**ELEC-E8405**

**Electric Drives**

**Assignment 2**

**Modelling and Simulation of DC Motor Drive**

**By**

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**Testing DC Motor Model**

Model Used:

DC Motor Model

Description automatically generated

*Figure 1.1*

A diagram of a machine

Description automatically generated

*Figure 1.2*

Simulated waveforms:

A screen shot of a graph

Description automatically generated

*Figure 1.3*

1. **Simulate the sequence corresponding to Figure 7. Modify the plotting script so that the per-unit current and the per-unit speed are plotted (use their rated values as base values and do not normalize time). Show this result in your report. Remember to change the axis labels. Explain why there is a very large peak in the current after the voltage step is applied**.

**Ans:**

p.u. plots of current and voltage:

A graph on a white surface

Description automatically generated

*Figure – 2.1*

Explanation of a large peak current:

As observed in Figure 2.1, when the rated voltage is applied to the DC Motor, there is a sharp increase in current (around 6 times of the rated current) followed by a decrease towards zero as the back emf () starts increasing. This undesirable phenomenon occurs while starting a DC motor (), during which it needs to overcome the inertia at its state of rest. The DC Motor requires a high torque and therefore a high current is consumed to do the work. The high current may cause the tripping of an overcurrent relay.

1. **Using the analytical motor model, calculate the values for the current and the rotor speed in the steady state, when the voltage and the load torque . Compare these values to your simulation results.**

**Ans:**

Calculated values:

At steady state, ,

Therefore, the final equations for the DC motor become,

&

Putting required values in the equations,

&

Simulated results:

A diagram of a machine

Description automatically generated

*Figure – 3.1*

1. **Limit the rising rate of the voltage to 120 V/0.1 s using the Rate Limiter block. Place this block between the voltage step and the motor model. Simulate the model and show the results in your report. Briefly comment on the current and speed responses.**

**Ans:**

Model used:

A diagram of a diagram

Description automatically generated

*Figure – 4.1*

Simulation Results:

A graph with blue lines

Description automatically generated

*Figure – 4.2*

Comments on the waveforms:

The introduction of the Rate Limiter into the model has enabled us to slow down the rate of terminal voltage ramp up, thus preventing the sharp rise in current while starting the DC Motor and protecting it from undesirable overcurrent.

1. **Augment your simulation model with unipolar PWM and converter models. Simulate the model and show the results in your report. Briefly comment on differences compared to the previous simulation, where an ideal voltage source was assumed.**

**Ans:**

Model used:

**A close-up of a diagram

Description automatically generated**

*Figure – 5.1*

Simulated Waveforms:

A graph with blue lines

Description automatically generated

*Figure – 5.2*

1. **Plot the waveforms of the actual current and the synchronously sampled current in the same subplot. Also show the waveform of the voltage .**

**Ans:**

Simulated waveforms:

A diagram of a diagram

Description automatically generated

*Figure – 6.1*

Testing Model for DC motor with 2DOF PI Current Controller:

Model Used:

**A diagram of a circuit

Description automatically generated**

*Figure – 7.1*

Simulated Waveforms:

A graph of a graph

Description automatically generated with medium confidence

*Figure – 7.2*

1. **Calculate the theoretical rise time of the torque and compare it to the simulated rise time.**

**Ans:**

Theoretical Rise Time:

For closed-loop systems, rise time, is calculated from a range of **to.**

Now, transfer function for closed loop current controller (value converted to Torque) –

= [Since ]

Therefore, rise time, [Where = Time Constant]

Simulated Rise Time:

A graph of a graph

Description automatically generated

*Figure – 8.1*

From *Figure-8.1*,

&

Therefore, rise time,

1. **Tune the speed controller of your simulation model for the closed-loop bandwidth αs = αc/10. Test your model using the square-wave speed reference, whose amplitude is 160 rad/s and frequency is 4 Hz. Generate the rated load torque step at t = 0.3 s. Show results of this simulation in your report. Show also the figures describing the main level of your simulation model and the implemented speed controller.**

**Ans:**

Models used:

**A diagram of a circuit

Description automatically generated**

*Figure – 9.1*

**A diagram of a computer

Description automatically generated**

*Figure – 9.2*

Simulated waveforms:

A diagram of a diagram

Description automatically generated

*Figure – 9.3*

A graph of a graph

Description automatically generated with medium confidence

*Figure – 9.4*

A graph of a graph of a graph

Description automatically generated with medium confidence

*Figure – 9.5*

Explanation of the models:

*Figure-9.1* represents the Two-Degree-Of-Freedom Speed Controller used where inputs are reference motor rational speed and actual motor rational speed as feedback. The output of the speed controller is the reference torque fed into the current controller after conversion to reference current (using ).

As mentioned in the question the reference tracking bandwidth of the speed controller,

**of**

The values of the gains used for the speed controller are as following:

1. Proportional Gain, [Since = 0]
2. Integral Gain,
3. Reference Feedforward Gain,

*Figure-9.2* represents the final form of the DC Motor drive with Two-degree-Of-Freedom Speed and Current controllers.

1. **This problem aims to illustrate the robustness of the closed-loop control scheme against parameter errors. Generally, resistances depend on temperature (about 0.4%/K) and inductances may vary due to the magnetic saturation. Change the actual resistance R in the motor model to 150% of its original value and the actual inductance L to 70% of its original value, but do not change the values in the control system. Simulate the model. Show the results and comment on them in your report. After this problem, restore the parameter values back to their original values.**

**Ans:**

Resistance and Inductance values changed:

A white background with green text

Description automatically generated

Simulated waveforms:

A diagram of a diagram

Description automatically generated

*Figure – 10.1*

A graph of a graph

Description automatically generated with medium confidence

*Figure – 10.2*

A graph of a graph of a graph

Description automatically generated with medium confidence

*Figure – 10.3*

Observations:

The comparison between figures *10.1*, *10.2* and *10.3* to *9.3*, *9.4* and *9.5* respectively indicate no change in the output waveform characteristics even when the estimated values of resistance and inductance are marginally inaccurate. This shows the usefulness of closed-loop controllers, the two-degree-of-freedom PI controllers in this case, to address parameter errors like resistance variance as a function of temperature. The integral action drives the control error to zero even with imprecise parameter estimation.

1. **This problem aims to illustrate the importance of the anti-windup scheme. Remove the anti-windup in the speed controller (but do not remove the saturation of the controller output). Show results of your simulation and comment on them. After this problem, restore the anti-windup method back to the original form.**

**Ans:**

Model Used:

A diagram of a machine

Description automatically generated

*Figure – 11.1*

Simulated waveforms:

A diagram of a diagram

Description automatically generated with medium confidence

*Figure – 11.2*

A graph of a graph

Description automatically generated with medium confidence

*Figure – 11.3*

A graph of a graph of a graph

Description automatically generated with medium confidence

*Figure – 11.4*

Observations:

As seen from the figures *11.2*, *11.3* and *11.4* there are significant overshoots for current, and the rotational speed, . This phenomenon occurs due to integral windup, where the integral term of the PI controller continues to accumulate the control error during the time of maximum torque output or saturation. When starts to get close to , the integrator has wound-up, so remains large. Therefore shoots over until the windup has been worked off by the accumulation of negative control error. Hence it is important to implement an anti-windup method to the two-degree-of-freedom PI Controller to compensate the mentioned issue.

1. **Parametrize the speed controller so that it becomes a regular (1DOF) PI controller, while keeping the closed loop poles the same. Furthermore, parametrize the speed controller so that it becomes the proportional controller, while keeping the same reference-tracking performance as that of the original 2DOF PI controller. For both cases, show the simulation results and briefly comment on them.**

**Ans:**

Parameters to convert the existing model to 1DOF PI Controller:

A screenshot of a computer program

Description automatically generated

Waveforms obtained after simulation:

A diagram of a graph

Description automatically generated

*Figure – 12.1*

A graph of a graph

Description automatically generated with medium confidence

*Figure – 12.2*

Parameters to convert the existing model to P Controller:

A screenshot of a computer program

Description automatically generated

Waveforms obtained after simulation:

A diagram of a diagram

Description automatically generated

*Figure – 12.3*

A graph of a graph

Description automatically generated with medium confidence

*Figure – 12.4*

A graph of a graph of a function

Description automatically generated with medium confidence