The Induction Machine

Home Assignment 6

Updated February 24, 2020

Introduction

The induction machine (also known as asynchronous machine) is one of the most common electrical machines in industry and home appliances due to its robustness, low maintenance requirements, high reliability and reduced cost when compared with other types of machines. However, it generally offers lower torque/power density and efficiency than permanent magnets machines.

Controlling an IM in highly dynamic regimes is a challenging task which in most cases involves the implementation complex control schemes. Moreover, since in the IM the position of the rotor flux cannot be obtained directly from the rotor position, it is usually necessary to implement estimators that use the available information (e.g. the currents, voltages, speed, etc.) to compute the stator and/or rotor fluxes. These estimators rely their calculations on the equivalent circuit parameters of the machine. Thus, if the IM that is being controlled is not properly characterized or if the parameters change over time (e.g. changes in the resistance due to temperature), the performance of the estimator is degraded and therefore the overall performance of the control system.

Over the years, a large number of control strategies have been developed for the induction machine. FOC (Field Oriented Control) and DTC (Direct Torque Control) are some traditional control schemes, they are present in countless industrial applications and extensive descriptions can be found in the literature. However, this home assignment is focused on a novel strategy called Dead Beat Direct Flux and Torque Control (DB-DFTC) and the aim is for the student to understand its advantages and disadvantages. Additionally, some of the operating principles of the induction machine are to be discussed based on the outcome of the simulations.

Simulation model

The Simulink file used for the simulations consists of an equation based model of an induction machine, a flux estimator based on the stator current and voltage, a flux selector that allows you to use or not use the flux observer in the simulation, a control system and some scopes to visualize interesting parameters. IF the Flux Observer is NOT used then the real stator and rotor flux linkages (which cannot be measured in reality) are used instead. The speed of the induction motor is controlled by an external torque source. The implemented control strategy is called Deadbeat Direct Torque and Flux Control (DB-DTFC) and it is explained in detail in the chapter 12 of the text book. It is essentially a discrete time control system able to reach both the flux and torque reference over one sampling period if the voltage limitation allows it.

The current, voltage and rotor position signals go through a zero-order hold with a sampling time of "Ts" in order to imitate the discrete behaviour of digital control systems and yet maintain the continues behaviour of the machine.

Note that there is no modulator or converter in the simulation model. Instead there is a “Unit Delay” between the voltage references and the applied voltage. The reason for this is that the simulation otherwise would be very slow.

Report requirements

Report requirements are given more thoroughly in the DC Machine home assignment manual. In short:

- **The plots in the report for this home assignment should not be screen shots. Instead log the data from the simulation and plot it using commands like “plot(x,y)”, “surf(x,y,z)”, “mesh(x,y,z)” or any other that you consider adequate.**
- Submit via email and attach your report as a **PDF file**, with **the file name starting with** `IM_Yourlastname`.
- You must submit your home assignment report to be allowed to do the lab. The first report does not have to be perfect, but you should have made honest attempts to complete all tasks.
- Please submit your report three days before your lab session, to give yourself a chance to make changes if the first version does not meet the requirements for you to be allowed to do the lab.
- One report per student.
- Anything unclear will be explained during the lab.
- You will receive your feedback after the labs are over.
- Try to finish all your feedback corrections before the exam for earlier Ladok results, or before the end of the summer to avoid having to redo the lab next year.
- There are no lab report for these labs, only the home assignment reports.

1 Slip and torque

The parameters you will need during the simulation are: (Copy and insert into Matlab console)

```
>> Rs = 20;                % Stator resistance
>> Rr = 8.33;              % Rotor resistance
>> p = 2;                  % Number of poles
>> Ls = 1.696;             % Stator inductance
>> Lr = 1.696;             % Rotor inductance
>> Lm = 1.67;              % Magnetizing inductance
>> Lsl = Ls-Lm;            % Stator leakage inductance
>> Lrl = Lr-Lm;            % Rotor leakage inductance
>> Udc = 500;              % DC link voltage. Note! In the lab it will
    be about 300 V.
>> J = 0.01;               % Rotor inertia
>> sigma = 1 - Lm^2/(Lr*Ls);
>> Ts = 1e-4;              % Sampling period
>> Kp = 100;               % Proportional gain of the speed controller
```

Those parameters correspond to the motor that is used in the IM lab. That is a low torque – high speed (15.000 rpm) machine. Unfortunately, additional information, such as rated power/torque, is not available.

Follow the instructions:

- Open the file `DBDTFCmodel.mdl`.
- Connect the *torque reference steps* block to the torque reference input of the control system (just above the flux reference). This will cause the torque reference to be increased 1 Nm every 50 ms from $t = 1$ s.
- Calculate the slip by comparing the mechanical speed with the electrical frequency of the phase voltage in every torque interval.
- Run a simulation with the settings in the table below the list.
- Present/answer the following in your report:
  - Plot your results in a clear way (stator frequency - rotor frequency, in Hz or % of the stator frequency) for different torque levels.
  - How is the torque and slip related?
  - Why does the IM require a difference between its rotational speed and the electrical frequency in order to produce torque?

Task	Flux reference	Torque reference	Speed reference
1	1 Vs	Steps of 1 Nm	100 rad/s

2 Flux observer

The aim of this section is to understand how the flux observers are affected by mismatches in different parameters at different speeds. Some parameters have a greater effect on the flux estimations than others and it is important to be aware of the limitations and weaknesses of every control system that you implement in order to be able to ensure an acceptable performance under the specific operating conditions.

Follow the instructions:

- Next to the flux selector subsystem, be sure that the "Observer ON" selector is set to 1 (It should be if you haven't changed it). This means that the control system uses the estimated fluxes instead of the real ones (coming directly from the machine).
- To create mismatches between the parameters used by the "real IM" and the ones used by the flux observer and control system: Double click the IM model and multiply the parameters there by a scaling factor that you consider (i.e. 0.8-1.2).
- Run the simulations you need in order to study the influence of mismatches in at least **two parameters (independently) at different speeds** and having different errors in the parameters (i.e. Speeds = [0 50 100] [rad/s] Rs = Rs*[0.8 0.9 1.1 1.2]).
- Present and discuss the following in your report:
  - Present your results in 3D surfaces having the speed in one axis, the parameter under study in the other axis and the difference between the requested and real torque/flux in the z axis.
  - What could the mismatches you have studied represent in a real application? How likely do would you say this mismatch is to happen?
  - What problems could these mismatches lead to? How can it be avoided?

Task	Observer	Speed reference	Two parameters of your choice
2	ON	Varying, i.e. [0 50 100]	Varying i.e. [0.8 .. 1.2]*real value

3 The control system

Follow the instructions:

- Step response analysis: Run case 3.1 according to the table below and answer the following
  - How is the torque and flux response of the system?
  - What are the rising times for flux and torque?
  - Is the controller really "dead beat"?
  - (How) could you reduce this rising time?
- Stability analysis: Run case 3.2 according to the table below and answer the following
  - Compare the results with case 3.1 and explain the difference.
  - What do you think would happen if you increased Ts further?

Case	**Flux reference**	**Torque reference**	**Ts**
3.1	0.7 Vs	3 Nm	0.1 ms
3.2	0.7 Vs	3 Nm	0.3 ms

4 Field weakening

Follow the instructions:

- Set `Kp = 0`. This eliminates the control over the rotational speed of the rotor shaft.
- Run case 4.1 according to the table below and answer
  - Why does the torque decrease after a few milliseconds?
  - What is the final speed? How would you extend this maximum speed?
- Run case 4.2 according to the table below and answer
  - Implement a simple field weakening strategy that allows you to go the maximum speed.
  - Tip: Be sure that the flux does not go below 0.6 Vs, so the machine has enough flux to produce torque.
  - Show a screenshot of your implementation and explain how it works.
  - Which speed were you able to reach?

Case	**Flux reference**	**Torque reference**	**Simulation time**
4.1	1 Vs	3 Nm	2 s
4.2	1 Vs $\pm$ field weakening	3 Nm	2 s