Concordia University

Department of Electrical and Computer Engineering

ELEC 6411 - Power Electronics I

Title of the Project

Separately Excited DC Motor Control using Chopper

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ABSTRACT

Back in 18th century, there was a great evolution of Dc motor, and during the 18th century, a great research has been done in DC motor and vastly introduced to the industries. The main reason was the varying of speed according to the requirements and can get the required operation.

Here In this report, The speed of DC motor up to the rated value is controlled by the chopper used as converter. The controller sends a signal to the chopper's defined firing circuit, causing the chopper to produce a flexible voltage connected to the motor's armature in order to reach the desired speed [1].

A thorough prototype of a separately excited DC motor is designed in this paper to eliminate the delay and provide quick control., PI controller is used, and In this way inclusive model of DC drive is obtained. In addition to that, current and speed controller has been designed.

Matlab Simulink library is used to completely model the DC drive system. The simulation of DC drive are done under two circumstances.

- Variable speed
- Variable load torque

CHAPTER 1: Introduction

For industrial application high performance motor are very important which has an excellent speed tracking facility system and variable load response. DC motor has very well known for controlling the speed. The DC motor's field is directly connected to the DC power source, allowing for exact voltage control, which is critical for speed and torque control applications. In industrial application, Dc motor has been the most preferable option because of their ease of application, simplicity, affordable cost and smooth reliability. In the same way, when compared to an AC drive system, DC drive system are simple and easy to understand. DC motor drive system has a remarkable history for being used as an modifiable speed. Like say for example a Heating blowers provides a hot air for wide range of speed.

D.C motor have been the primary source for the locomotion where a drag force is obtained from electric energy. Similarly Dc motor includes cranes air compressor elevators etc.

Dc motor is SISO system, which has single input and single output having torque/speed characteristic, which are well-matched by adjusting the terminal voltage properly throughout a wide speed range [2]. Nowadays in electric traction induction motor, brushless DC motor and synchronous motor play vital role.

For advanced control algorithm DC motor are always good option, since the DC motor speed control can also be applied to other types of motors.In this report two techniques are used to control the speed of DC separately excited motor.

- For below rated speed, armature voltage is used to vary the speed.
- For above rated speed, Field flux should be changed in order to achieve the desired speed.

CHAPTER 2: Literature Review

2.1 CHOPPER :

A Chopper is power electronics device through which we obtained variable DC voltage. DC chopper exactly behave like AC transformer and it is more efficient because the conversion process includes only one stage. Due to efficient working choppers are now used for different application all over the world.

The future of choppers in automobile industries are very bright because they are likely choppers for the control of speed.

Normally, for chopper circuit different power semiconductor devices are used like BJT, MOSFET, IGBT and GTO. As we know that these devices act like a switch and no current will flow through the device when the switch is OFF and Current will start flowing when the switch is ON.

The voltage drop across these switch are 0.5 to 2.5V. but here for simplicity these voltage drop has been neglected.

2.2 PRINCIPLE OF CHOPPER OPERATION:

Chopper act as a fast switch and it directly connect and disconnect the source from the load. The following figure show the chopped load voltage across the constant DC voltage of magnitude Vs.

During the period, T_{on} the Chopper is ON, and the load voltage is equal to source voltage Vs and during the period T_{off} the load voltage is equal to 0V. And on the similar manner the output voltage of the chopper is produced at the terminal [3].

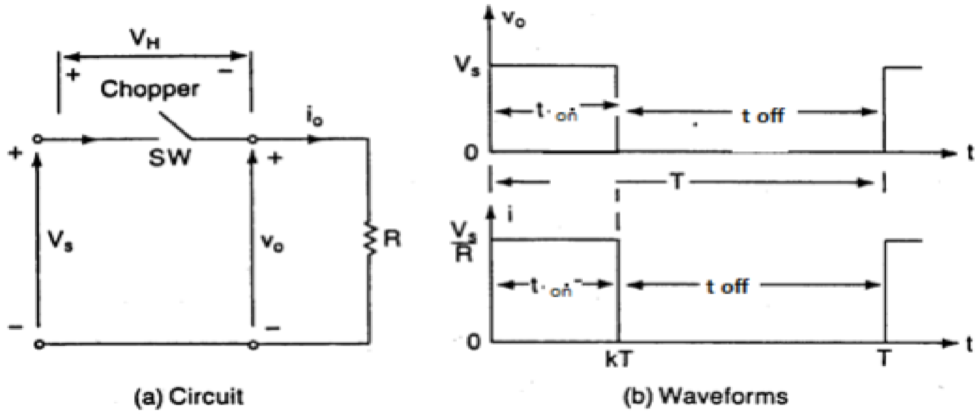


Fig:1 Voltage and Current waveform of Chopper Circuit

Mathematical Calculation:

$$Average\ voltage, V_o = \frac{T_{on}}{T_{on} + T_{off}} * V_s$$

$$= \frac{T_{on}}{T} * V_s$$

$$= \propto V_s$$

Where $\alpha = \frac{T_{on}}{T_{off}}$

The output voltage can be changed by altering the duty cycle, as shown in the equation above. In term of frequency we can write

$$V_o = f * T_{on} * V_s$$

2.3 Different Control Methods:

The duty cycle is changed to alter the output voltage, and this can only be done by repeatedly opening and shutting the semiconductor switch. Here in this report we would discuss only two strategies for varying the duty cycle.

- Time ratio Control (TRC)
- Current Limit Control.

2.4 Time ratio Control (TRC):

In this control strategy, time ratio $\frac{T_{on}}{T}$ is varied. This proportion can be examined in two ways.

1. A system with a constant frequency.
2. 2. A system with a variable frequency.

These two methods are explained in the following sections.

- **Constant Frequency System:**

The chopping frequency is kept constant while Ton is adjusted in this manner. Now changing the T_{on} means that on period is increased or decreased as a result of which the width of pulse is changing, as such schemes is also called pulse width modulation scheme (PWM).

- **Variable Frequency system:**

In this technique, the chopping frequency is adjusted, and either the ON time or the off time is kept constant.

Finally, this technique alters the width of the signal, which is why we call it pulse width modulation..

2.5 CURRENT –LIMIT CONTROL:

The highest load current and lowest load current are used to turn on and off the chopper circuit in this control method. The chopper turn OFF when the load current passes the upper limit. And when the load current fall down below the low limit of current, the chopper is turn ON [4]. Therefore, it means that the switching frequency can be controlled by fixing the upper limit and lower limit of current.

Current control system is more complex because it need to be some sort of tracking system so therefore in this report PWM is technique is used for the power control in chopper circuit.

CHAPTER 3: DC Motor

Separately excited DC motor

Separately excited dc motor is the one of the most common types of dc motor. To better understand it, the equivalent circuit of SEDC is given below:

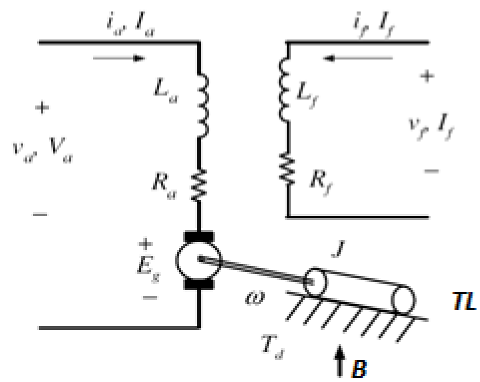


Fig.2 Model of Separately DC excited motor

As the name suggests, in separately excited dc motor, Unlike a shunt motor, where the field winding is fed directly from the armature circuit, the field winding is supplied from a separate voltage source.

It works similarly to a dc shunt motor in terms of operation. Lf and Rf are the filed inductance and field resistance of the field circuit and current If flows through the circuit. In the armature circuit, armature resistance and inductance are represented by La and Ra while Eg is the internal generated voltage.

3.1 Working principle and Field and armature equations

DC motors work on a basic concept. is that “whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force”. When field winding of a SEDC is supplied with field current then it produces a field magneto motive force, which in return produces flux in the machine. So this flux is directly proportional to back EMF (also known as speed voltage) and torque produced in the machine given by equations [5]:

$$E_{g=k_v\varphi\omega} \tag{3.1}$$

Whereas

E_g is the back emf ()

k_v is the motor voltage constant

φ is the flux in the machine

ω is the speed

$\tau_{d=k_t\varphi i_a}$	(3.2)

Whereas

τ_d is the torque developed

k_t is the torque constant

i_a is the armature current

Practically there are frictional and copper losses too, so the torque developed becomes

For normal operation, the developed torque must be equal to the load torque plus the friction and inertia, i.e.:

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L$$

where

B : viscous friction constant, (N.m/rad/s)

T_L : load torque (N.m)

J : inertia of the motor (kg.m^2)

In order to find instantaneous armature and field voltage, we have following relation

$$v_f = R_f i_f + L_f \frac{di_f}{dt}$$

where R_f and L_f are the field resistor and inductor, respectively

Instantaneous armature current :

$$v_a = R_a i_a + L_a \frac{di_a}{dt} + e_g$$

where Ra and La are tne armature resistor and inductance respectively

3.2 Characteristic Curves of SEDC.

Three main characteristics curves of the Dc are given below

1. Torque versus. current in the armature.
2. Speed versus the current in the armature.
3. Terminal characteristics speed vs torque

3.2.1 Torque vs armature current

Since the torque produced is directly proportional to the armature current, the plot is a straight line, as shown in the figure 3.

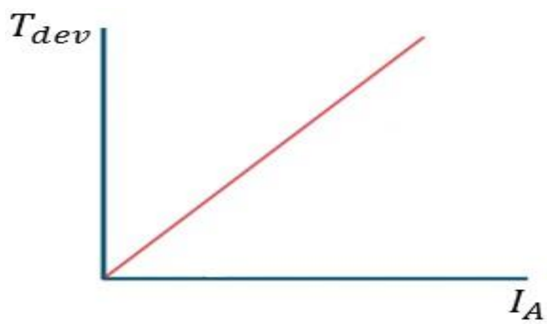


Fig.3 Relation between Torques developed and armature current

3.2.2 Speed vs armature current

From equation (3.1), we have

$E_{g=k_v\varphi\omega}$	(3.1)
$V_{a=E_g+i_aR_a}$	(3.3)
$V_{a=k_v\varphi\omega+i_aR_a}$	
$\omega_{m=\frac{V_a-i_aR_a}{k\varphi}}$	(3.4)

Since the flux is supposed to be constant, the speed drops as the armature current increases, yet flux falls due to the armature reaction, which is inversely proportional to the motor speed, as highlighted by equation (3.4) so only a minor decrease in speed is observed as clearly reflected by the figure given below:

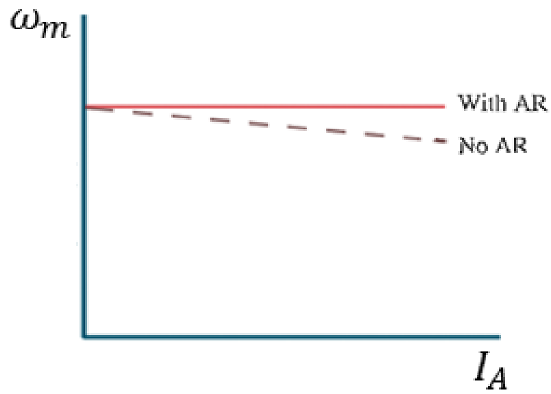


Fig.4 Graphical relation between speed and Armature Current

3.2.3 Torque vs Speed

$$i_{a=\frac{\tau_d}{k\varphi}}$$

Substituting the value of i_a in the equation (3.3), we have

$$\omega_{m=\frac{(V_a-\tau_d R_a/k\varphi)}{k\varphi}} \quad (3.5)$$

Ideally, the toque-speed characteristics of such typeof motor is straight line with negative slope but practically, with armature reaction, speed is almost constant.

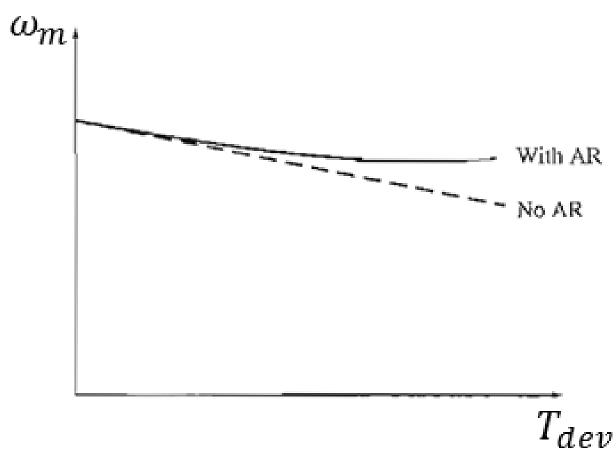


Fig.5. Graphical Relation between speed of DC motor and torque developed

3.3 Torques and speed control methods

There are three methods of varying speed-torque characteristics of a dc motor, which are given below:

1. By altering the resistance of field.
2. By altering the voltage of Armature.
3. By the addition of a resistance in the armature circuit

3.3.1 By varying the Field resistance

When the field resistance of a separately excited dc motor is varied, then field current decreases which results in decrease in the flux. Decrease in flux causes reduction in back emf which then reduces motor's armature current. Decrease in flux reduces speed while at the same time, increase in armature current causes increase in torque developed. Figure given below indicate impact of varying the field resistance inorder to change the torque-speed characteristics [6].

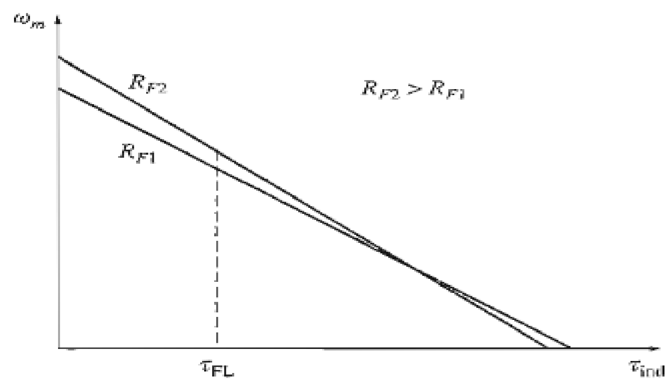


Fig.6 Graphical relation between speed and torque developed with respect to Field resistance

3.3.2 By varying terminal voltage

In this method, field voltage of the motor is kept constant while armature voltage is varied in order to obtain desired torque-speed features. The graph given below describes the behavior at two different speeds.

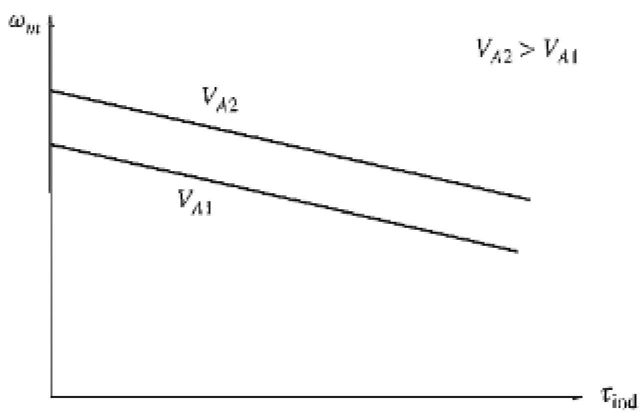


Fig.7 Graphical relation between speed and torque developed with respect to terminal voltage

3.3.3 By adding a resistance on the armature circuit

This method decreases the slope of torque-speed characteristics of motor thus causing to operate slowly. Also this method causes unnecessary resistive losses which is why this method is not commonly used. Decrease in slope can be clearly observed in the figure given below

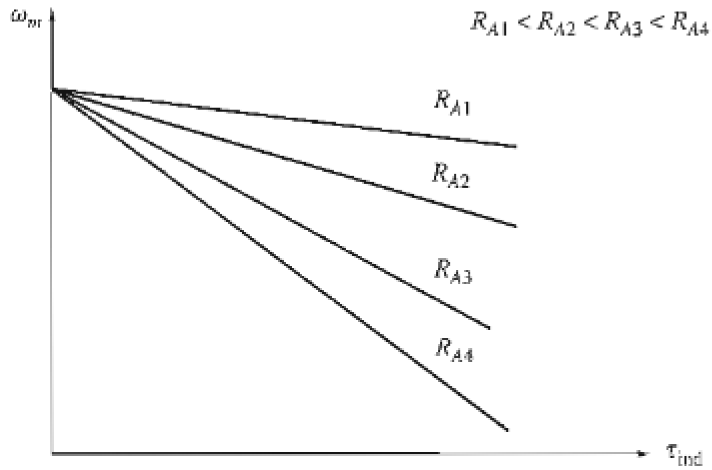


Fig 8 Graphical relation between speed and torque developed with respect to additional resistance with armature circuit

3.4 Base speed and Field Weakening

When the motor runs at rated armature voltage and current and rated field current then its speed is said to be base speed. According the figure given below

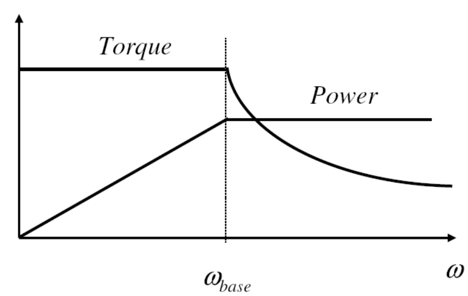


Fig. 9 Constant torque and Constant power regions.

3.4.1 Case I: Constant torque region

When the field current and armature current remain constant while the armature voltage is changed to increase or reduce the speed. The condition for operating in constant torque region is that speed should not exceed the base speed.

3.4.2 Case II: Constant power region

For machine to work in constant power region, its operating speed should be kept higher than base speed. In this region, armature voltage is maintained at constant point while field current is varied.

CHAPTER 4: Drive System for DC motor.

4.1 The Main Idea:

The primary concept behind DC motor speed control is that the output speed is adjusted by modulating the armature voltage while the field voltage remains constant. By comparing the output speed to the reference speed, error signals are created and provided to the speed controller. When there is a mismatch between the reference and output speeds, the controller's output varies. Basically the output voltage of the controller is then used to control the variation of duty cycle [3].

The converter produced the E_c output voltage, which is required to restore the motor's target speed. As we know that the potential divider is linear device which approximately generate output linear voltage so potential divider is used to provide the reference voltage. Tacho-generator is used to measure the speed of the motor. The output voltage of Tacho contain some irregular ripple in order to remove the ripples filter with some gain is used in order to bring back the output of Tacho to controller level.

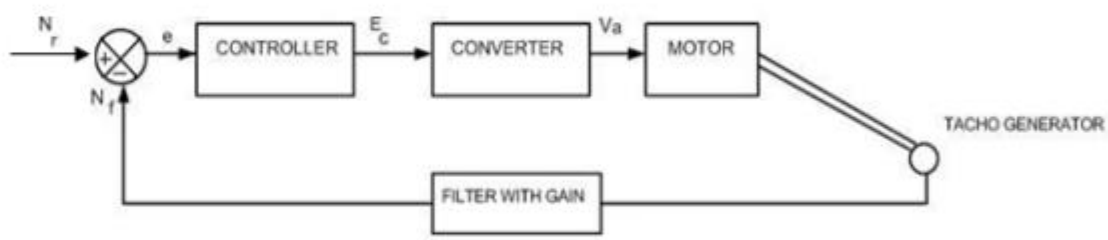


Fig: 10 Model of a closed loop system for DC motor speed control.

4.2 MODELING OF SEPARTLY EXCITED DC MOTOR:

We know the basic equation of Dc separately excited motor is

$$\boldsymbol{V_a = E_g + I_a R_a + L_a \frac{dI_a}{d_t}}$$

$$\boldsymbol{V_a \text{ is the armature voltage}}$$

$$\boldsymbol{E_g \text{ back emf of the motor}}$$

$$\boldsymbol{I_a \text{ is the armature current}}$$

$$\boldsymbol{R_a} \textbf{\textit{ is the armature resistance}}$$

$$\boldsymbol{L_a} \textbf{\textit{ is the inductance of armature}}$$

Similarly we know that torque equation will be given by:

$$T_d = \frac{Jd_\omega}{d_t} + B_\omega + T_L$$

$$T_L \ \ is\ load\ torque$$

$$T_d\ is\ the\ torque\ developed$$

$$J\ is\ the\ moment\ of\ inertia$$

$$B\ is\ the\ fricition\ coefficient\ of\ the\ motor$$

$$\omega\ \ is\ the\ angular\ velocity$$

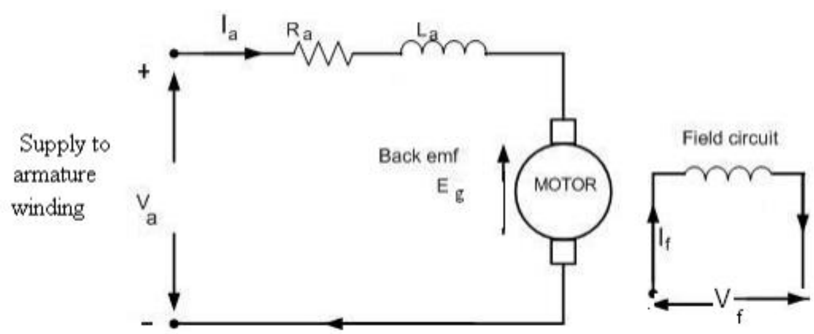


Fig: 11 Electrical Circuit of separately excited DC motor

$T_d = \frac{Jd\omega}{dt} + T_L$---------- (i)

If B=0 so new torque equation will be developed like above equation.

Using Kv as the back emf constant and Φ field flux.

The back emf equation will now be: $E_g = K\ \Phi\ \omega$ ---------(ii)

$T_d = K\Phi$ Ia---------- (iii)

After taking the laplace of the basic motor equation we will get

$$I_a(s) = \frac{V_a - E_g}{R_a + L_a s}$$

Now put equation (ii) into the above equation: we will get

$$I_a(s) = \frac{V_a - K\,\Phi\,\omega}{R_a(1+\frac{L_a s}{R_a})}$$

And also we can write

$$\omega\ (\mathrm{s}) \quad = \frac{T_d - T_L}{JS} = \frac{K\Phi\ \mathrm{Ia} - T_L}{JS}$$

We know that armature time constant $T_a = \frac{L_a}{R_a}$

After simplification:

$$\frac{\omega\ (\mathrm{s})}{\mathrm{Va(s)}} = \frac{\mathrm{K\Phi}}{\mathrm{Ra}(\ 1\ + (\mathrm{K}^2\Phi^2\ /\mathrm{Ra})}$$

Let assume $T_m = \frac{JR_a}{(\mathrm{k\Phi})^{\ 2}}$ as electromechanical time constant.

Then the above equation can be written as

$$\frac{\omega\ (\mathrm{s})}{\mathrm{Va(s)}} = \frac{\frac{1}{\mathrm{K\Phi}}}{ST_m(1{+}ST_a){+}1} \quad \text{------(iv)}$$

Let's suppose the motor's load torque is TL=0 when it first starts.

Also, consider that we have very low armature inductance. so the basic armature equation can be written as:

$$\boldsymbol{V_a} = K\ \Phi\ \omega + \boldsymbol{I_a R_a}$$

Similarly, the basic torque equation will become:

$$T_d = \frac{Jd\omega}{dt} = K\ \Phi\ I_a \text{----------(v)}$$

Taking Ia value from the above equation and putting in equation of V_a

$$\boldsymbol{V_a} = K\ \Phi\ \omega + \frac{Jd\omega}{dt}\boldsymbol{R_a} * \frac{\mathbf{1}}{\mathrm{k\Phi})^{\ 2}}$$

Dividing both side by $K\ \Phi$ we will get,

$$\frac{\mathrm{V_a}}{K\Phi} = \omega\ (\mathrm{t}) + \quad \frac{R_a \frac{Jd\omega}{dt}}{(\mathrm{K\Phi})^2}$$

$\frac{\mathrm{V_a}}{K\Phi}$ is the value of speed when there is no load.

After simplification and some assumption

We will get the following motor equation:

$\omega(s) = [(R_a / K_m) I_a(s) - T_L R_a / (K_m)^2] (1/T_m(s))$

$$\boxed{\omega(s) = \frac{R_a}{K_m} I_a(s) - (\frac{T_L R_a}{{K_m}^2})^1 \frac{1}{T_m}}$$

where $K_m = $ $K\Phi$

Now as we know that armature time constant is negligible in comparison with electromechanical time constant so $T_a \ll T_m$

Simplifying $1 + ST_m + S^2 T_m T_a = (1 + ST_m)(1 + ST_a)$

The greatest time constant plays a crucial role in delaying the system when the transfer function is in time constant form. Now to adjust the delay we use PI controller as speed controller. And this because that delay can be canceled by the zero of PI controller.so the equation can be written as

$$\frac{\omega\ (s)}{\mathrm{Va}(s)} = \frac{\frac{1}{K\Phi}}{(1+ST_m)(1+ST_a)} \quad \text{----(vi)}$$

Ta and Tm are the time constant hence The transfer function generated from the preceding equation can be used to replace the DC motor.

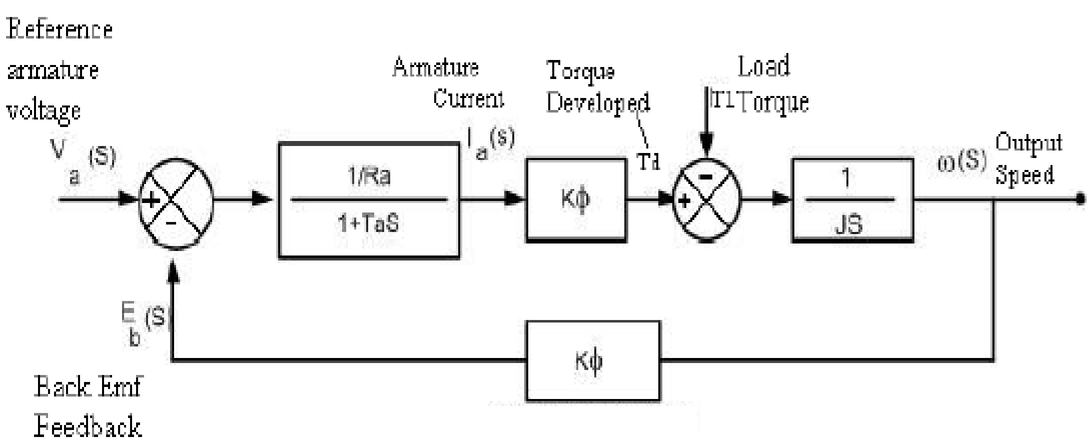


Fig 12.

Block diagram of closed loop Separately DC excited motor

Chapter 5: Controller Design

5.1 Controller Fundamentals

Controlling the speed of a DC motor with a closed loop feedback control system is highly convenient. By using such a system, any set-point speed can be achieved accurately. In a closed loop feedback system, a tachometer is installed on the rotor of the motor which measures the speed of rotation and sends this speed in the form of a voltage signal and then it is provided as a input the adder, where it is subtracted from the main input signal and thus a new error signal corresponding to the error is generated so that speed could be adjusted accordingly. For instance, if the error speed is positive then this means that the motor is running faster than the set point. In that case, the output of the controller would be decreased, and correspondingly opposite behavior would be observed if error signal is negative.

Since in proportional control, the control signal corresponds to product of error and gain but as the controlled system reaches close to the set point value, the error becomes smaller and smaller and thus the system settles down at a point lower than the set point. Due to this inherent offset, proportional controller cannot be used for controlling the speed of a motor accurately [7].

To counter the drawbacks, proportional integrator controller which stops the system from fluctuating and has the ability to give zero steady state error. Its response is a bit slower than proportional controller but is faster than integrator controller but as compared to P controller, it can accurately reach the desired set point speed. Pi controller can also be said to be a simplified form of PID controller having a zero-derivative term. PI controller is mathematically given by below equation

$$\boldsymbol{C(t) = k_C\left(e(t) + \frac{1}{Ti}\int e(t)\,dt\right) + c}$$

Where e(t) is the error

k_C is the controller gain

C(t) is the controller output

T_i is the integral time

C is the initial value of the controller

PI controller is represented in matlab Simulink by the figure given below

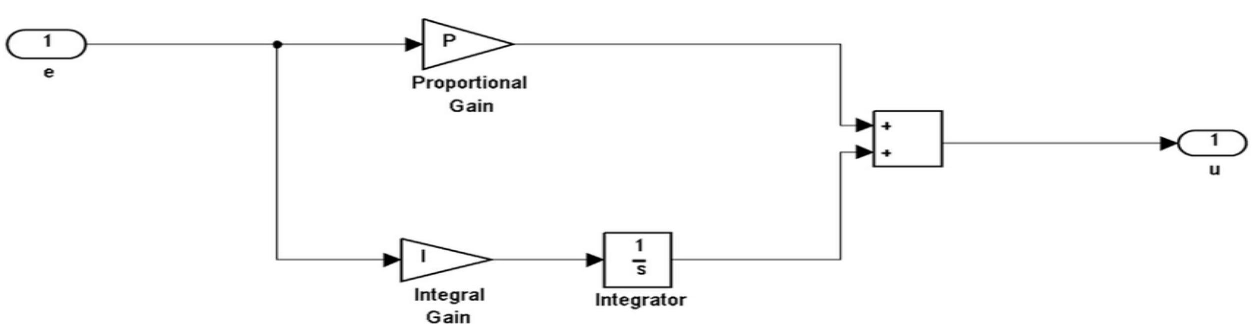


Fig. 13 Block Diagram of PI controller

5.2 Significance of current controller

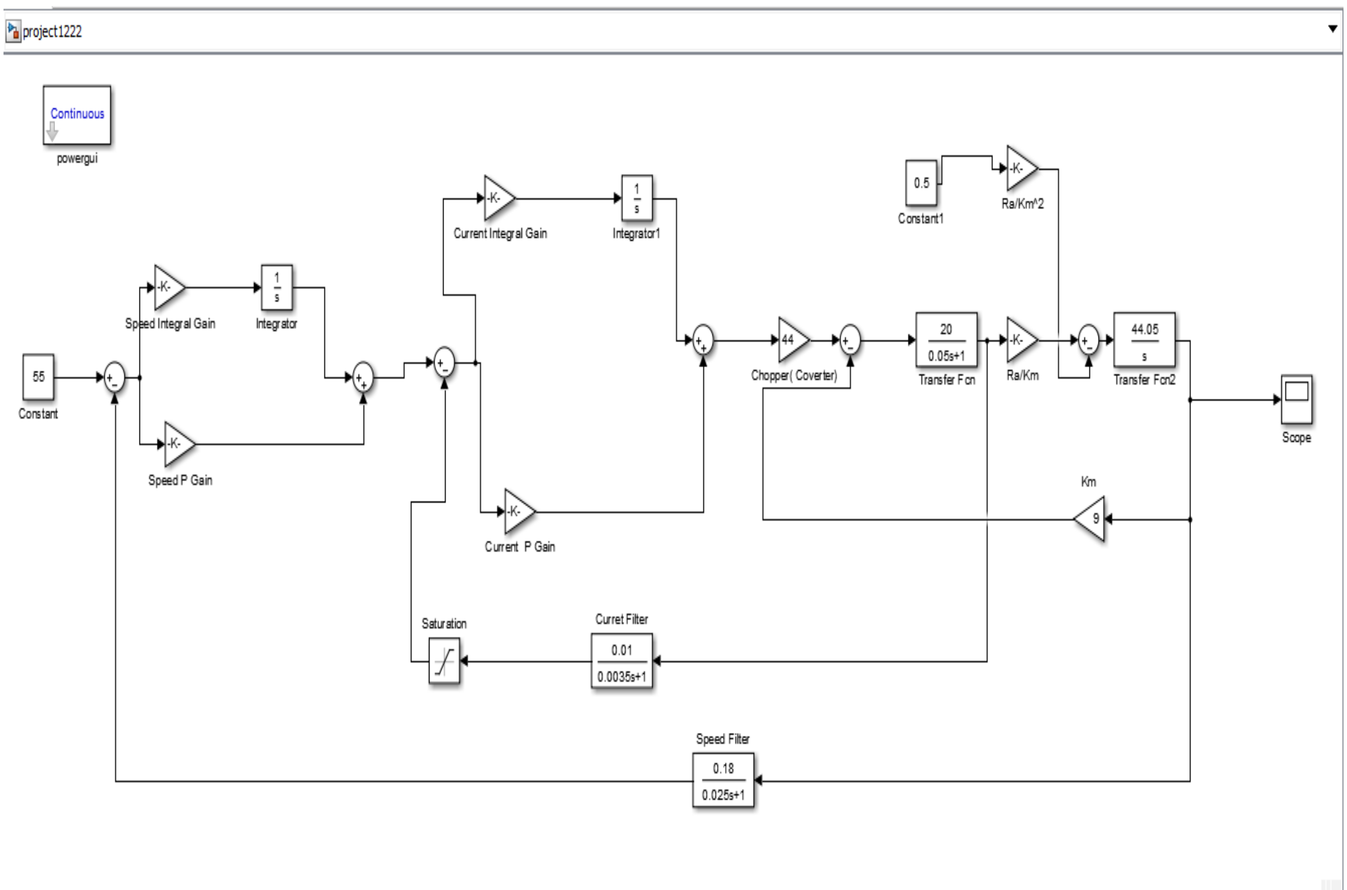
When the motor initially runs from zero speed then it would take a lot of time to reach the desired set point speed due to mechanical time constant but the proportional gain of the system responds very aggressively to counter this and since the feedback would be zero initially so the maximum current would flow to the motor which may exceed the maximum current rating of the motor thus damaging it. In order to resolve this issue, a current controller is used to limit the current so that it may not exceed maximum allowed current rating of the motor and that is the reason why inner current loop has been employed in the control scheme.

5.3 Transfer Function of Chopper and Its representation

DC chopper employed here works using pulse width modulation technique by taking fixed DC input and at its output, giving out a variable DC voltage according to the duty cycle. Since no delay exists in its operation so it can simply represented by constant gain k_t.

5.4 Model for DC motor speed control

Fig.14 Complete Model of DC motor speed control



5.5 Current Controller Design

When the moto is starting initially so there is zero back emf due to which large amount current can flow thus badly damaging the windings of the motor. To prevent that, a current controller is to be implemented which would limit the current to a safe level. The block diagram for that is given below [8]:

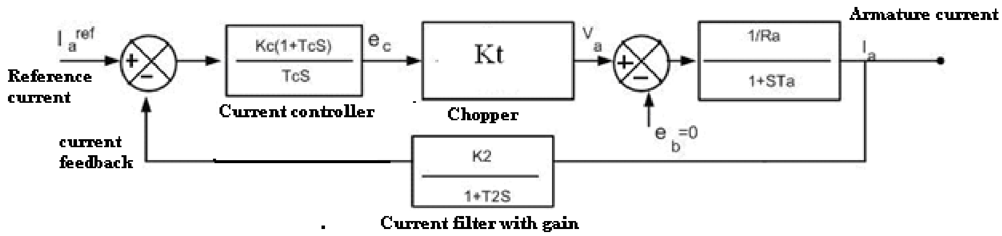


Fig.15 Block Diagram of Current controller design

Transfer function of above model could be written as below:

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \left\{ \frac{\left[\frac{K_c(1+T_cS)}{T_cS}\right](K_t)\left[\frac{\frac{1}{R_a}}{(1+sT_a)}\right]}{1+\left[\frac{K_c(1+T_cS)}{T_cS}\right](K_t)\left[\frac{\frac{1}{R_a}}{(1+sT_a)}\right]\left[\frac{K_2}{(1+T_2S)}\right]} \right\}$$

T_c can be altered to meet the requirements, and it should be chosen so that it cancels the transfer function's largest time constant in order to lower the system's order. $\boldsymbol{T_c = T_a}$

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \left\{ \frac{K_c\left(\frac{K_t}{T_aR_a}\right)(1+T_2S)}{S(1+T_2S)+\frac{K_cK_tK_2}{T_aR_a}} \right\}$$

Let $K_o = \left(\frac{K_cK_t}{T_aR_a}\right)$

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \frac{K_o(1+T_2S)}{[S^2T_2+S+K_oK_2]}$$

Where $\boldsymbol{T_2}$ corresponds filter lag. Dividing $\boldsymbol{T_2}$ on R.H.S:

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \frac{\frac{K_o}{T_2}(1+T_2S)}{\left[S^2+\frac{S}{T_2}+\frac{K_oK_2}{T_2}\right]}$$

Characteristics equation:

$$S^2+\frac{S}{T_2}+\frac{K_oK_2}{T_2} \approx S^2+2\zeta\omega+\omega^2$$

Here $\boldsymbol{\omega} = \sqrt{\frac{K_o K_2}{T_2}}$

$$\boldsymbol{\zeta} = \frac{\mathbf{1}}{\mathbf{2}\boldsymbol{T}\boldsymbol{\omega}} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\boldsymbol{K_o K_2 T_2}}}$$

Since it is a second order system so to get a proper response zeta should be 0.707

$$\frac{\mathbf{1}}{\sqrt{\mathbf{2}}} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\boldsymbol{K_o K_2 T_2}}}$$

$$\boldsymbol{K_o} = \frac{\mathbf{1}}{\mathbf{2}\boldsymbol{K_2 T_2}} = \frac{\boldsymbol{K_c K_t}}{\boldsymbol{R_a T_a}}$$

$$\boldsymbol{K_c} = \frac{\boldsymbol{R_a T_a}}{\mathbf{2}\boldsymbol{K_2 T_2 K_t}}$$

Here $\boldsymbol{K_o} = \frac{K_c K_t}{R_a T_a} = \frac{1}{2K_2 T_2} \xrightarrow{yields} \boldsymbol{K_o K_2} = \frac{1}{T_2}$

From equation (XVi)

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \frac{\frac{\mathbf{1}}{\boldsymbol{K_2}}(\mathbf{1} + \boldsymbol{T_2 S})}{\mathbf{2}\boldsymbol{S^2 T_2^2} + \mathbf{2}\boldsymbol{S T_2} + \mathbf{1}}$$

We can see how the zero in the previous equation could cause an overshoot.

As a result, we'll employ a time lag filter to eliminate the effect.

The filter time constant is substantially higher than the present loop time constant.

As a result, a minor delay will have little impact

$$. \frac{Ia(s)f(1+T_2 S)}{Ia(s)ref} = \frac{\frac{1}{K_2}(1+T_2 S)}{2\,S^2 T_2^2 + 2S T_2 + 1}$$

Hence

$$\frac{\boldsymbol{Ia(s)f}}{\boldsymbol{Ia(s)ref}} = \frac{\frac{\mathbf{1}}{\boldsymbol{K_2}}}{\mathbf{2}\boldsymbol{S^2 T_2^2} + \mathbf{2}\boldsymbol{S T_2} + \mathbf{1}}$$

5.6 Speed Controller Design

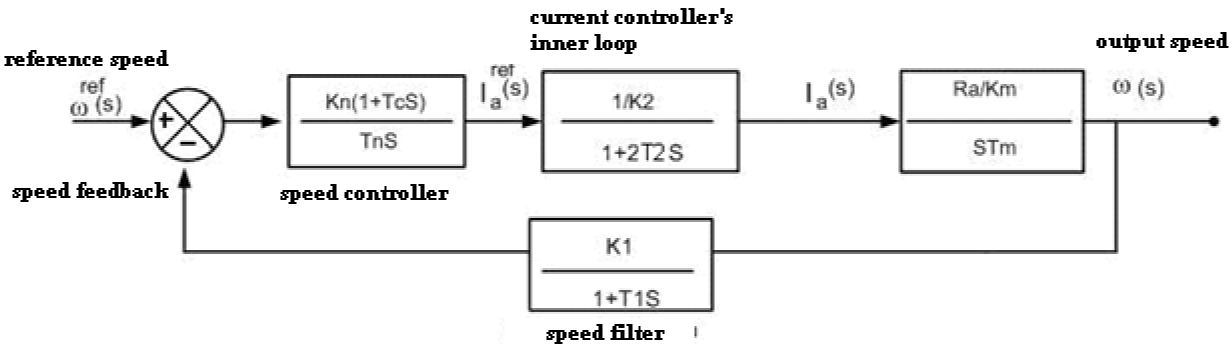


Fig.16 Block Diagram of Speed Controller

Now, Converting the block in transfer function, we will get [9]

$$\frac{\boldsymbol{\omega(s)}}{\boldsymbol{\omega(s)ref}} = \frac{\left(\frac{K_n}{K_2}\right)\left(\frac{R_a}{T_mT_nK_m}\right)\frac{(1+T_nS)}{(1+2T_2S)S^2}}{1+\left(\frac{K_nR_a}{T_mT_nK_2K_m}\right)\left(\frac{(1+T_nS)}{(1+2T_2S)S^2}\right)(1+T_1S)}$$

Here, we have the choice to T_n, which cancels the transfer function's greatest time constant. **So**

$$T_n = 2T_2$$

$$\frac{\omega(s)}{\omega(s)ref} = \frac{\frac{K_nR_a}{T_mT_nK_2K_m}(1+T_1S)}{T_nK_2K_mS^2(1+T_1S)+K_nR_aK_1}$$

$$\textbf{Ideally } \omega(s) = \frac{1}{S(S^2+\alpha S+\beta)}$$

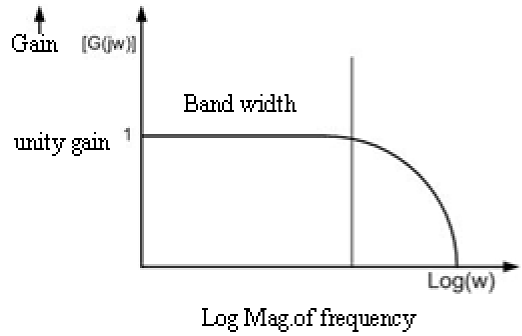
Because the S term is missing in the aforementioned transfer function, the damping ratio is zero, resulting in an oscillating and unstable system.We get a transfer function with a gain near to unity to optimise this.

5.7 Modulus Hugging approach for optimization of Speed controller transfer function:

The dynamic performance of the control system is regarded good if the variable to be managed swiftly approaches the intended value.

To achieve unity gain, any frequency variation within the input variable's bandwidth should cause the output to follow the input variable at the same time [10].

Modulus hugging is the process of bringing the output variable close to the input variable in order to achieve unity gain over a large frequency range..



$$\frac{\omega(s)}{\omega(s)ref} = \frac{K_n R_a(1+T_n S)(1+T_1 S)}{S^2 T_m T_n K_2 K_m (1+2T_2 S)(1+T_1 S) + K_n R_a K_1 (1+T_n S)}$$

$$(1+2T_2 S)(1+T_1 S) = 1 + T_1 S + 2T_2 S + 2T_2 T_1 S^2$$

$$\approx 1 + S(2T_2 + T_1) + 2T_2 T_1 S^2$$

$$\approx 1 + S(2T_2 + T_1)$$

Here T_1 and T_2 are smaller time constants so their product can be approximated to zero. So,

$$1 + S(2T_2 + T_1) = 1 + \delta S$$

Assuming $\delta = (2T_2 + T_1)$

$$K_o = \frac{K_n R_a}{K_2 K_m}$$

$$\frac{\omega(s)}{\omega(s)ref} = \frac{\frac{K_n R_a}{K_2 K_m}(1+T_n S)(1+T_1 S)}{S^3 T_m T_n \delta + S^2 T_m T_n + (K_o K_1 T_n) S + K_o K_1}$$

Above transfer function is of third order. Terms $(1+T_n S)$ *and* $(1+T_1 S)$ in the denominator will be cancelled by using filters.

Taking a standard third order system

$$G(j\omega) = \frac{b_o + j\omega b_1}{a_o + j\omega a_1 + (j\omega)^2 a_2 + (j\omega)^3 a_3}$$

For low frequency $b_o = a_o$ *and* $b_1 = a_1$

$$|G(j\omega)| = \frac{{a_o}^2 + \omega^2 {a_1}^2}{[{a_o}^2 + \omega^2({a_1}^2 - 2a_o a_2) + \omega^4({a_2}^2 - 2a_1 a_3) + \omega^6({a_3}^2)]^{\frac{1}{2}}}$$

Now, modulus hugging principle $|G(j\omega)| = 1$ for that coefficients of $\boldsymbol{\omega^2}$ **and** $\boldsymbol{\omega^4}$ are made equal to zero, So

$$\boldsymbol{a_1}^2 = 2\boldsymbol{a_o a_1} \ \& \ \boldsymbol{a_2}^2 = 2\boldsymbol{a_1 a_3} \quad \textbf{(A)}$$

We need to use filters on the $\omega(s)$ref side to cancel $(\boldsymbol{1 + T_n S})(\boldsymbol{1 + T_1 S})$ term

$$\frac{\boldsymbol{\omega(s)}}{\boldsymbol{\omega(s)ref(1 + T_n S)(1 + T_1 S)}} = \frac{\frac{\boldsymbol{K_n R_a}}{\boldsymbol{K_2 K_m}}(\boldsymbol{1 + T_n S})(\boldsymbol{1 + T_1 S})}{\boldsymbol{S^3 T_m T_n \delta + S^2 T_m T_n + (K_o K_1 T_n) S + K_o K_1}}$$

Now from optimization condition in A, we get

$$(\boldsymbol{K_o K_1 T_n})^2 = \boldsymbol{2 K_o K_1 T_m T_n}$$

$$\boldsymbol{K_o K_1 T_n = 2 T_m}$$

$$\boldsymbol{T_m} = \frac{\boldsymbol{K_o K_1 T_n}}{\boldsymbol{2}}$$

$$(\boldsymbol{T_m T_n})^2 = \boldsymbol{2 T_m T_n \delta K_o K_1 T_n}$$

$$\boldsymbol{T_m = 2\delta K_o K_1}$$

$$\frac{\boldsymbol{K_o K_1 T_n}}{\boldsymbol{2}} = \boldsymbol{2\delta K_o K_1}$$

$$\boldsymbol{T_n = 4\delta} = (\boldsymbol{2T_2 + T_1}) \qquad \textbf{Eq(xxi)}$$

$$\boldsymbol{T_m = 2\delta K_o K_1 = 2}\left(\frac{\boldsymbol{K_n R_a}}{\boldsymbol{K_2 K_m}}\right)\boldsymbol{K_1 \delta}$$

$$\boldsymbol{K_n} = \frac{\boldsymbol{T_m K_m K_2}}{\boldsymbol{2 K_1 R_a \delta}}$$

Now putting values of $\boldsymbol{K_n}$ and $\boldsymbol{K_m}$ in the main transfer function

$$\frac{\boldsymbol{\omega(s)}}{\boldsymbol{\omega(s)ref}} = \frac{\boldsymbol{1}}{\boldsymbol{K_1 + 4\delta K_1 + 8S^2 \delta K_1 + 8S^3 \delta K_1}}$$

Chapter 6: Problem Statement

A separately excited DC motor with name plate ratings of 320KW, 440V (DC), 55 rad/sec is used in all simulations. Following parameter values are associated with it.

- Moment of Inertia, J = 85 $Kg\text{-}m^2$.
- Back EMF Constant = 9 Volt-sec/rad.
- Rated Current = 715 A.
- Maximum Current Limit = 1000 A.
- Resistance of Armature, R_a = 0.0241 ohm.
- Armature Inductance, L_a = 0.718 mH.
- Speed Feedback Filter Time Constant [1], T_1 = 25 ms.
- Current Filter Time Constant [1], T_2 = 3.5 ms.

Current Controller Parameter:

Current PI controller is given by:

$$\frac{K_c(1+T_cS)}{T_cS}$$

$$K_c = \frac{R_aT_a}{2K_tK_2T_2}$$

$$\text{Here } T_c = T_a, \text{ So}$$

$$T_a = \frac{L_a}{R_a} = \frac{0.718 \times 10^{-3}}{0.0241} = 29.79\ msec$$

For analog circuit, maximum controller output is $\pm 10\ volts$. So

$$K_t = \frac{440}{10} = 44$$

$$K_2 = \frac{10}{1000} = \frac{1}{100}$$

$$K_c = 0.233$$

Speed Controller Parameter

Speed PI controller is given by

$$\frac{K_n(1 + T_n S)}{T_n S}$$

$$T_n = 4\delta = 4(T_1 + 2T_2) = 4(25 + 7) = 128\ msec$$

$$K_n = \frac{T_m K_m K_2}{2K_1 R_a \delta}$$

$$K_1 = \frac{10}{55} = 0.181$$

$$T_m = \frac{JR_a}{K_m} = \frac{85 \times 0.0241}{9^2} = 25.3\ msec$$

$$K_n = \frac{25.3 \times 10^{-3} \times 9 \times 1}{2 \times 0.181 \times 0.0241 \times 32 \times 100} = 8.15 \times 10^{-3}$$

Chapter 7:

Results and Conclusion

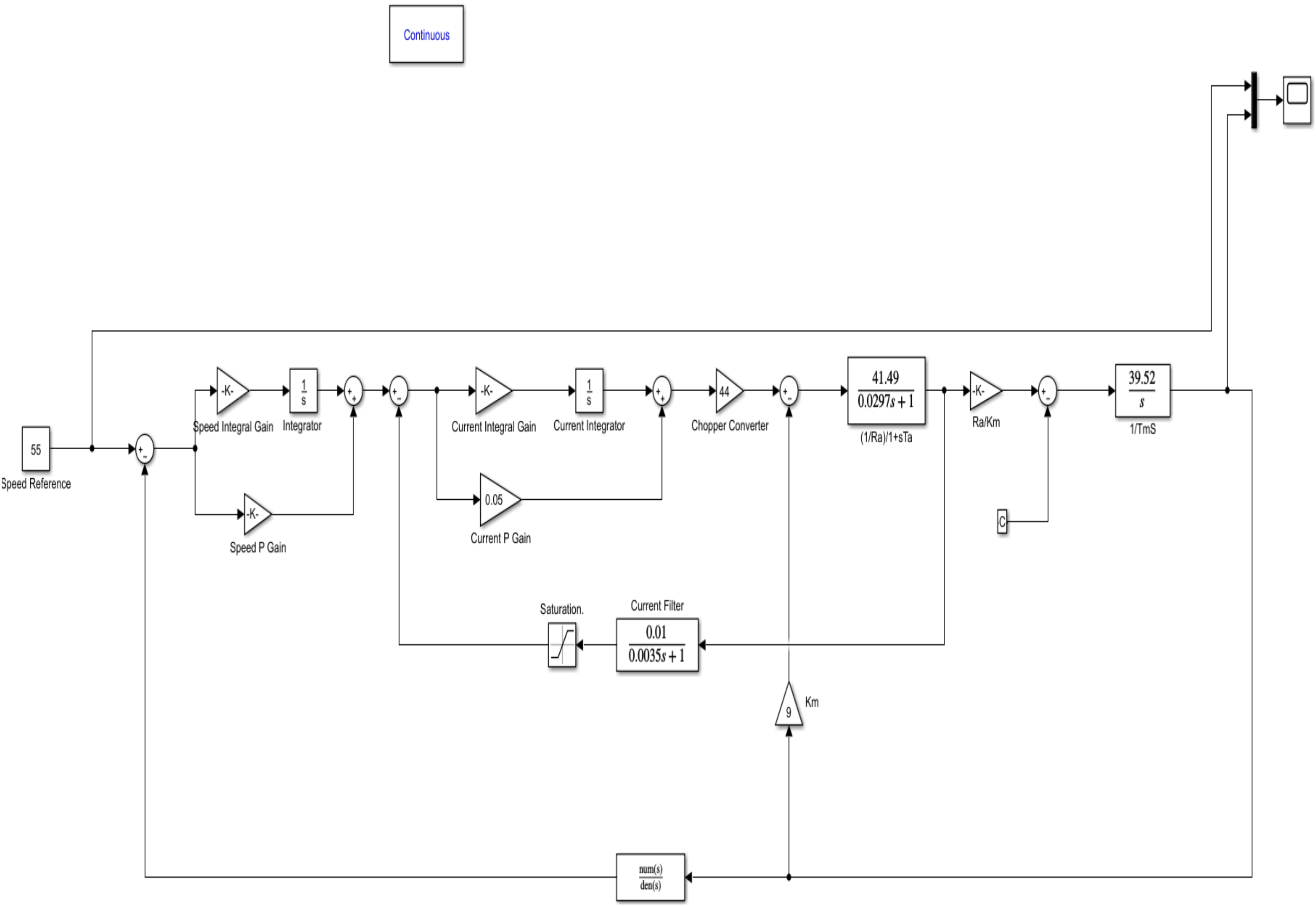
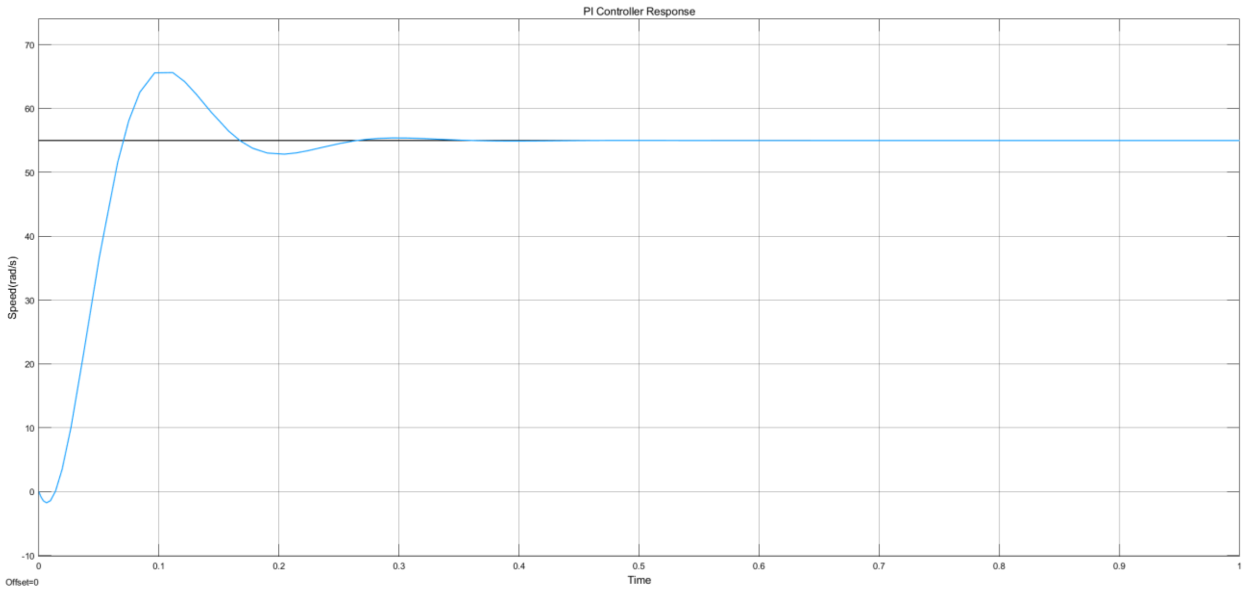


Fig.17 Matlab Simulink model for Controlling of speed using chopper.



Response of the DC motor using PI controller

Conclusion

The speed of a dc motor was regulated in this project utilizing a closed loop system model, a chopper as a converter, and a Proportional-Integral Type Speed and Current controller. Since initially when the motor starts, the back emf is zero which will result in full controller output thus exceeding the rated maximum current resulting in a damaged winding. In order to compensate that a current controller is implemented. After that, a more detailed model of the DC motor is created, as well as a thorough layout of the DC drive system. It is planned to build a current and speed controller. The Modulus Hugging technique is used to optimize the speed control loop. A DC motor specification is used, and the resulting design approach is used to drive the appropriate parameters. Finally, simulations are run, and the simulation results produced at various reference speeds and loads are also subjected to analysis. The model performs admirably under all of the simulation conditions.

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