Middle East Technical University

Electrical and Electronics Engineering

EE462 – Utilization of Electrical Energy

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<u>Project 1: Modeling a DC-motor Drive System</u>

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Contents

Introduction

In this project, DC Motor driver application is modeled in Simulink as three different versions. By modelling DC Motor with basic components, with electrical blocks and with electromechanical blocks, it is learnt how a DC Motor block is constructed and modified for the rated operation. Then, by analyzing these three models and comparing them, the characteristics of the DC motor are studied. In order to understand DC Motor behavior, critical graphs are obtained and investigated in this project. Lastly, the obtained results are studied and commented for each model.

Part I – Simulink Model of DC Motor with Basic Components

Analysis and Results

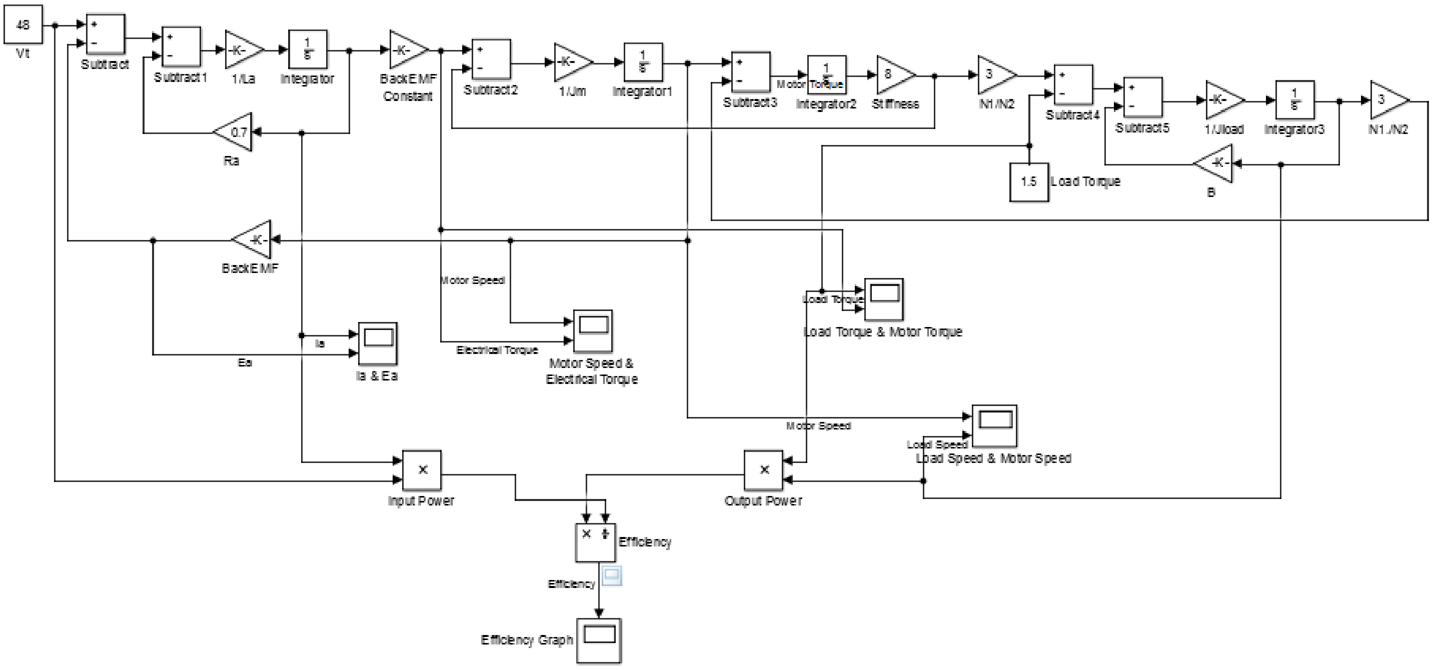

Figure 1: The Simulink Model of DC Motor with Basic Components

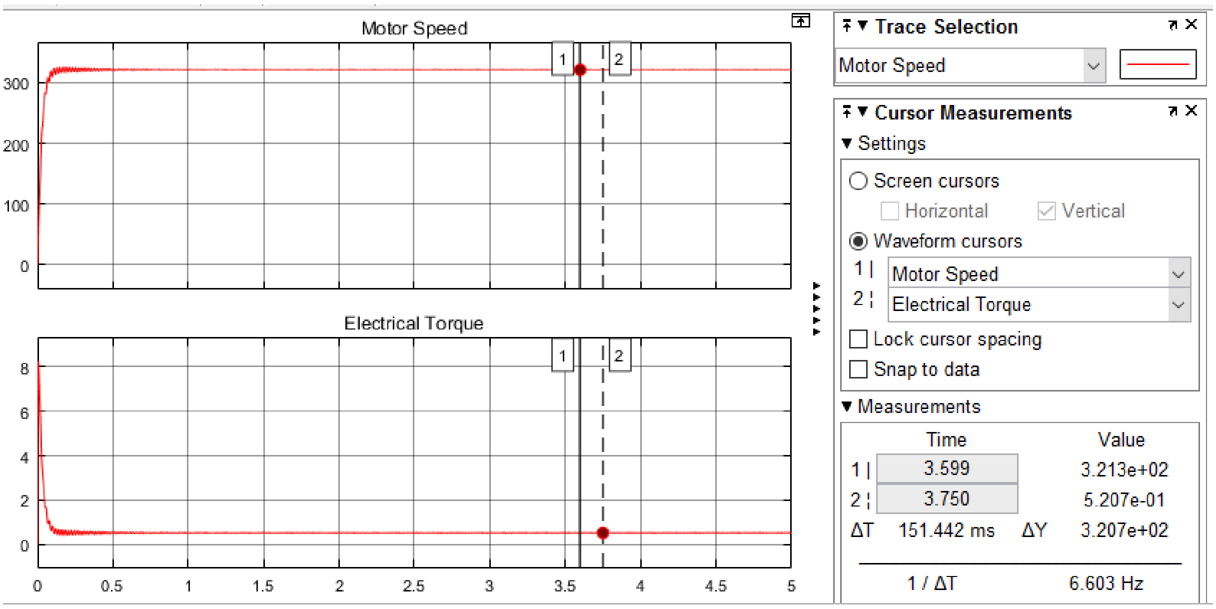

Figure 2: Motor Speed(rad/sec) and Electrical Torque(N.m) vs Time(s) Graph

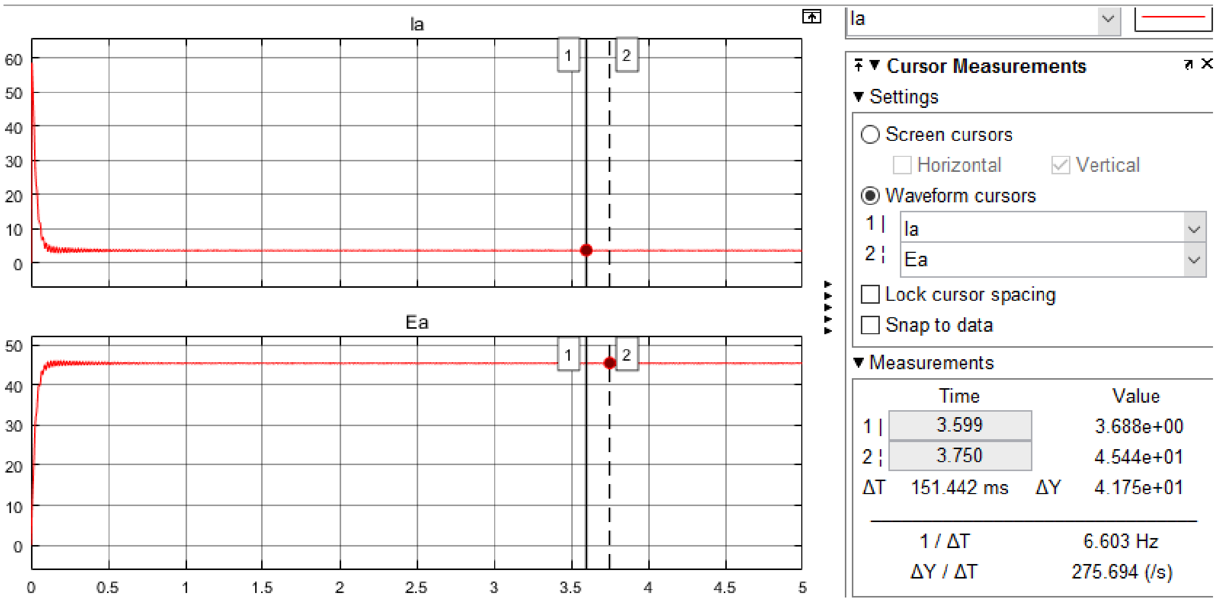

Figure 3: Armature Current(A) and Back EMF Voltage(V) vs Time(s) Graph

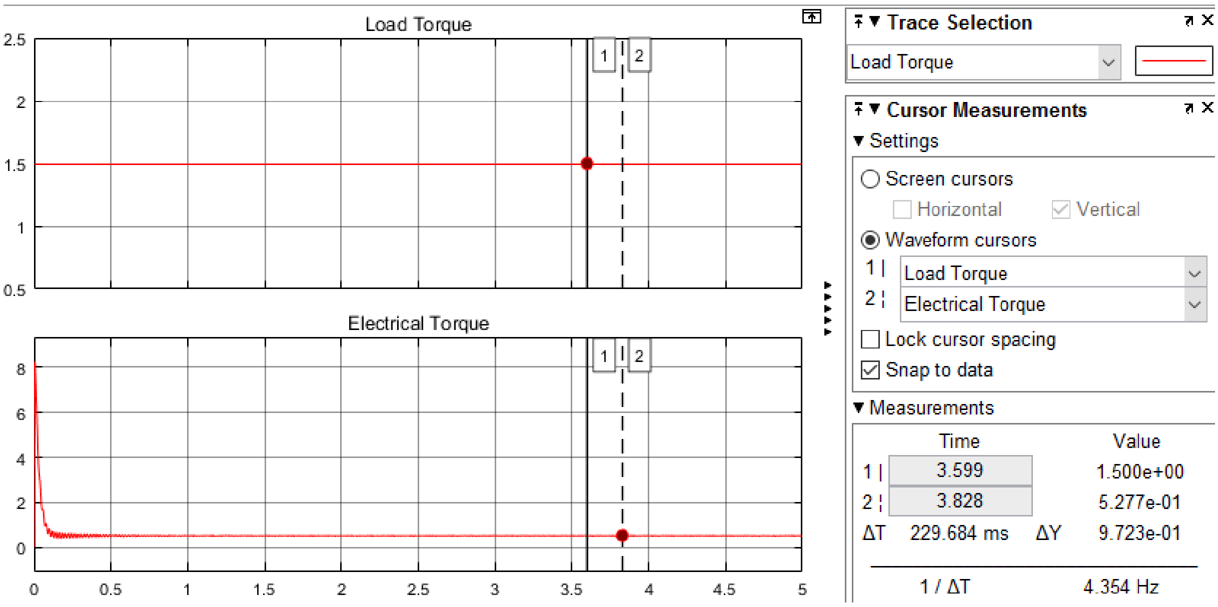

Figure 4: Motor Torque(N.m) vs Load Torque(N.m) vs Time(s) Graph

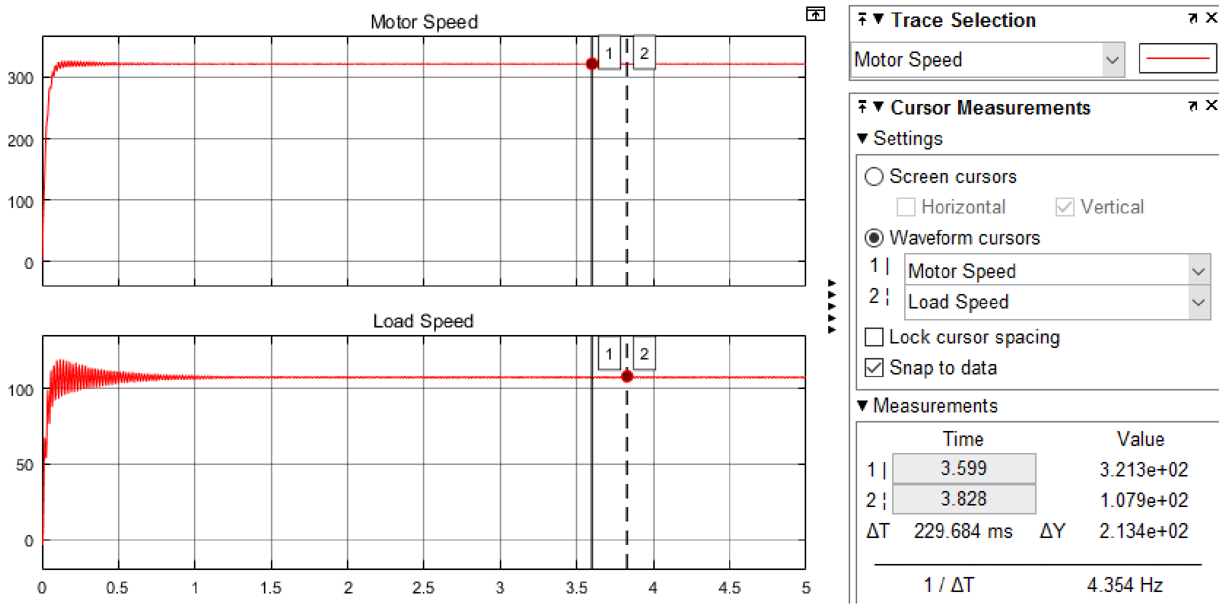

Figure 5: Motor Speed(rad/s) and Load Speed(rad/s) vs Time(s) Graph

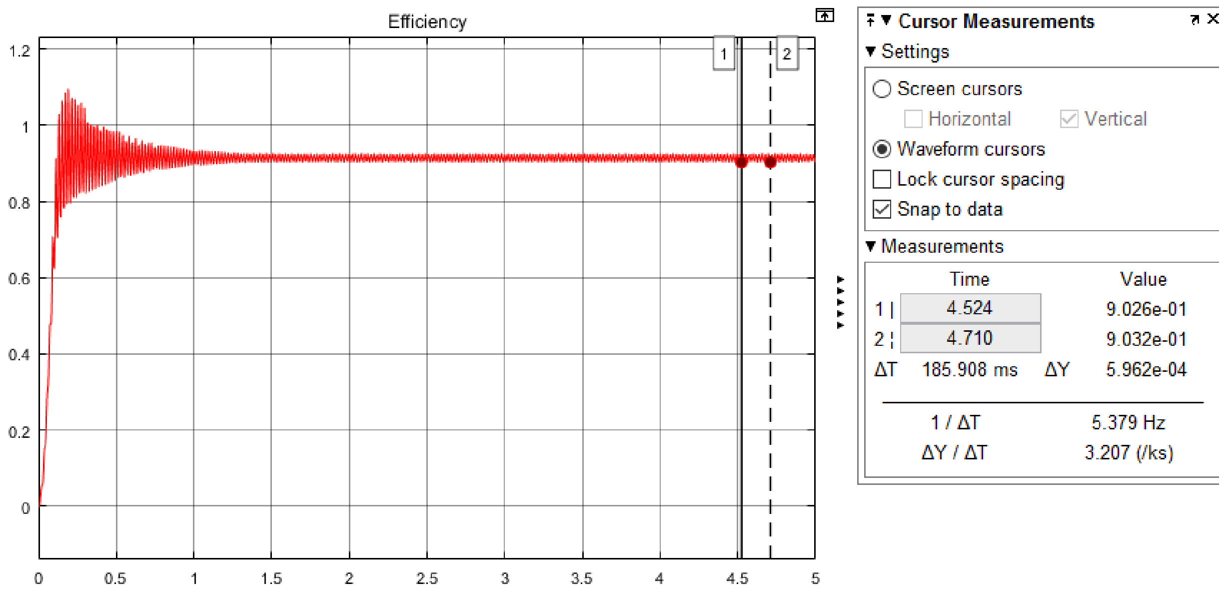

Figure 6: Efficiency vs Time(s) Graph

Comments

In this part, a DC motor driver application is modelled with basic components. After getting the corresponding equations, the simulation model is constructed with the given rates.

In the DC motor driving operation, in order to have the rated speed and torque, since the motor is a permanent magnet motor, only armature voltage is applied with rated value. Applying this voltage, armature current started to flow and the motor started to generate torque. With this generated torque the motor starts to turn. The motor is connected to the gearbox with a shaft and generated torque is transferred to the load with this gearbox. The rotation speed increases until the speed reaches the rated value at which the motor is able to rotate forever. In a couple of hundred milliseconds all parameters reach the rated values.

Moreover, when we look at the electrical torque and armature current graphs or back EMF voltage and motor speed graphs, it is observed that the graph characteristics are similar to each other. For example, for the beginning, the torque and armature current peak to maxima and when the armature starts to keep voltage; that is, when the motor starts to turn and accelerate, the current and torque starts to decrease and it continues until reaching the rated speed. At the rated speed, we observe that the electrical torque is higher than the load torque, referred, because of the friction; in other words, the friction sinks a part of the generated torque. However, when we look at the motor speed & load speed at rated, their rate is equal to the gearbox ratio because the stiffness does not make any speed drop if speed stays constant but when the speed is changed, the stiffness affects until reaching the next steady state.

During the acceleration, back EMF voltage increases for each moment. Therefore, the armature current decreases, so does the torque. Thus, for the beginning moment with the minimum back EMF voltage, the armature current has the highest value. Then, the motor begins to accelerate with generated torque until reaching the rated speed. Getting closer to the rated speed, since the generated torque decreases, the acceleration gets lower and at the end acceleration becomes zero. Therefore, we can say that the applied torque decides how great the acceleration will be.

The inertia is the tendency to stay at the existing speed. (Northwestern University, n.d.) Therefore, if an object has higher inertia it more resists to speed change. For DC Motor application, if the motor has high inertia, it takes more time to reach steady state and the mechanical time constant shows the tendency of the motor to change its speed. Generally, time constant is the amount of taking time to approach final value's 1/e factor less, which is %63.2. Therefore, to get the mechanical time constant, a timer can count time while measuring the motor speed at and when the %63.2 of the rated speed is reached, that time shows the mechanical time constant. Note that, the given time constant on datasheet is for no load. For loading, due to increasing inertia we have longer time constant values which can be found using same method. Similarly, electrical time constant can be found by following the armature current. Also, time constant can be calculated analytically with the following equations:

$$\tau_e = {}^{La}/_{Ra}$$

For our case, mechanical time constant is 25ms and electrical time constant is 1.86ms. Consequently, it can be said that electrical time constant decides how fast the rated torque is generated mechanical time constant decides how fast the rated speed is reached.

Motor speed and load speed has the same mean value at steady state when the load is referred. However, during the transient times, the shaft stiffness also keep a mean value on itself. Thus, the load speed lags motor speed. Stiffness is the parameter defining how rigid the shaft is. If the shaft would be not so rigid, it can be twisted and the motion cannot be transferred to the load. On the other hand, if the shaft is too large, no twisting, any change on the motor speed would affect directly the load speed. Therefore, we can say that, the shaft serves filtering also alongside of transferring the motion. Therefore, shaft stiffness has a role of filtering distortions produced on the motor side.

About the efficiency, when we look at the graph we see that efficiency is larger than unity which is absolutely not possible. This result is obtained because for the beginning, since there is constant load torque and the motor beginning new, the load moves in the opposite way, such as a bike goes downfall. Therefore, for the beginning, the load generates power and it enforces armature to turn in opposite way. As a result, since the output behaves like input for the beginning, efficiency graph has values larger than one. Secondly, we see that the efficiency increases with increasing speed because load torque is constant so output power gets higher in time. Also, we see that armature current peaks at the beginning and it decreases in time and since input voltage is constant input power decreases. At the end, efficiency increases in time with increasing speed.

Part II – Simulink Model of DC Motor with Electrical Components

Analysis and Results

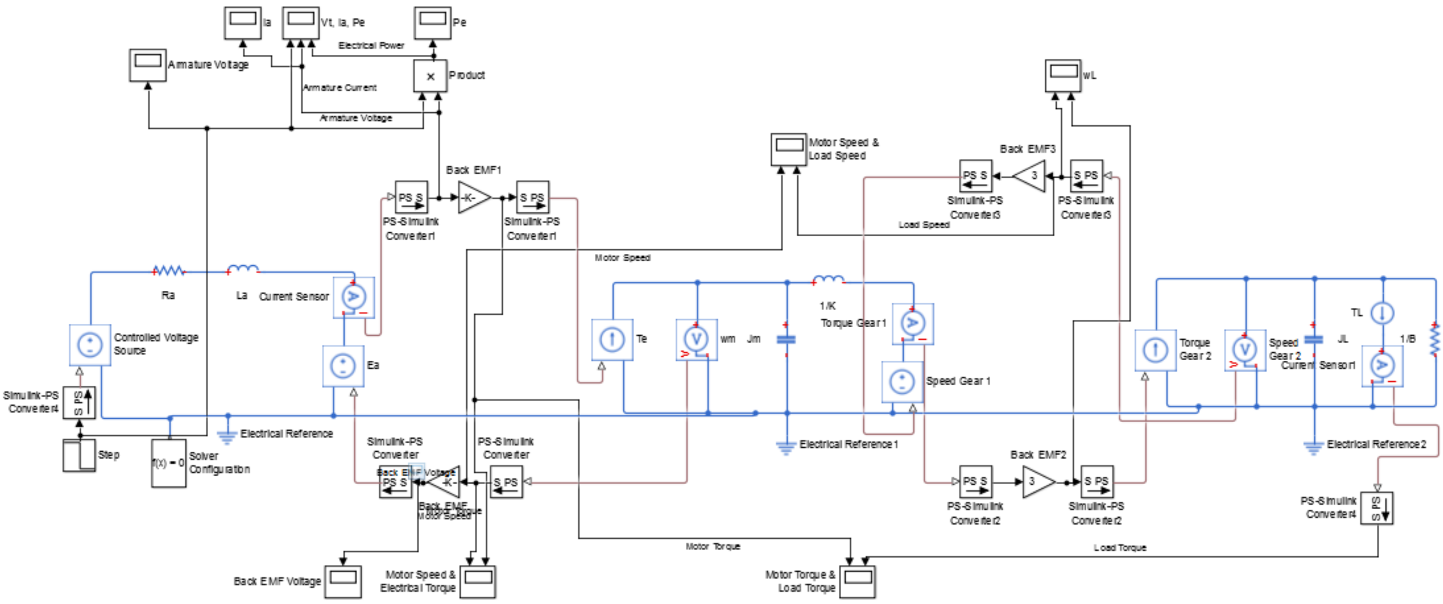

Figure 7: The Simulink Model of DC Motor with Electrical Components

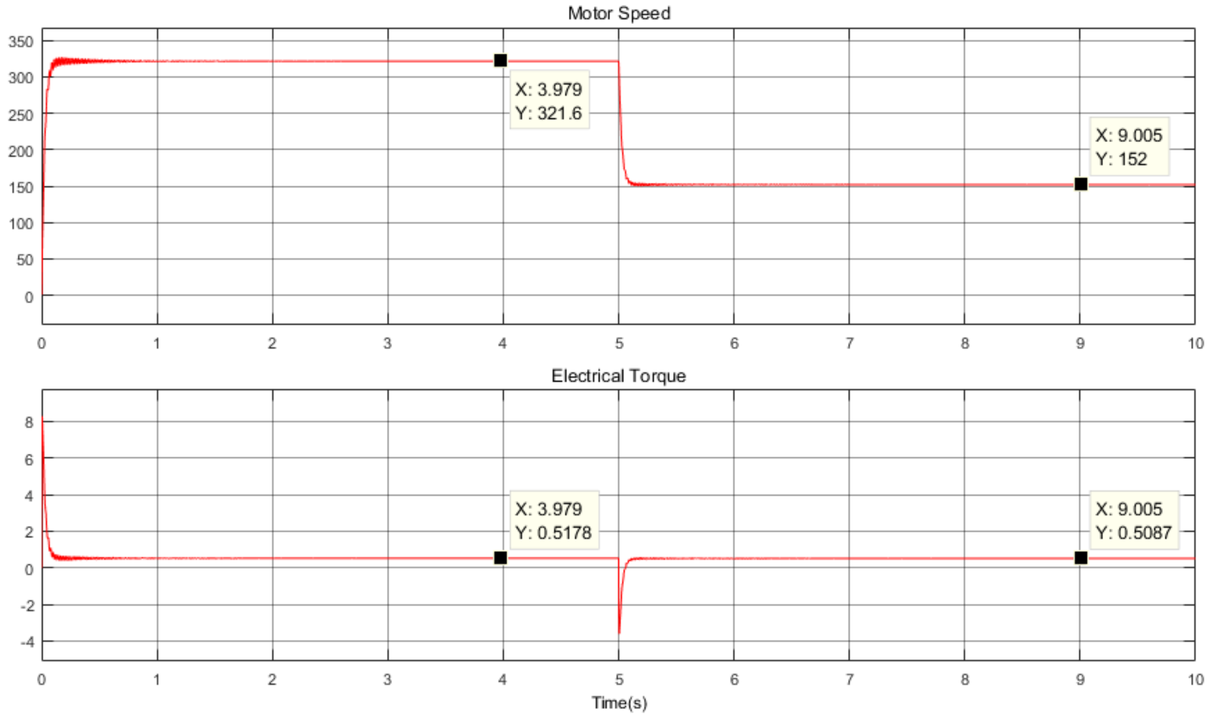

Figure 8: Motor Speed(rad/s) and Electrical Torque(N.m) vs Time(s) Graph

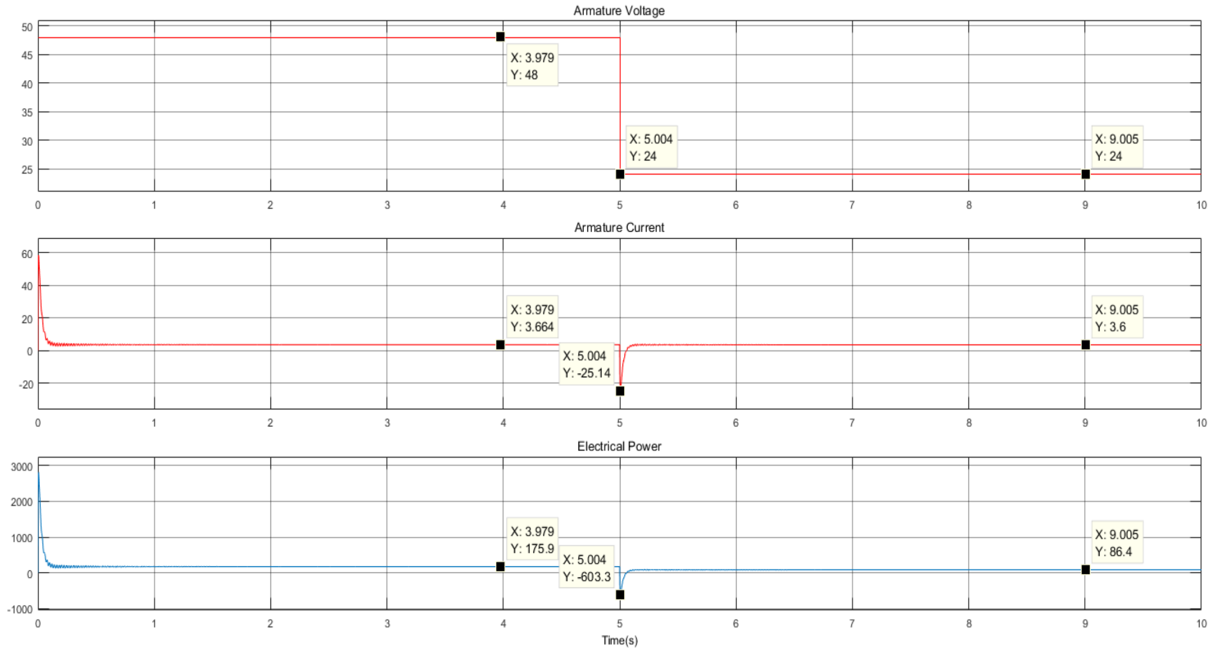

Figure 9:Armature Voltage(V), Armature Current(A) and Electrical Power(W) vs Time(s) Graph

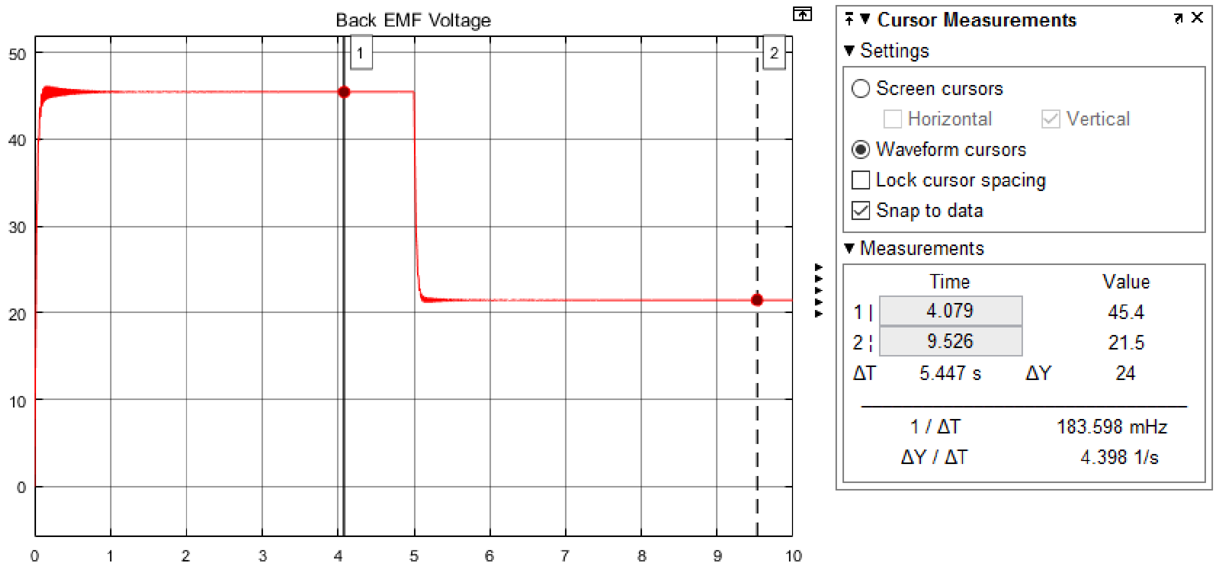

Figure 10: Back EMF Voltage(V) vs Time(s) Graph

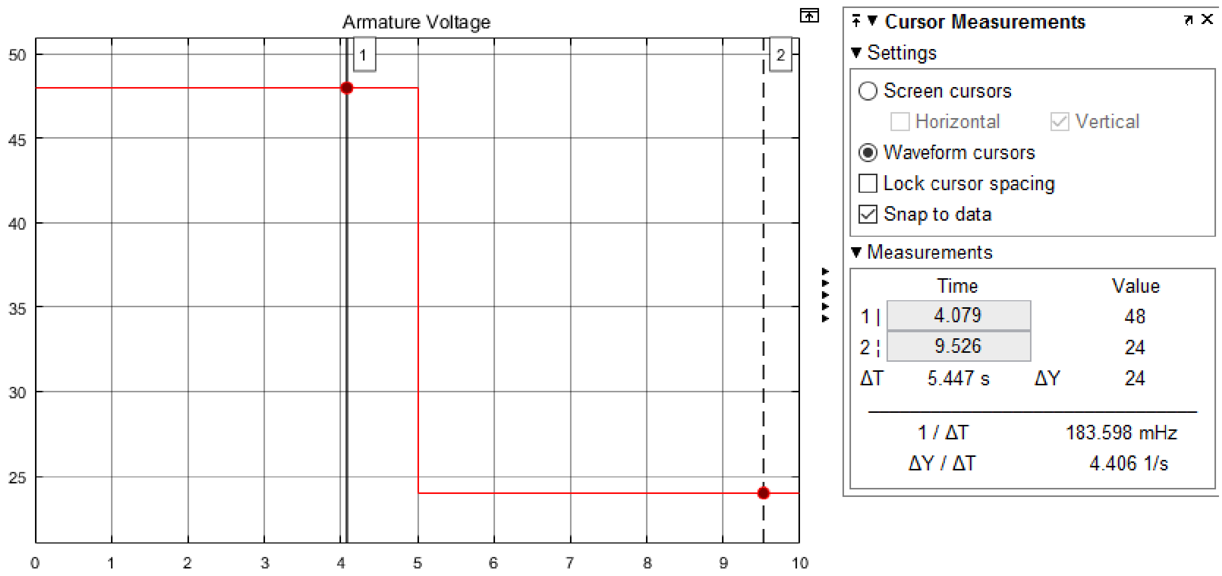

Figure 11: Armature Voltage(V) vs Time(s) Graph

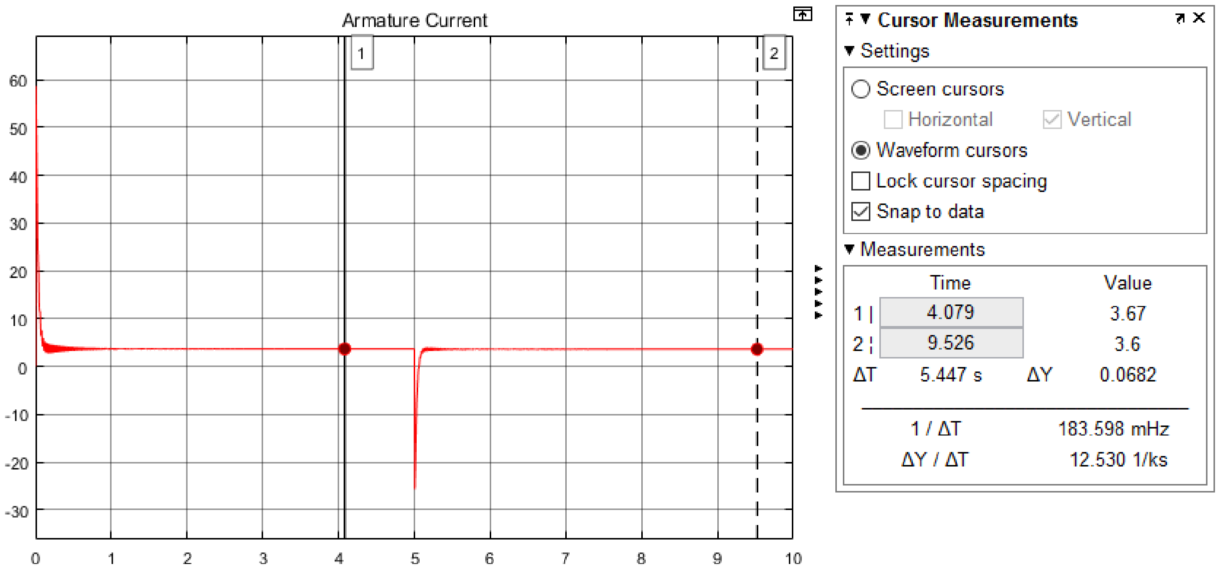

Figure 12: Armature Current(A) vs Time(s) Graph

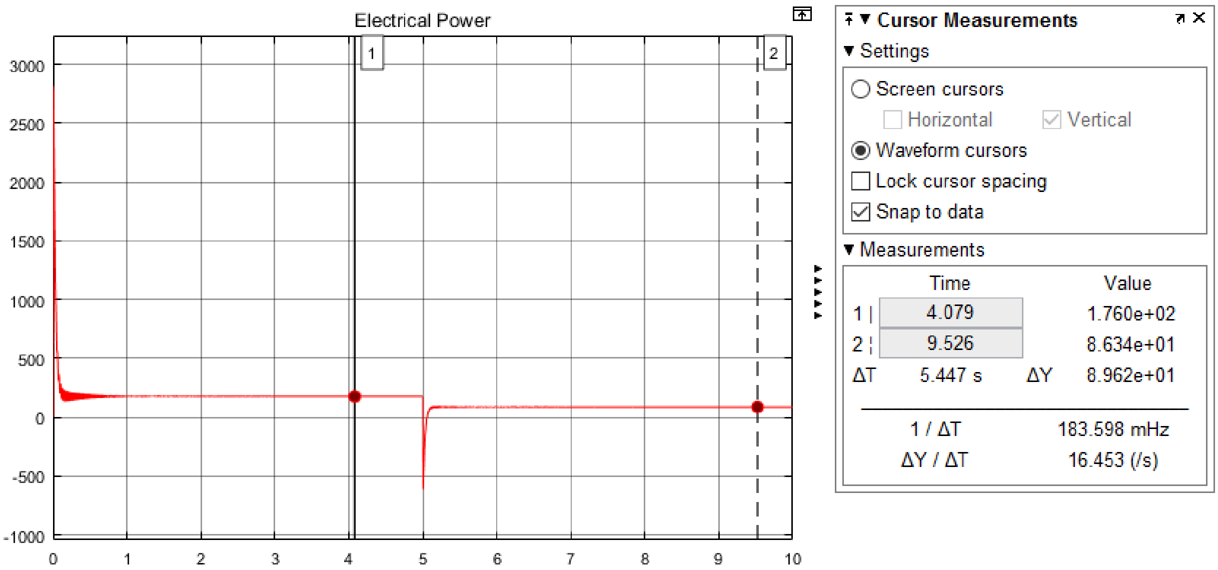

Figure 13: Electrical Power(W) vs Time(s) Graph

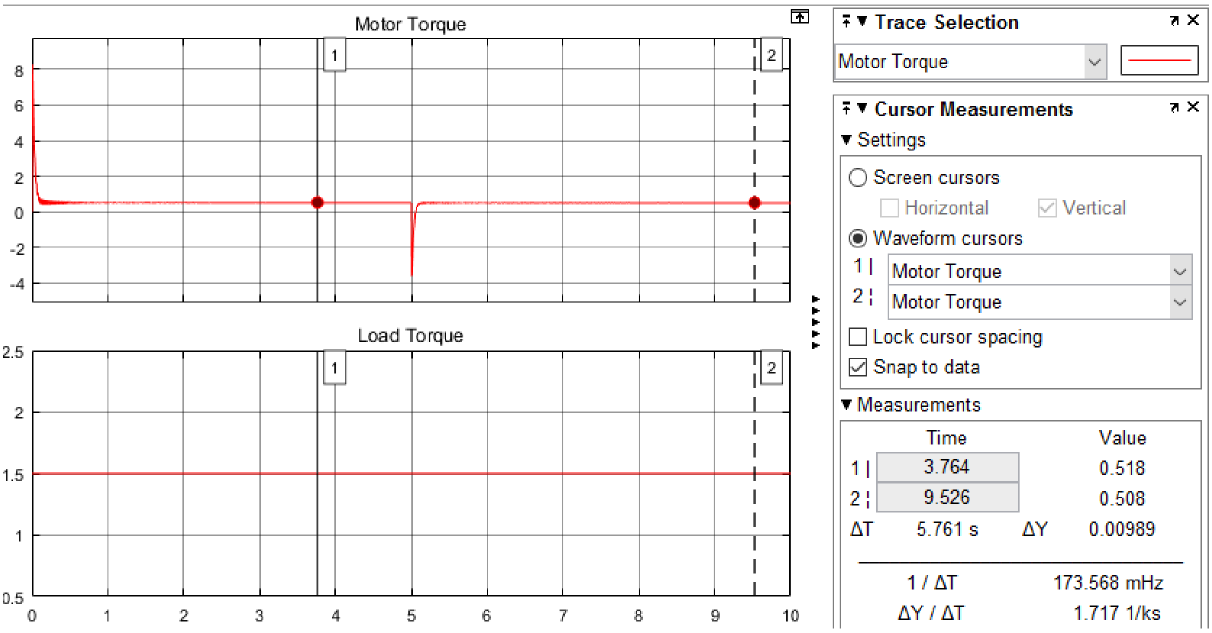

Figure 14: Motor Torque(N.m) and Load Torque(N.m) vs Time(s) Graph

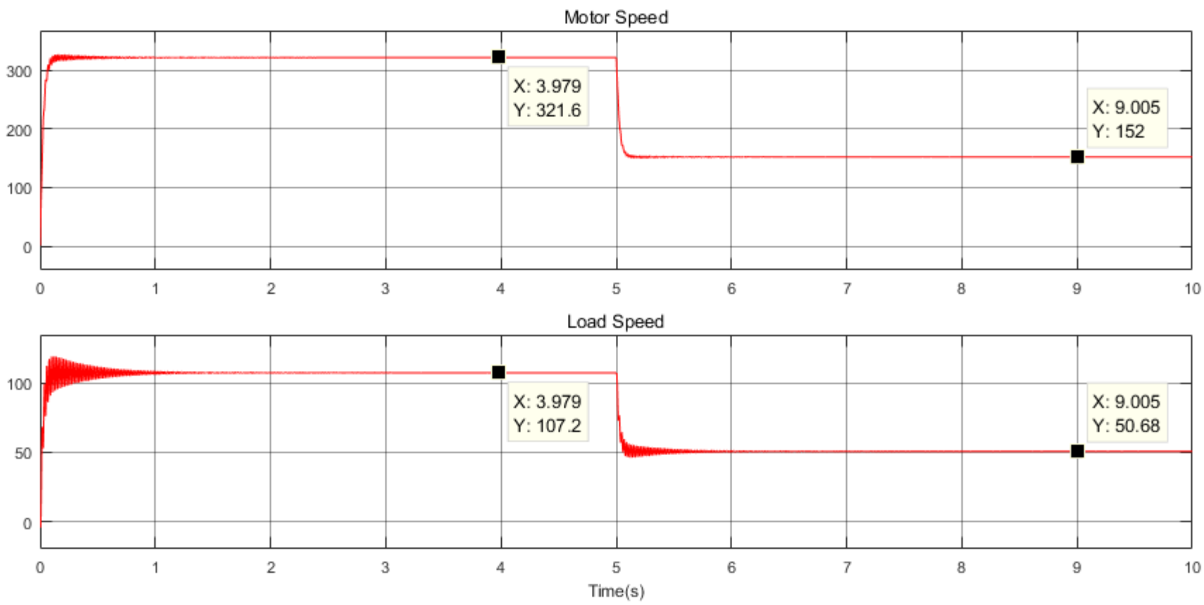

Figure 15: Motor Speed(rad/s) and Load Speed(rad/s) vs Time(s) Graph

Comments

Now, the DC motor is modelled using electrical components. For gearbox, the physical signals converted to Simulink signal and multiplied by gain and then reconverted to physical signal rather than referring. The results of this model are complying with the first one modeled by basic components. Different than first one, this time input terminal voltage is halved at t=5ms.

As in the first one, torque peaks at the beginning and decreases to the rated value while the speed increases to reach the rated speed. When half of the input voltage is applied, as seen on the graphs, the torque rapidly decreases and increases again and reach its rated value. On the other hand, speed starts decreasing and it stays nearly half of the rated speed. Why the torque decreases sharply is that before halving the input voltage the load rotates at the rated speed and it has a torque which is constant. When the input voltage is halved, the load still rotates at that moment with the rated speed and this speed considerably slowly decreases, therefore the back EMF becomes larger than terminal voltage, and the current starts to flow in opposite direction, so we have negative torque. Because of the friction, the load slows down, so back EMF decreases and when it decreases below input voltage, the positive torque is applied and since the load side's torque is constant, the rated torque does not change. Motor now finds a new rated state for halved input voltage. At this state, the speed is nearly halved also, but it is lower than half of the rated speed because since the same torque is applied; in other words, the same armature current flows, Ia*Ra becomes more significant which results in back EMF is lower than half of the rated one, so is speed.

Normally, power flows from input terminal to motor and the load rotates. However, when the input voltage is halved as explained before the current flows in opposite direction; in other words, motor starts to operate in 2nd quadrant, regenerative breaking mode. The problem might be about the power supply; that is, if the power supply is designed to carry power only from input to the load side, the current cannot find a path, so it damages the supply. If we have unidirectional power supply, the armature current should flow in one direction. Therefore, we can connect a diode serial and a MOSFET to dissipate the back-EMF voltage.

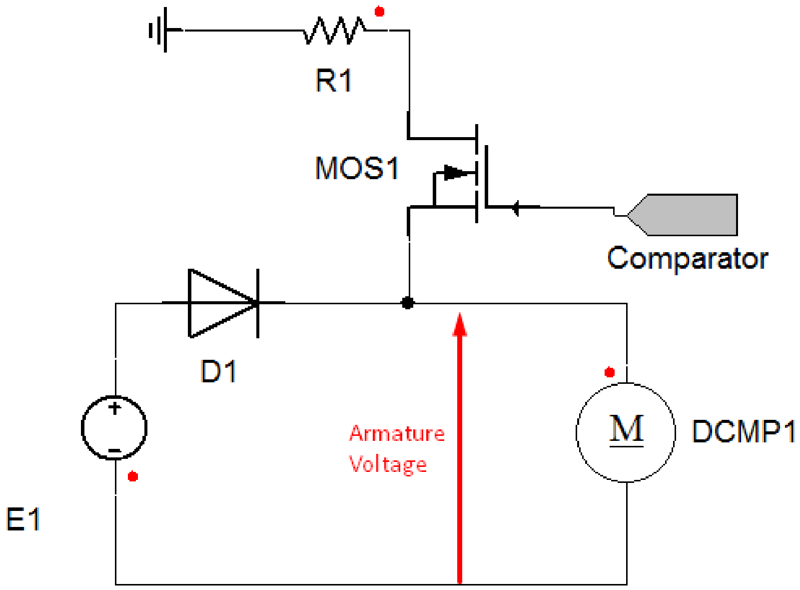

Figure 16: Back EMF Dissipation Circuit

There should be a comparator which compares the armature voltage and input voltage. When the armature voltage is greater than the input voltage, the switch is activated and the power can be dissipated on the resistor as illustrated in Figure 16.

Part III – Simulink Model of DC Motor with Electromechanical Components

Analysis and Results

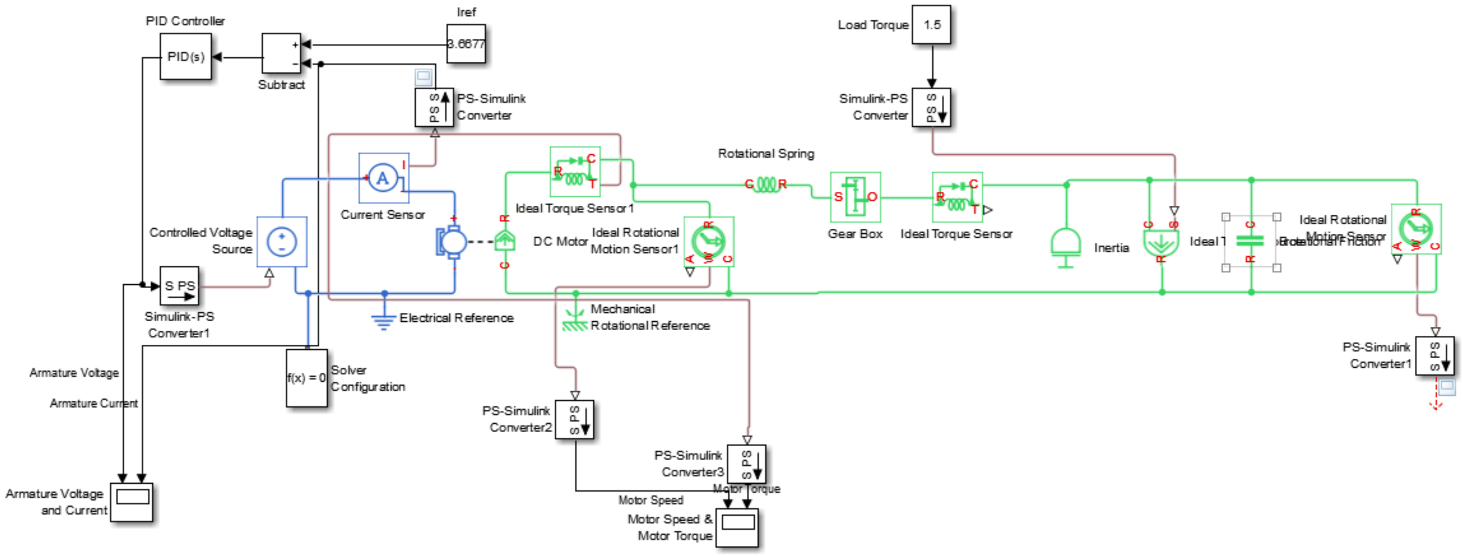

Figure 17: The Simulink Model of DC Motor with Electromechanical Components

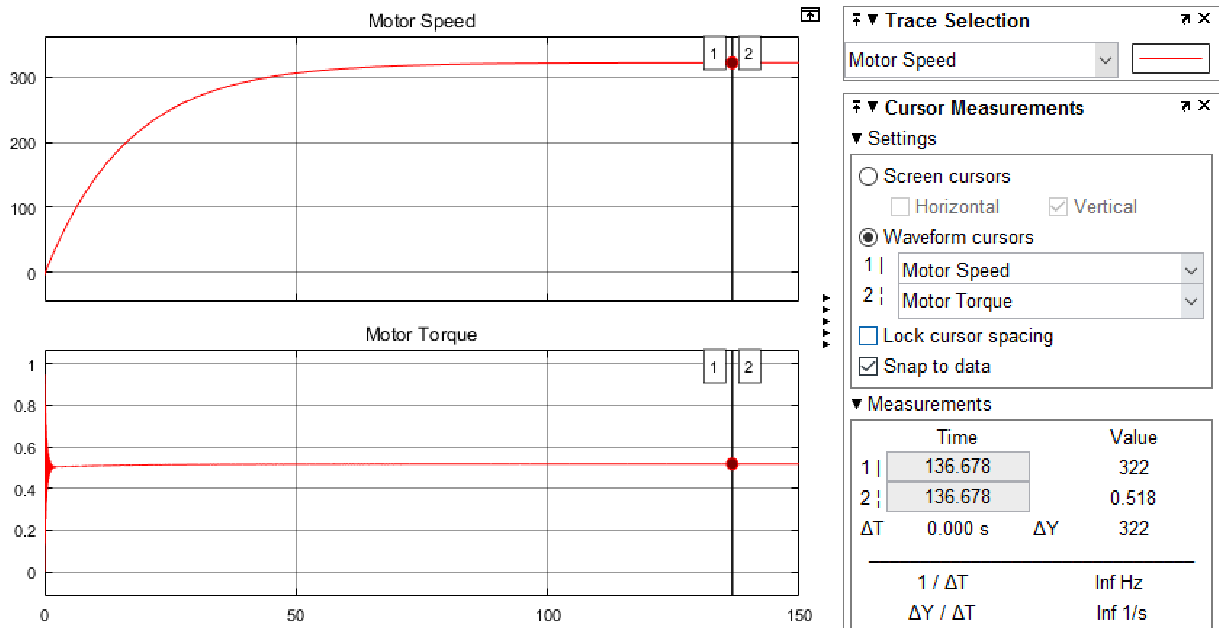

Figure 18: Motor Speed(rad/s) and Motor Torque(N.m) vs Time(s) Graph

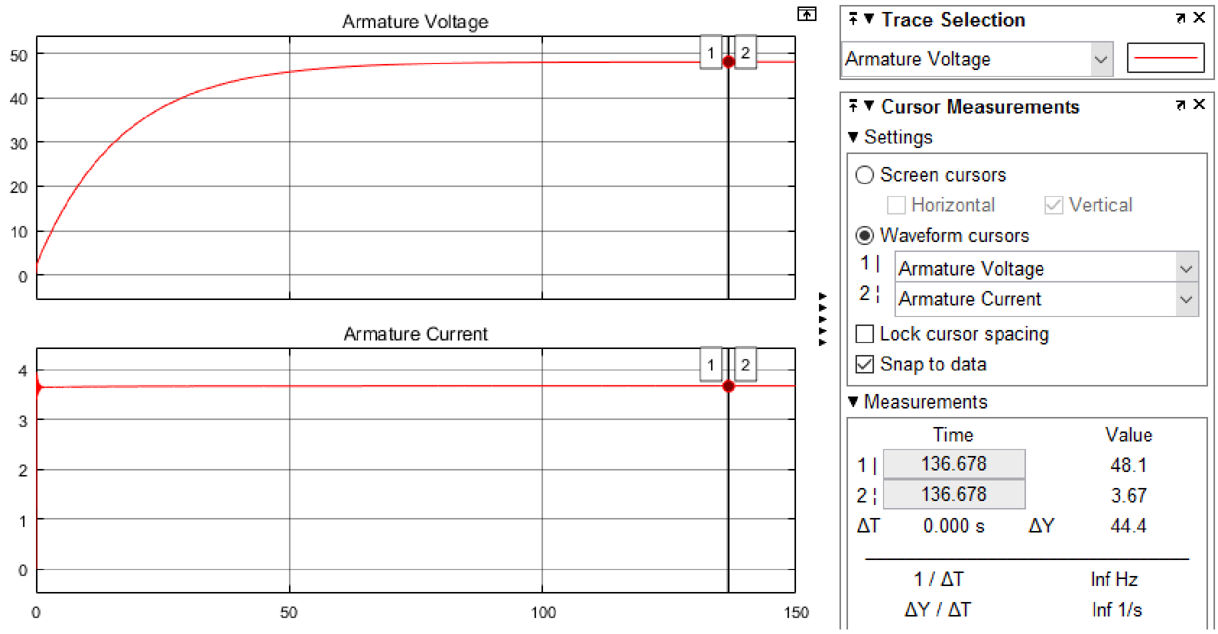

Figure 19: Armature Voltage(V) and Armature Current(A) vs Time(s) Graph

Comments

Now the same DC motor is modelled with electromechanical components. Different than the previous models, armature voltage is controlled with a PI controller by measuring the armature current. In this model, the simulation takes more time to settle due to the PI controller. In part I, we see that the motor accelerated to the rated speed in a couple of hundred milliseconds because we directly apply all supply voltage to the armature, so the current peaks. However, in this part, with a PI controller the supply is controlled, and the armature voltage is increased in time. Now, it takes more time to reach steady state, but there is no ripple on motor speed and there are no huge fluctuations on armature current.

In order to calculate the dissipated power on Ra during the acceleration armature current square integrated over time and the power dissipation for first part found as 53J while in the last part 700J.

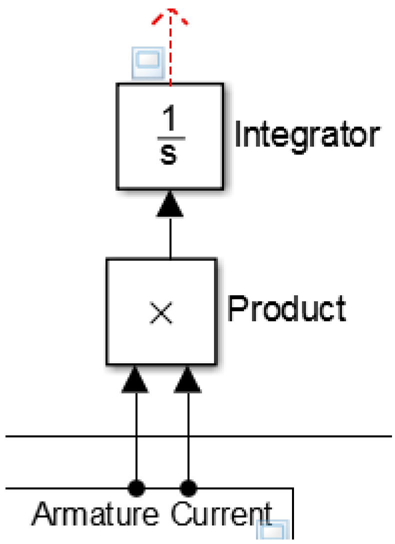

Figure 20: Model to calculate power dissipation

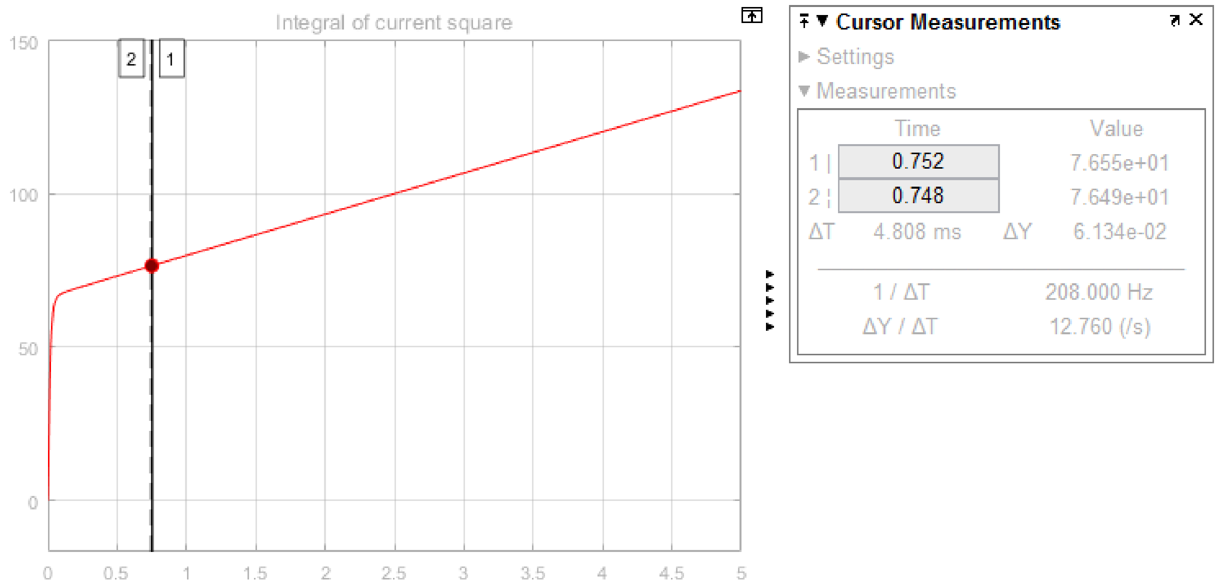

Figure 21: Integral of current square graph for Part I

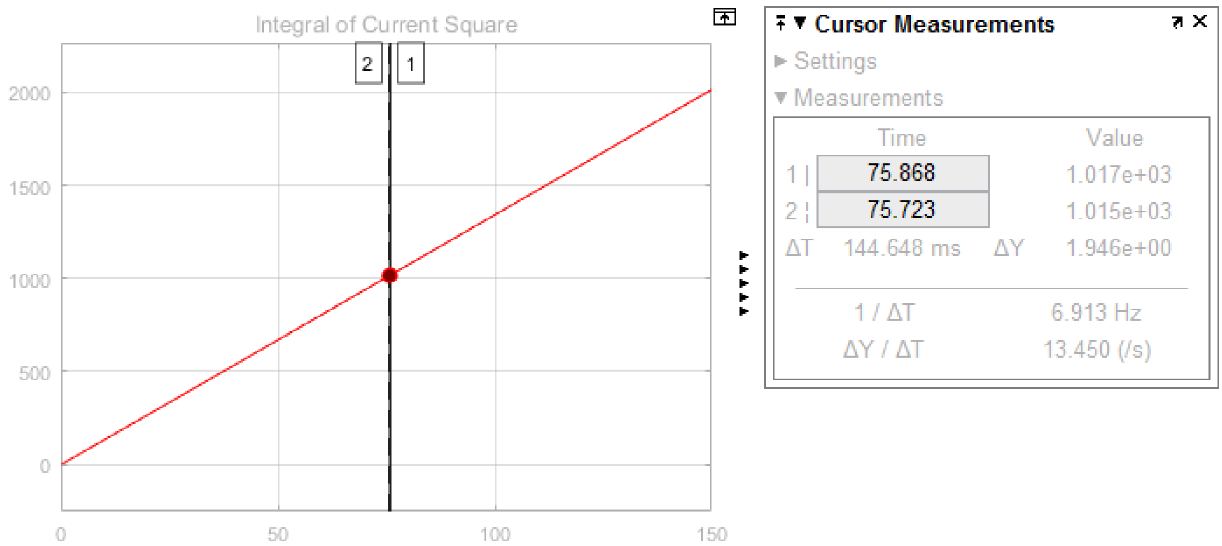

Figure 22: Integral of current square graph for Part III

If we calculate average power, in part I, 70.6 W generated while in part III, 9.3W generated. Therefore, in first application even though less energy dissipated, since it is produced in too short time, the heating is destructively high; however, in soft starting the generate power is lower and the temperature will not be harmfully high. Therefore, soft-starting is important for motor life.

For soft starting a DC Motor when the input voltage is not controllable, an NTC might be connected in series to armature. As conduction continues, the resistance value gets lower, so the armature current rises. Also, the input can be applied as PWM with increasing duty cycle; however, for this application a freewheeling diode should be used.

Conclusion

In this project, a permanent magnet DC Motor is modelled with using simple blocks, electrical blocks and electromechanical blocks. In all three models, compatible results are obtained and the on-hand models are verified. Moreover, during this study, main DC motor behaviours are investigated and commented. The armature voltage – speed, torque – armature current relationships are verified. In Effect of the stiffness & friction is worked. Also, the results of sudden change on the input voltage is studied in this project with the consideration of power flow and operating modes. Furthermore, starting a DC Motor with a controllable input voltage source is completed and the temperature performance is compared with direct starting. Additionally, some soft-starting methods for noncontrollable input power supply are suggested in this work.

Bibliography

Northwestern University. (n.d.). Retrieved from What is Inertia?: http://www.qrg.northwestern.edu/projects/vss/docs/propulsion/2-what-is-inertia.html