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Project 0

DC Motor Drive and Analysis

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1 Part A DC Motor Modelling via Different Toolbox

1.1 DC Motor Properties and Equations

Table 1: DC Motor Properties

Rated Armature Voltage (V)	*24*
Rated output power (W)	121
Rated speed (rpm)	2700
Armature resistance (Ω)	0.43
Armature inductance (mH)	*0.9*
Back EMF constant (volts/rad/sec)	*0.08*
Motor inertia (gcm^2)	2118

Table 2: Mechanical System Properties

Gearbox ratio (N1:N2)	*2:1*
Load side friction coefficient (mNm.s/rad)	0.18
Motor Shaft stiffness (Nm/rad)	7.5
Load inertia (gcm^2)	1800
Load torque (Constant) (Nm)	*0.75*

Firstly, I tried to derive the equations step-by-step.

$$Ea = Ke\omega \ (BackEMF) \tag{1}$$

$$L\dot{I_a} + RI_a i = Vt - Ea \ (KVLoftheDCMotor) \tag{2}$$

$$I_a = \int \frac{Vt - Ke\omega - RI_a}{L} \tag{3}$$

As we see from the equation 3 , we have two negative feedback one of them is voltage drop on resistor and the other one is back EMF and input is from Vt which is terminal voltage.

If we look mechanical side of the system ,

$$T_e = KeI_a \tag{4}$$

To calculate back EMF we have to find the speed. To calculate the speed , we try to derive equations from mechanical side of the motor.

$$\dot{\theta} := \omega \tag{5}$$

$$T - k(\theta_m - \theta_l) = J_m \ddot{\theta_m} \ (StabilityEquation) \tag{6}$$

$$k(\theta_m - \theta_l) = T_g \tag{7}$$

- Where T_g is Torque preprocessed or torque in motor side of the gearbox.
-Where T_p is Torque processed or torque in load side of the gearbox

$$\frac{N1T_g}{N2} = T_p \tag{8}$$

$$T_p = J_l\ddot{\theta}_l + B\dot{\theta}l + T_l \tag{9}$$

As we see from the equation 5, we have one negative feedback which is loss due to shaft which is connection between load and motor and one input which is torque. And to obtain the effect of stiffness on the torque we have to calculate θ_m and θ_l individually. To calculate them we have some extra feedback loops as we see from equation 9

Now, we have the relation between mechanical and electrical system ,and we can start to build our simulink files.

1.2 DC Motor via Simulink Blocks

1.2.1 Simulink Model-1

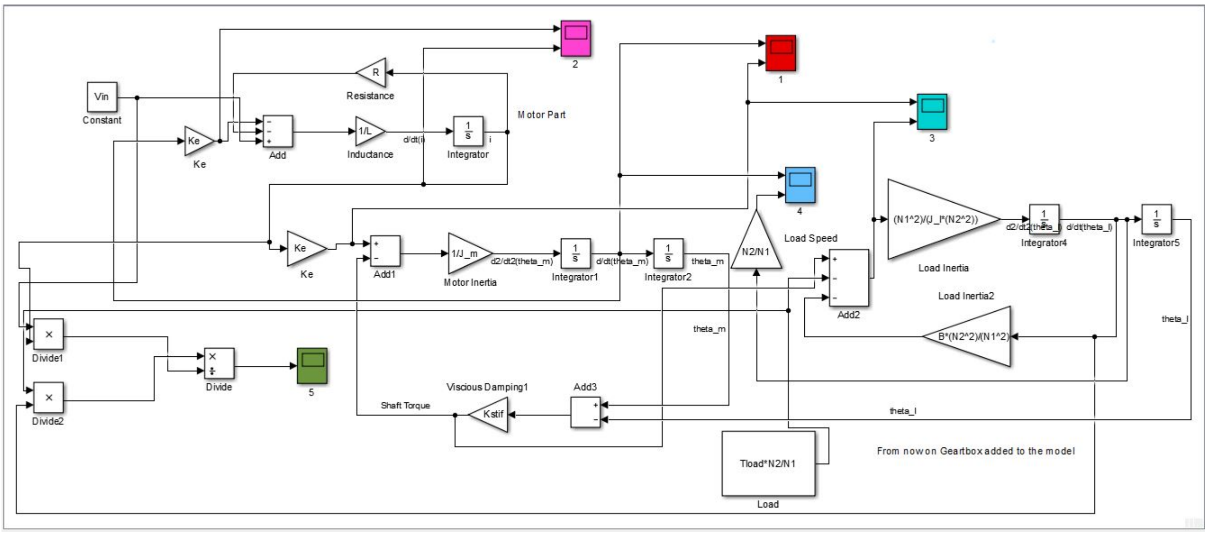

Figure 1: DC Motor Model via Simulink blocks

In Model-1 , I used transfer equations topology and basic Simulink blocks such as Integration, Gain , Add , constant , etc. to derive the model. As you from figure 1, the system divided to two parts ,first part is electrical side of the motor and second part is the mechanical side and connection with load. Each loop derived w.r.t. equations 1- 9 . The connection between electrical side and mechanical side established by two different feedback,one of them via Current,other one via Speed.

1.2.2 Important Waveforms about Model-1

Figure 2: Motor Speed and Motor Torque

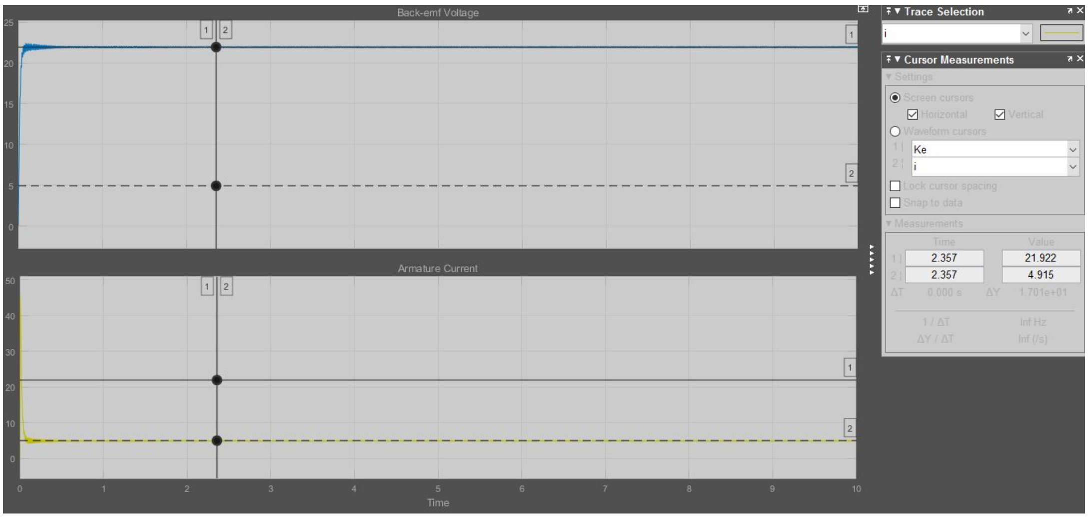

Figure 3: Back-emf Voltage and Armature Current

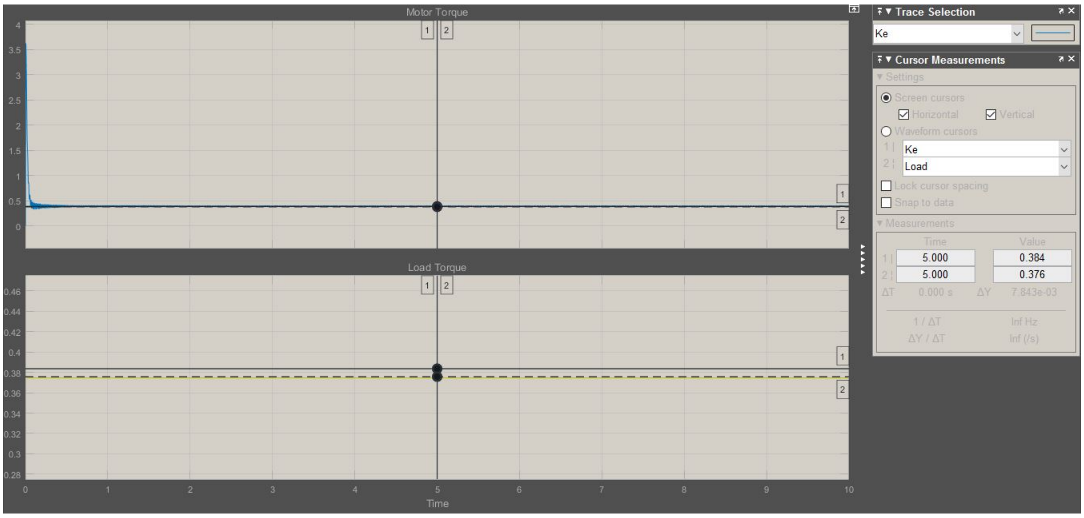

Figure 4: Motor Torque and Load Torque

Figure 5: Motor Speed and Load Speed

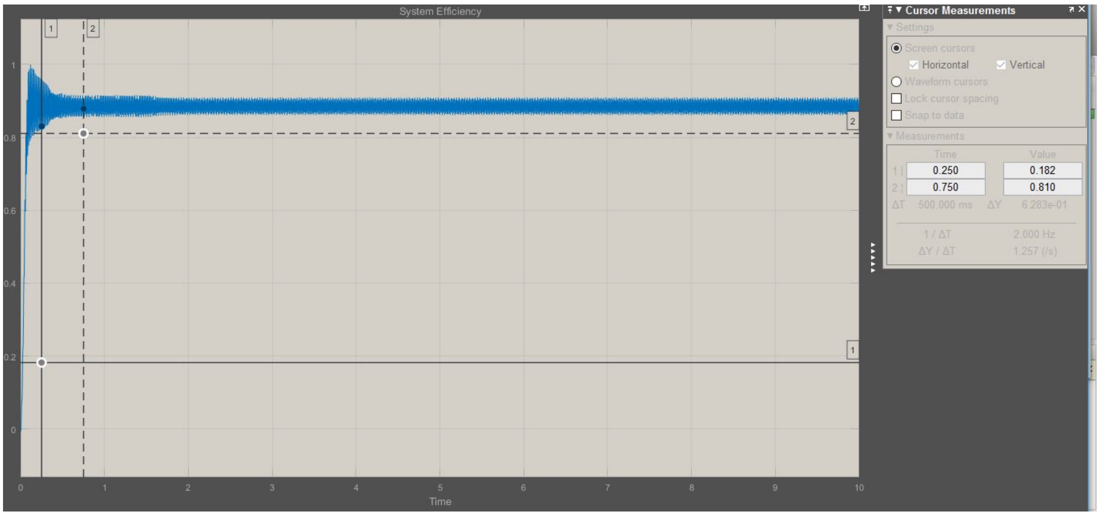

Figure 6: Motor Efficiency

1.3 DC Motor via SimScape PowerSystem Components

1.3.1 Simulink Model-2

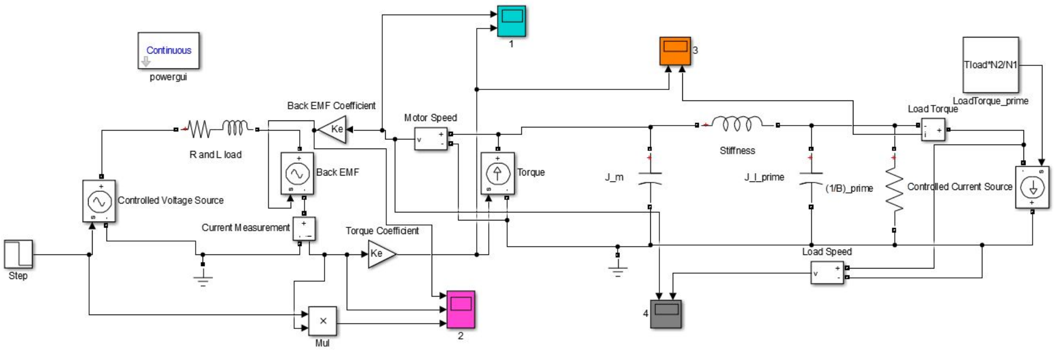

Figure 7: DC Motor Model via Simulink blocks

In these system, I tried to model a DC motor via SimScape Power System models which are passive(inductor,capacitor,resistor) and source elements(dependent or independent voltage and current). Firstly to construct Motor side , I used the simple model of DC Motor which consist of resistor,inductor and Controlled Voltage Source(induced voltage) . On the other side of the circuit I tried to model Mechanic part of the system. To construct the circuit, Instead of common mechanical model I used their electronical model equivalent . With regard to that sentence,

- Torque $\rightarrow ControlledCurrentSource$
- Inertia $\rightarrow Capacitor$
- Motor Stiffness $\rightarrow Inductor$
- GearBox $\rightarrow Transformer$

In the beginning I tried to use transformer instead of Gearbox,than I decided to use equivalent circuit of transformer in primary side

Lastly to combine mechanical and electrical system , I measured the voltage from mechanical side to use feedback for induced voltage with regards to equation 1 , and measured the current from electrical side to use as a feedback for torque with regards to equation 4 .

1.3.2 Important Waveforms about Model-2

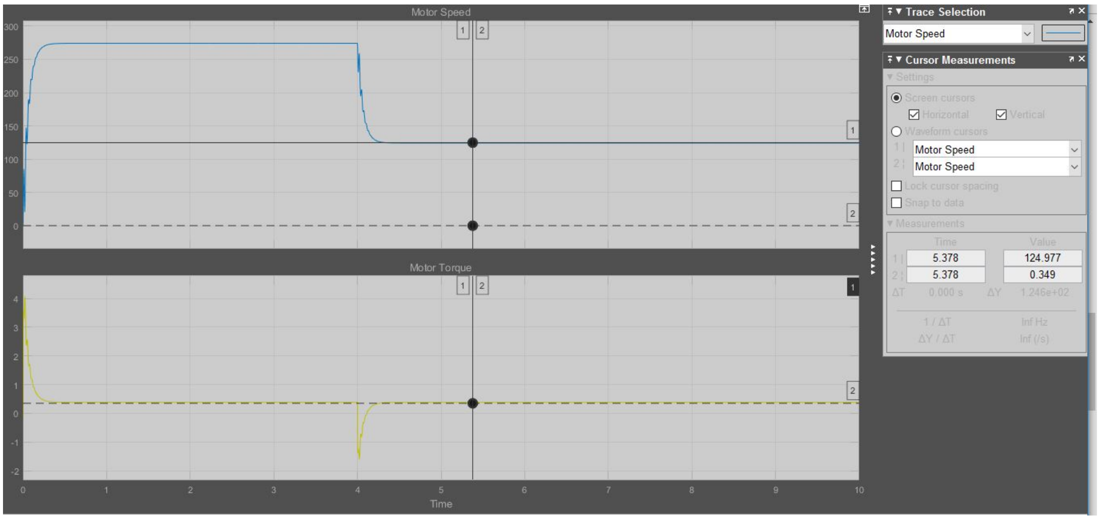

Figure 8: Motor Speed and Motor Torque

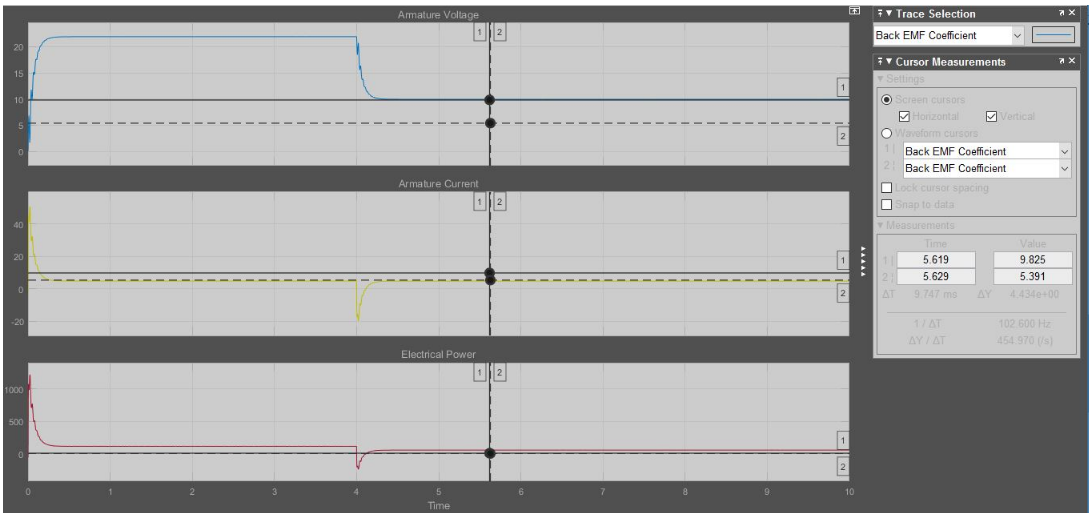

Figure 9: Back-emf Voltage and Armature Current

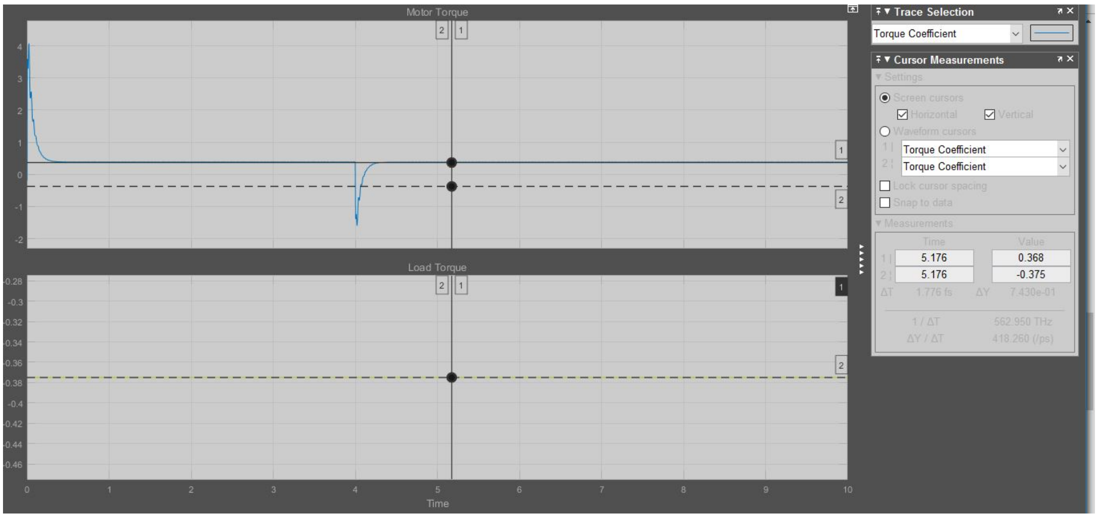

Figure 10: Motor Torque and Load Torque

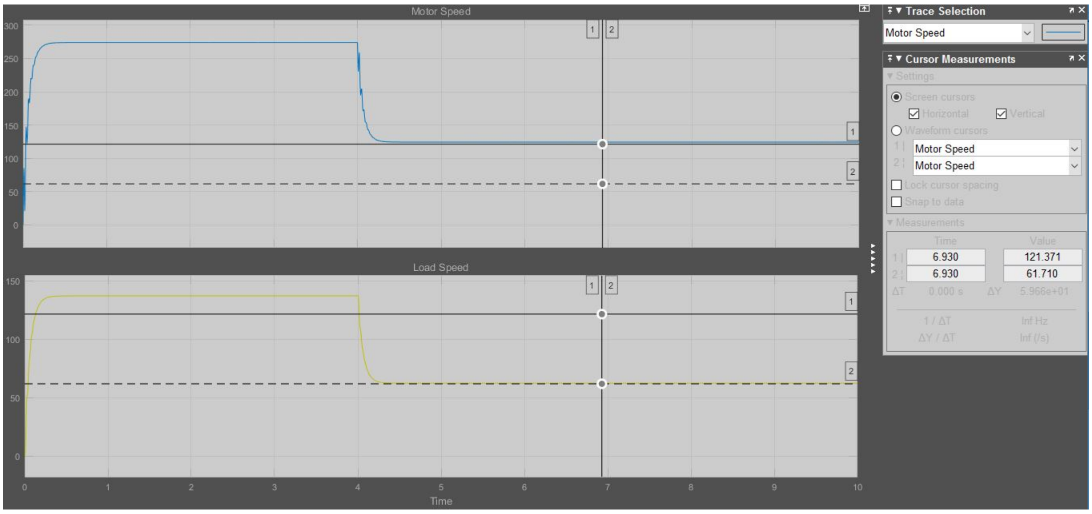

Figure 11: Motor Speed and Load Speed

1.3.3 Specific Comments for Model-2

As we see from the figure 9 , after decreasing the terminal voltage to 50% its rated value, the current and torque is decreasing below to zero instantaneously because in electrical side current changed its polarity.As a result of that in the system there will be negative torque ,so the motor speed start to decrease. One of the most important observation is the continuous decrease on the speed .In other words, there is not any jump between the values because of the mechanic inertia. The final value of the speed will be half of the its past value due to terminal voltage decreased to its half value. The reason of interactive mechanism is the correlation between the induced voltage and torque.

1.4 DC Motor via SimScape PowerSystem Components

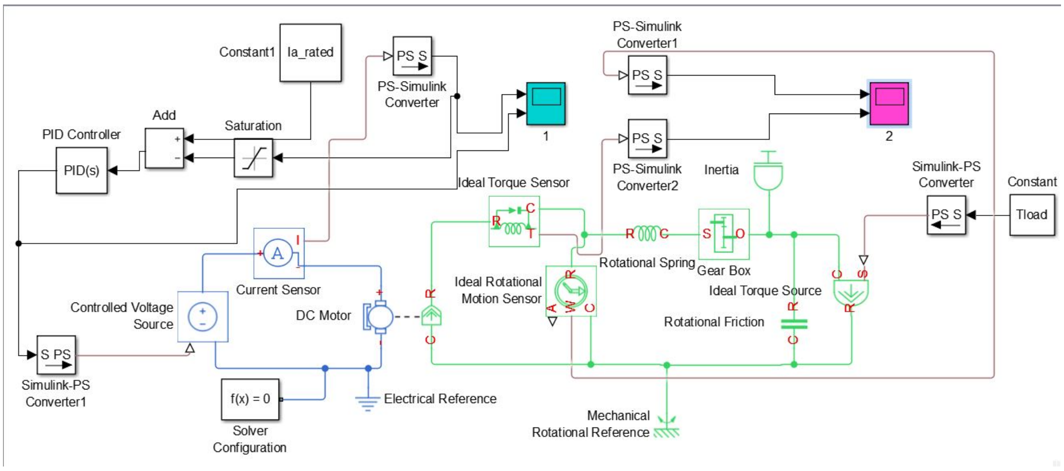

Figure 12: DC Motor Model via Simscape Models

As you see from figure 12 , I used SimScape DC Motor block to simulate the system. DC Motor block contains mechanical and electrical side. To have soft start on the system, I used basic PID topology to decrease the response time and decrease the overshoot .Also I used saturation block , to prevent the armature current exceeds its 150% of the rated value . To simplify the stiffness part instead of flexible shaft , I used normal rotational spring . That is the explanation of that simulink model .

1.4.1 Important Waveforms about Model-3

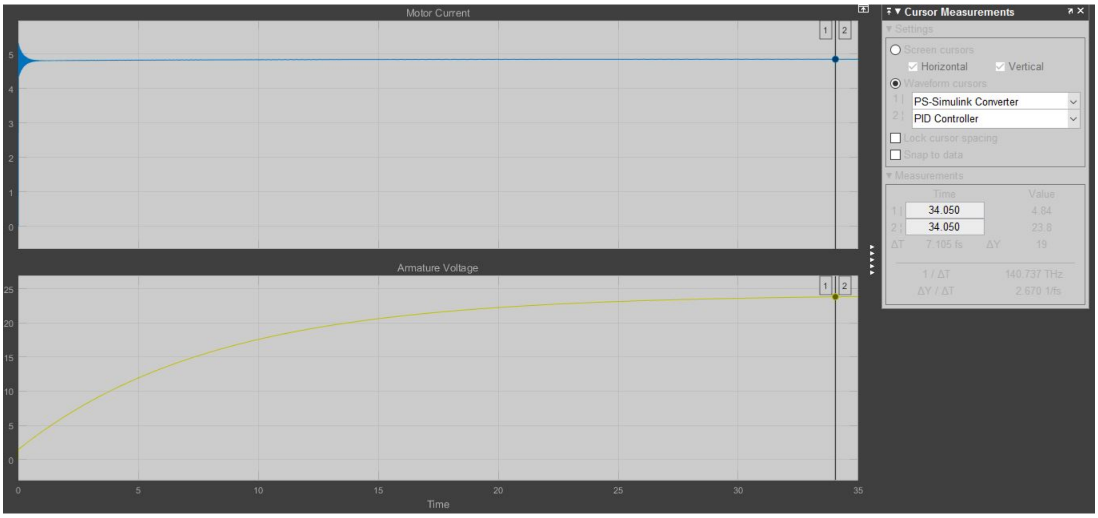

Figure 13: Motor Current and Armature Voltage

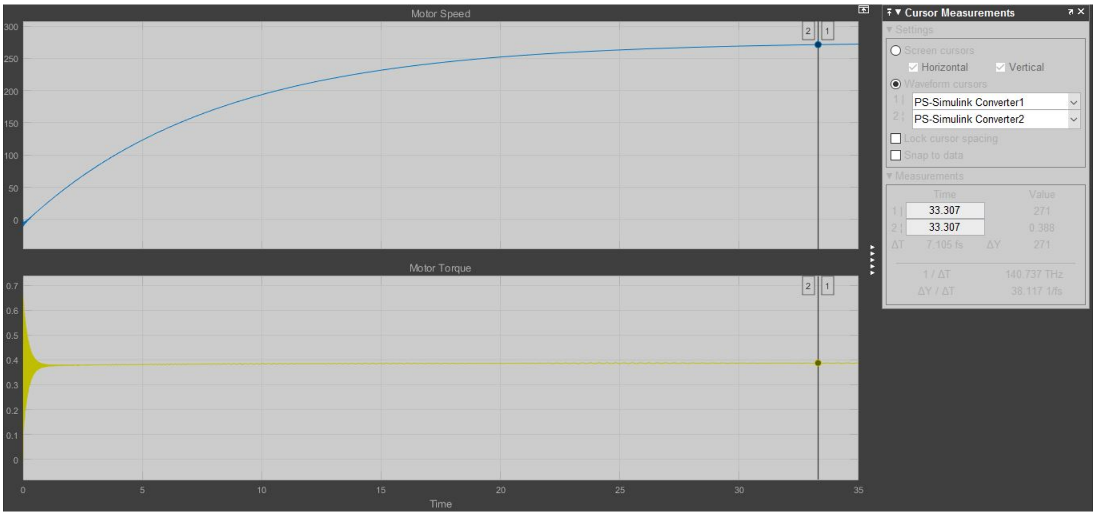

Figure 14: Motor Speed and Motor Torque

2 Conclusion

In Project 1 , our purpose was creating DC Motor models by using different Simulink Topologies. The first model which is called Model 1 is based on basic Control Theory and Laplace Domain equations. The Simulink blocks used with regards to transfer equations and mathematical model of the components . The second model which is called Model 2 is an implementation of circuit components and the correlation between mechanical and electrical models. For example, instead of using ideal torque source , I used current source to supply mechanical side. Model 2 is constructed by using SimScapePowerSystem passive elements or instead of using Gearbox , I used equivalent circuit of transformer which referred to primary side . The final model which is called Model 3 is an implementation of SimScape Electrical and Mechanical box and instead of deriving the components mathematically or equivalently, I used directly the components itself. Also , to drive the motor I developed a basic Current based controller which consist of PID topology.

As we see from all of the models armature current waveforms , in the beginning of the simulation the current value is 5-6 times higher than rated value ,these current also called inrush current. Inrush current is the maximum, instantaneous input current drawn by an electrical device when first turned on and it is too important to know how to limit the inrush current to prevent possible damage . There is some different topologies for starting DC Motor such as starting resistance ,motor drivers , etc. reference 3 . In Model 3 , as we said before to prevent inrush current ,we drove the motor softly ,in other words we increased the input voltage with regards to PID controller slowly. Sometimes mechanical side can cause some mechanical ripple on load side due to ripples on the load side torque. You can see that load speed ripple on figure 5 .

In Model2 , after decreasing the terminal voltage to its rated value ,we observed that the armature current decreased but then it increased back to its past value . On the other hand, speed decreased to half of the rated speed . So we understand that when we decrease the terminal voltage our torque stay same but our speed will decrease and our efficiency decrease to its 50% value because electrical power stay same .

In Model3 , we observed that the system reaching its steady state value in very long period. The reason of that is our controller structure which consisted of digital components . In analog world , to analyze the data digitally we have to spend some time to convert data from analog to digital and that whole loop consume too much time . In my opinion , the reason why motor reached its rated value in more time is that. To prevent that ,instead of using digital controller we can use analog circuitry based controllers.

To sum up , we saw that same DC motor topology can be derived by different Simulink blocks , and there is some differences between that derived simulations. To do actual simulation on Simulink we have to cover almost all parasitic mechanical and electrical effects.

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