, and the torque

Note that all the above equations are functions of the rotational speed. Now you can plot the performances of the motor from the computed equations. Before that run the scrip and correct any mistake. Since the slip goes to zero at some operation point and you need to divide by the slip in some equations, MATLAB might see this as an error or it assigns a value of "NaN" to the variable. In that case you restrict your slip some small positive value (e.g. 1e-10).

Plotting

Once the script runs without errors or warnings, plot the following quantities, each in its own figure. In MATLAB you can write the plotting commands in your script too and you can number the figures where you plot each data separately, e.g. (figure(1); plot(x,y, '-r', 'LineWidth', 1.5);). You can also keep the plot in the figure while plotting another data by using the command (hold on;). Pay attention to the font size of the

plotting and their line thicknesses. Other commands you might need are: xlabel and ylabel to add labels to the axis.

Plot1: plot the torque-speed characteristic of the motor with the nominal parameters from table I.

Does the characteristic correspond to the theory?

Plot2: plot the stator current as a function of the speed.

Does the characteristic correspond to the theory? why the current is very high at zero speed and why there is still some current at no-load (synchronous speed)?

Plot3: plot the efficiency of the motor as function of the speed with the nominal parameters.

Is the efficiency reasonable? compare it with the ideal efficiency from the lectures.

Plot4: plot the power factor of the motor as a function of the speed.

Does this power factor look reasonable? Why the power factor is not equal to zero at zero speed and synchronous speed although the motor is not producing any mechanical power?

Effect of parameters variation

After checking that all the plots are correct and correspond to the theory, you can now investigate the effect of some parameters on these performances of the motor. For this purpose, make the following changes to the specified parameters, one parameter at the time and plot the corresponding speed-torque characteristics for the whole set in a single figure, with adequate legend.

Voltage effect: change the value of the supply voltage from 380 to 380/2 and 380/4 V and plot the speed-torque for all three in the same figure, with different colours and adequate legend. What did you notice? Does this correspond to your understanding and the theory from the lectures?

Effect of the rotor resistance: keep the voltage now at 380 V and change the rotor resistance from R_r to $2 \cdot R_r$ and $4 \cdot R_r$. Plot the corresponding torque-speed characteristics in the same figure with different colours and adequate legend. What did you notice? does this result correspond to the lectures theory?

Effect of the stator reactance: keep the voltage at 380 V and the rotor resistance at R_r and change the stator leakage reactance from X_s to $2 \cdot X_s$ and $3 \cdot X_s$. Plot the corresponding torque-speed characteristics with different colours and adequate legend in the same figure. What did you notice? does this corresponds to the theory from the lectures.

You might want to use your script to check how other parameters will affect the torque-speed characteristics and/or check how the above changes affected the other characteristics of the motor, e.g. the efficiency, the stator current, or the power factor.

After you have gathered all the figures as required above. Draft a report with the required figures and answers and append the MATLAB scrip to the report. At the end of the report write a short paragraph about what did you learn from this assignment and give comments on how it was useful or not and challenging to do or not. This last paragraph is required but it will not contribute to the marks.

Appendix 1:

Some figure to help you check the correctness of your code.

