**EE535: Control of Electrical Drive Systems**

**Assignment 1: DC Motor Drive**

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**DC Motor Model**

A simulation model of the permanent-magnet DC motor was built. The armature voltage ua and the load torque TL are the inputs of the model. The armature current ia and the angular rotor speed ωM are the outputs of the model. The DC Motor Dynamic Equations are

1. **Per unit Current and per unit Speed**

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Figure : Per unit current and speed

DC Model Transfer Function

is a 120 V step input applied at t = 0.1 s.

Substituting in .

Hence

Which represents a decaying sinusoid starting at t = 0.1s. Hence the simulation results are correct and thus a peak is seen in ia when ua is applied.

1. **Steady State per unit Current and per unit Speed**

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Figure : Steady state current and speed

Steady State Values

In steady state,

The calculations match with the steady state simulation results in Figure 2 .

1. **Limiting Rising Rate of Voltage**

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Figure : Per unit current and speed

Effect of Rate Limiter

is a 120 V / 0.1 s ramp starting at t = 0.1 s and ending at t = 0.2 s.

Hence,

Which represents a pulse starting at t = 0.1 s and ending at t = 0.2 s. The current also has an exponentially decaying sinusoid starting at t = 0.1s, an exponentially decaying cosine staring at t = 0.1 s, an exponentially decaying sinusoid starting at t = 0.2 s and an exponentially decaying cosine staring at t = 0.2 s. It can be verified using this equation that ia(t) = 0 A (0 p.u.) at t = 0.1 s and ia(t) = 9.796 A (0.4898 p.u.) at t = 0.2 s. This matches with the simulation result.

Since,

Hence, is the scaled integral of current. It is a ramp function starting at t = 0.1 s and ending at t = 0.2 s; because current was a pulse function starting at t = 0.1 s and ending at t = 0.2 s. It also has an exponentially decaying cosine function starting at t = 0.1 s, an exponentially decaying sine function starting at t = 0.1 s, an exponentially decaying cosine function starting at t = 0.2 s and an exponentially decaying sine function starting at t = 0.2 s. These results also match with the simulation results.

**DC-DC Converter and Unipolar PWM**

1. **Testing the Model**

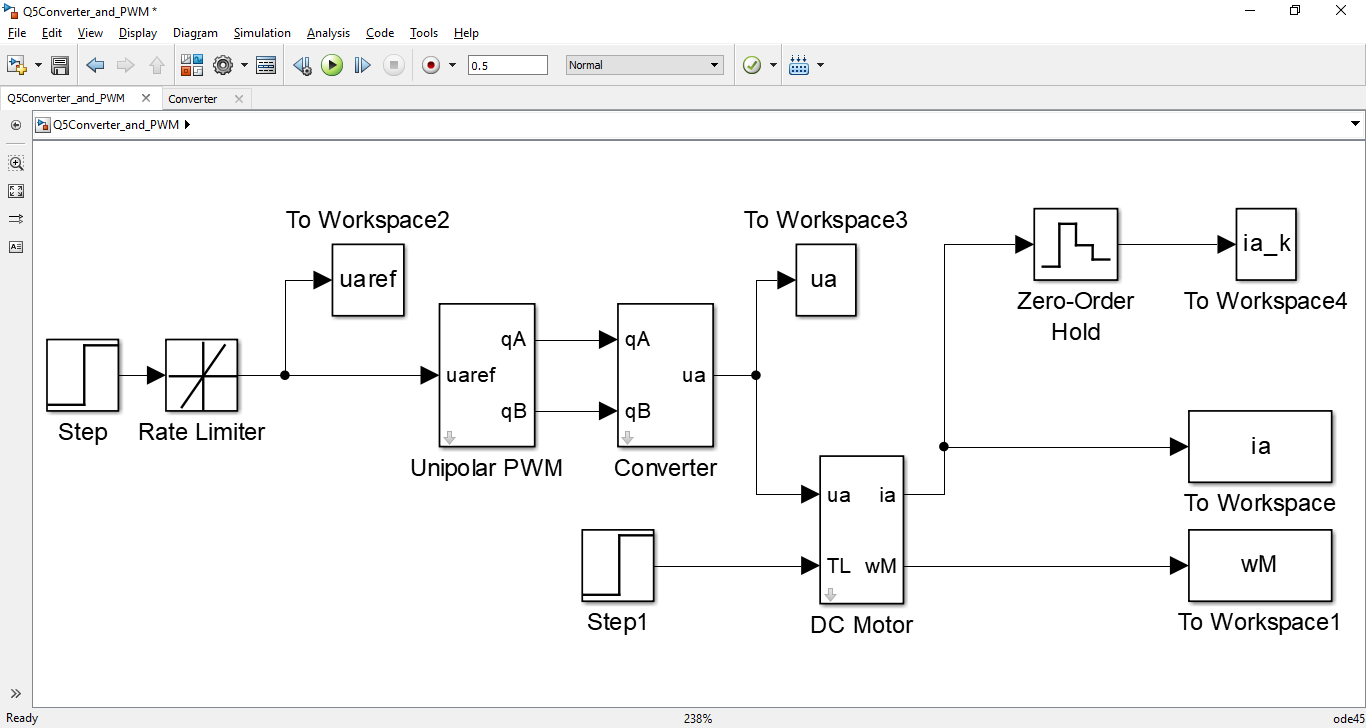


Figure : Voltage Control based Model

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Figure : Per unit current and speed

In this simulation, ua is supplied using PWM technique. The Average value of ua is equal to the reference ua. This is achieved by changing the duty cycles dA and dB. The results of current and speed are almost the same as the last section, where an ideal voltage source was used. The current has much more ripple around the mean value as compared to the last case. This is because the current graph has a much thicker line during transition periods. This is when unipolar PWM is adjusting the duty cycles to reach steady state current. The adjustments cause current to oscillate around the mean value. The Moment of Inertia is quite high hence the speed is unaffected by current oscillations. The speed graph is just like the earlier case.

1. **Plotting Armature Voltage and Current**

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Figure : Steady state current and speed

The Armature current ia (blue) is a triangular wave because La charges up (current rises) when converter output ua is high; and La discharges (current deceases) when converter output becomes zero. The ua on/off sequence is such that the current rises and drops by equal amounts in steady state. Hence the sampled average current ia\_k (red) seems constant.

**Cascaded Control**

1. **Current Control**

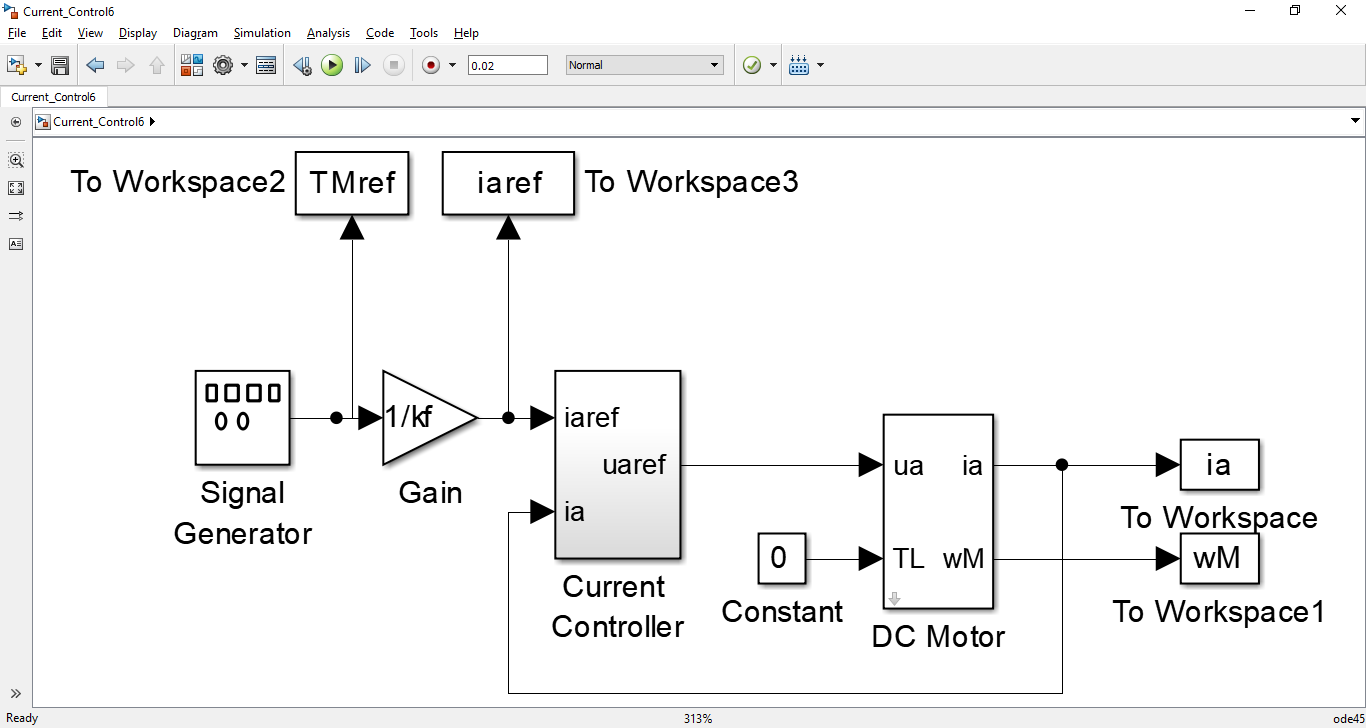


Figure : Current Control Loop Model

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Figure : Torque and Speed Response



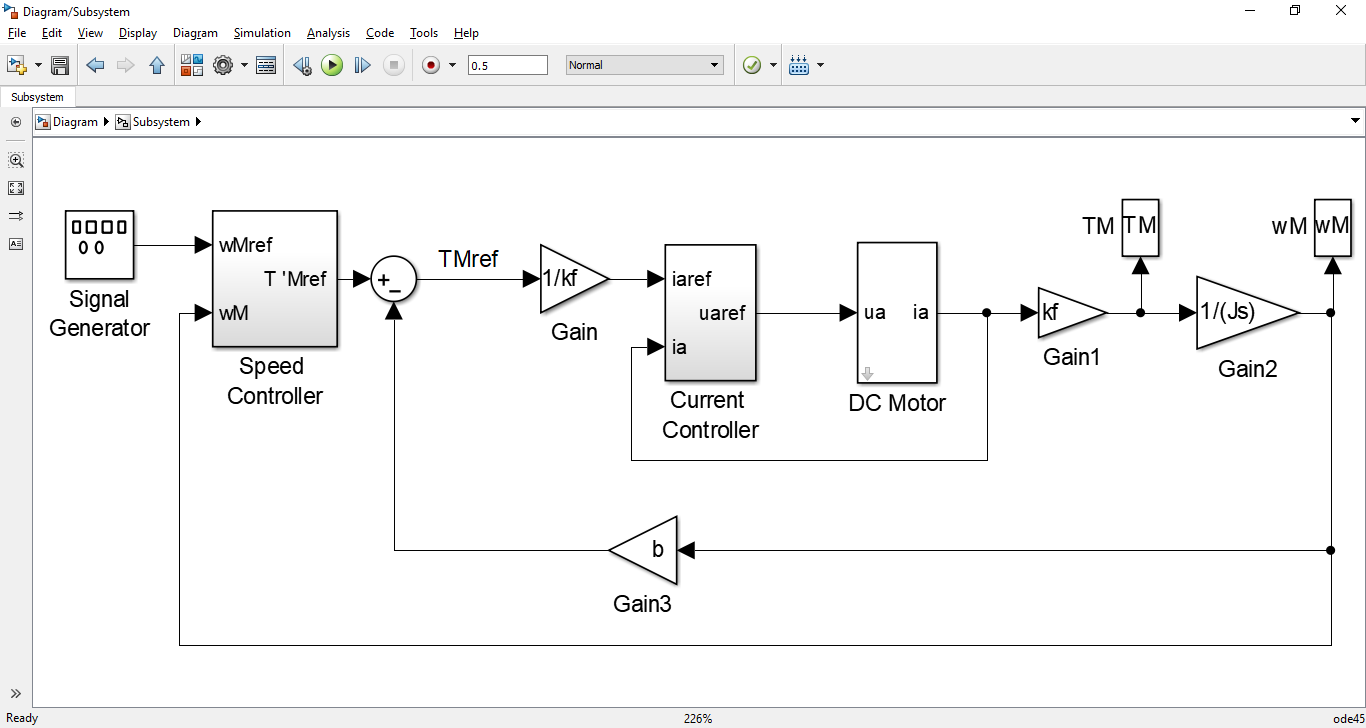
Figure : Torque Response

From the simulation results (Fig. 9), the rise time (from TM = 0.1Nm to TM = 0.9 Nm) is 0.709 ms.

The Time Constant of Torque is . The rise time is 0.6994 ms. Hence the simulation result is correct.

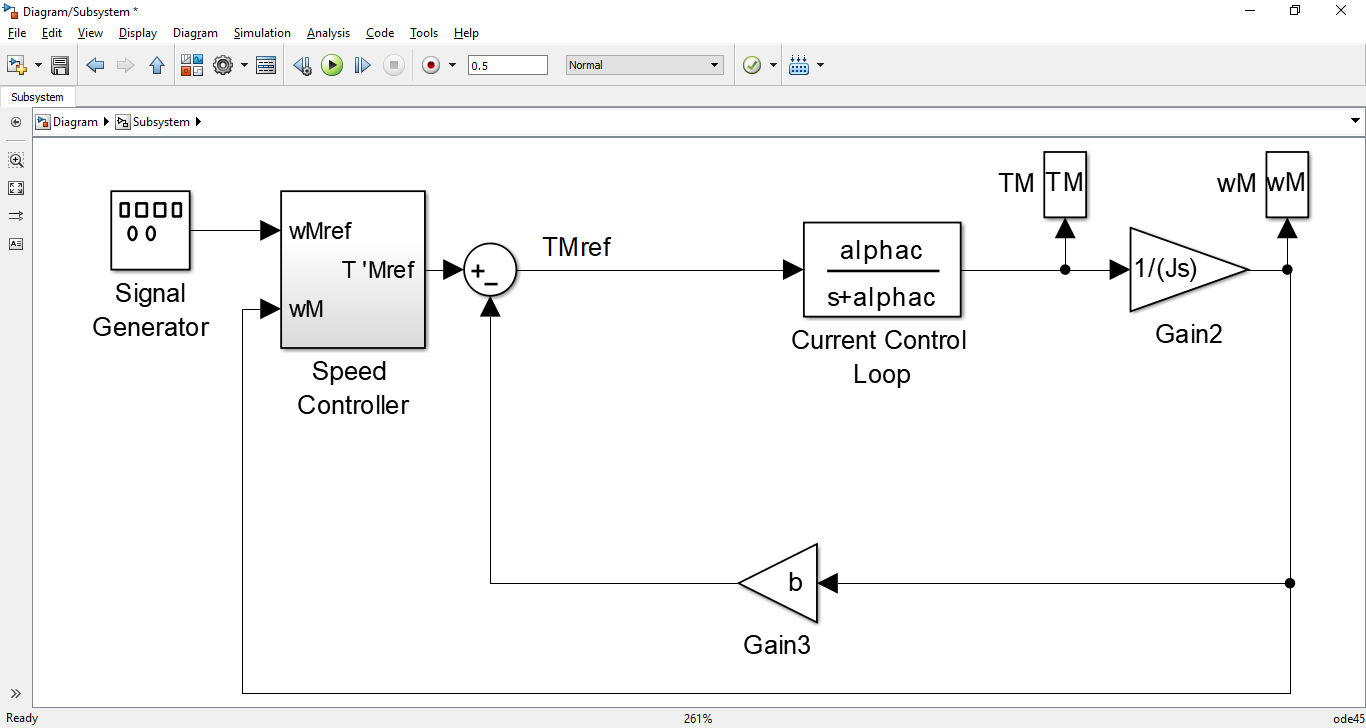
**Speed Control**

1. **Transfer Function**



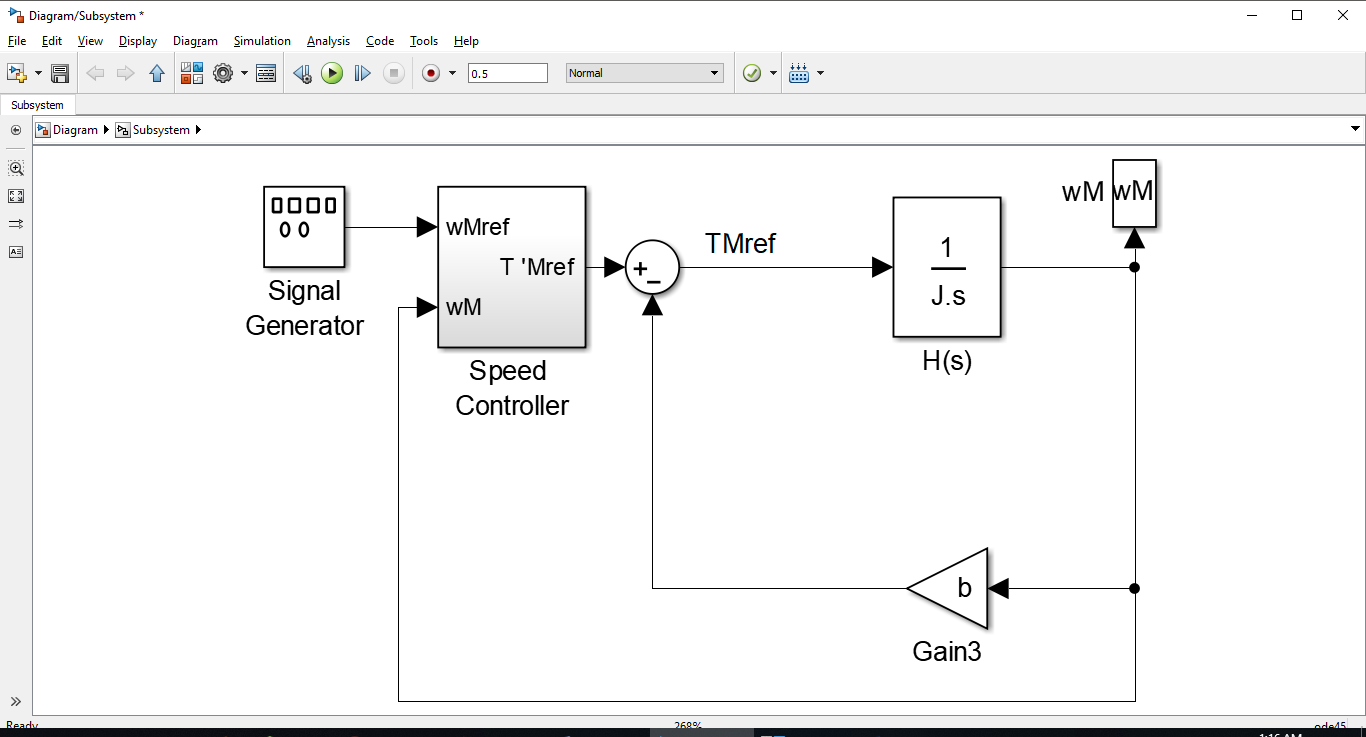
The Current Control loop has the transfer function

Hence,

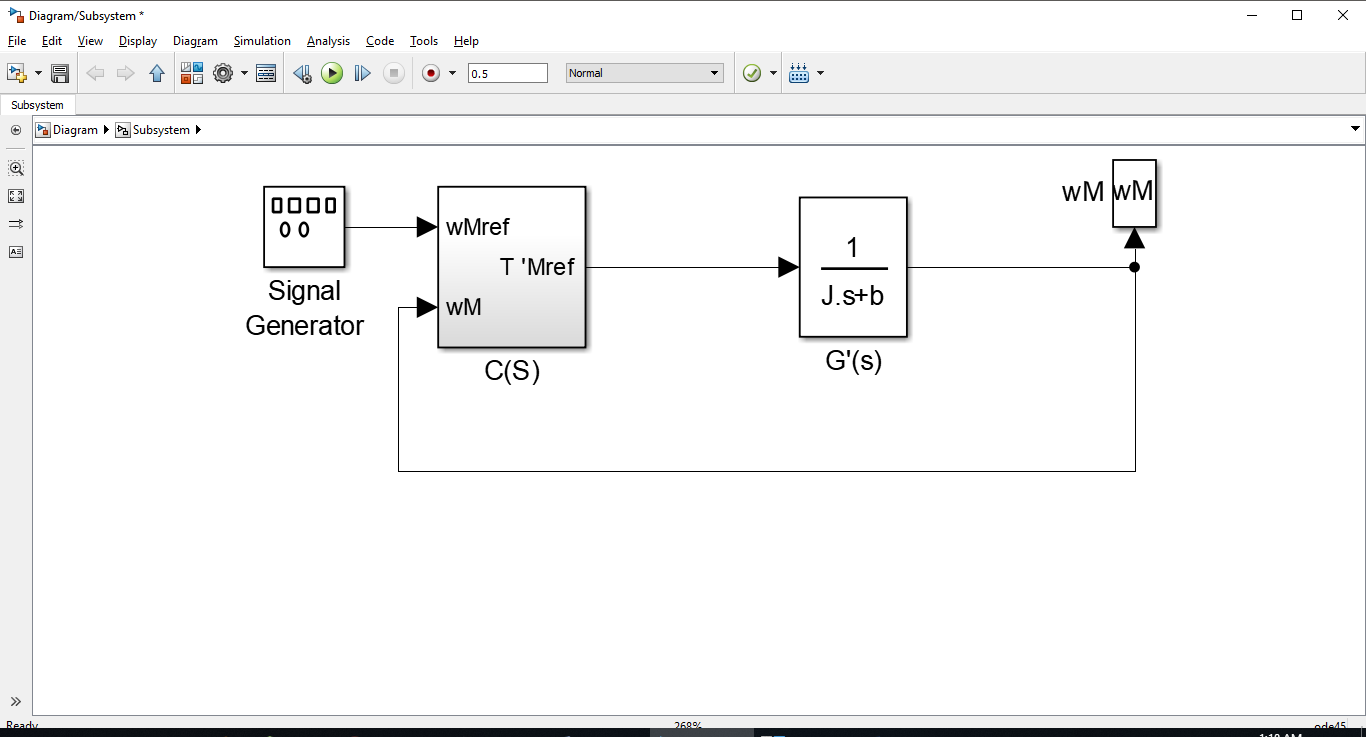


Assuming ideal torque control,

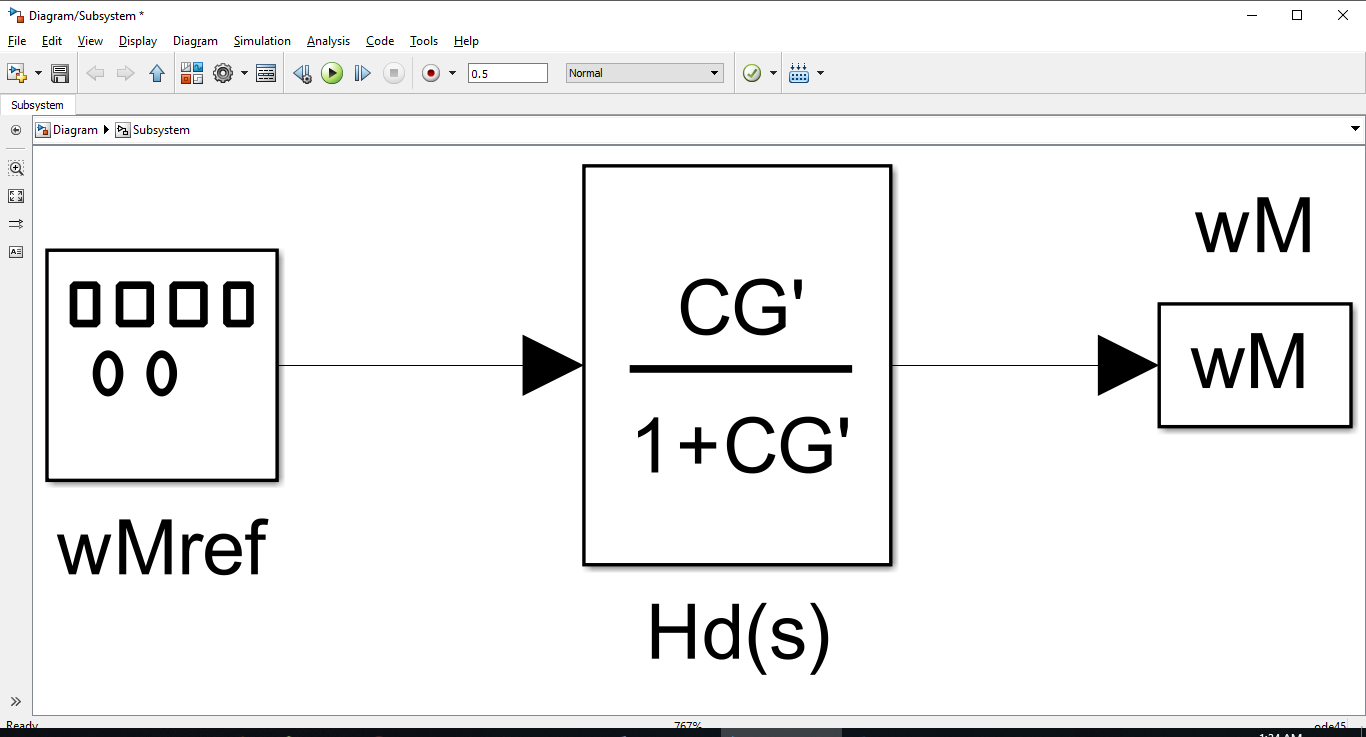
Since,



Using the equation,



The speed PI controller has desired transfer function C(s)=. Hence the desired speed control loop transfer function is



Hence,

At ,

1. **Testing the Model**

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From the simulation results, the rise time (from wM = 0.1 to rad/s = 0.9 rad/s) is 6.4 ms.

The theoretical rise time for wM is:

6.994 ms

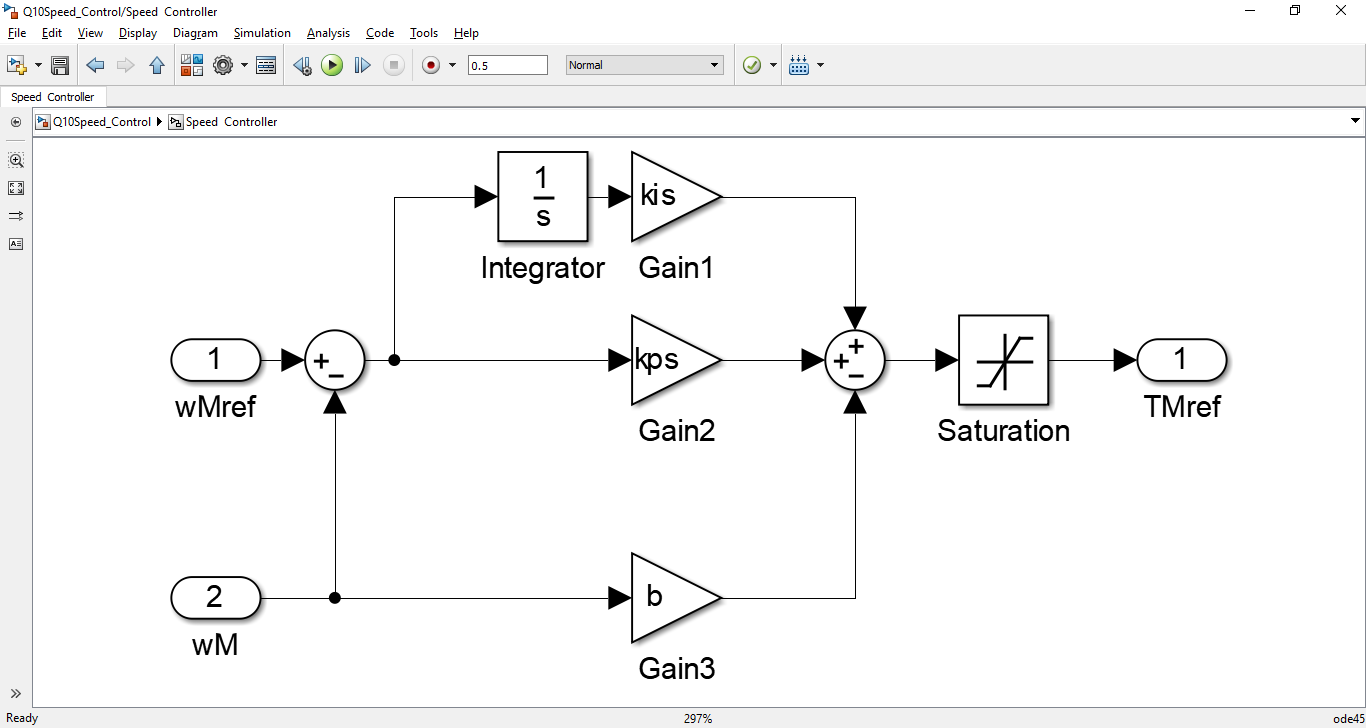
Hence the result matches with the simulation. The speed controller has the desired bandwidth.

1. **Tolerances**

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With temperature changes, Ra increased and La decreased. As a result, the damping of the system increased. We can observe that the speed, current and torque overshoots have decreased. These overshoots were present in the earlier case. The PI speed and current controllers have been affected by the deviations from design parameters. They are now able to generate precise control commands. The references for current and torque do not show oscillations and overshoots before settling to the desired value.

1. **Removing Anti-windup from Speed Controller**



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