Dynamic Performance Enhancement of an Armature Controlled Separately Excited D.C. Motor

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Abstract: *In this paper the dynamic performance (speed regulation performance versus reference and load torque changes) of a separately excited D.C. motor is enhanced, the D.C. motor is fed by a D.C. source through a chopper which consists of GTO thyristor and free-wheeling diode. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque TL. The performance enhancement is achieved by using a speed control loop uses a proportional-integral (PI) controller which produces the reference signal for the current control loop and this is a (PI) current controller compares the sensed current with the reference and generates the trigger signal for the GTO thyristor to force the motor current to follow the reference. The simulation of the D.C. drive is performed using MATLAB/Simulink program version 7.10 (R2010a).*

Keyword: D.C. motor, D.C. drive, GTO. PI controller, speed controller, current controller.

1. Introduction

D.C. motors have long been used in industrial application and they are used as having excellent control of speed. Development of high performance D.C. motor drives are very important for industrial application, the high performance D.C. motor drives system must have good dynamic speed command tracking and load regulating response. The Proportional-Integral (PI) controller is one of the conventional controllers and it has been widely used for the speed control of dc motor drives. The major features of the P-I controller are its ability to maintain a zero steady-state error to a step change in reference [1]. A chopper is a static power electronic device that converts fixed D.C. input voltage to a variable D.C. output voltage. The chopper is driven by a high frequency PWM signal, controlling the PWM duty cycle is equivalent to controlling the motor terminal voltage, which in turn adjusts directly the motor speed [2]. In this paper the dynamic performance (speed regulation performance versus reference and load torque changes) of a separately excited D.C. motor is enhanced, the D.C. motor is fed by a D.C. source through a chopper which consists of GTO thyristor and free-wheeling diode. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque TL. The performance enhancement is achieved by using a speed control loop uses a proportional-integral (PI) controller which produces the reference signal for the current control loop and this is a (PI) current controller compares the sensed current with the reference and generates the trigger signal for the GTO thyristor to force the motor current to follow the reference. The simulation of the D.C. drive is performed using MATLAB/Simulink program version 7.10 (R2010a).

2. Simulated Model of the Variable – Speed D.C. Motor Drive

In this paper a variable-speed D.C. motor drive using a cascade control configuration is designed and simulated by Matlab /

Simulink. The block diagram of this drive is shown in figure 1. The motor torque is controlled by the armature current Ia, which is regulated by a current control loop. The motor speed is controlled by an external loop, which provides the current reference Ia* for the current control loop which generates the required trigger signal for the GTO thyristor chopper.

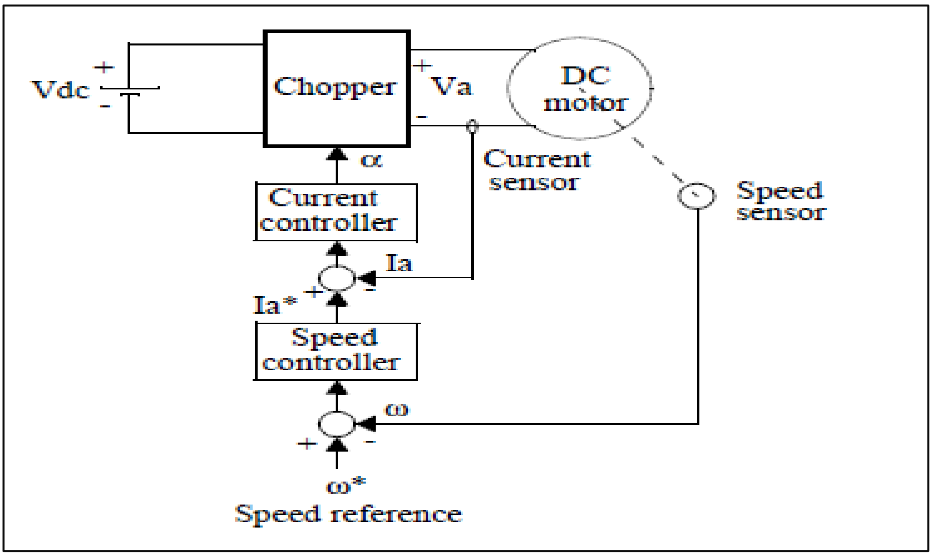


Figure 1: Variable – speed D.C. motor drive

The output speed of D.C. motor can be varied by controlling armature voltage Va for speed below and up to rated speed keeping field voltage constant. The output speed is compared with the reference speed and error signal is fed to speed controller. The Controller output will vary whenever there is a difference in the reference speed and the speed feedback. The required trigger signal for the GTO thyristor is generated by the current controller which forces the motor current to follow the reference within maximum current limit. The GTO chopper output gives the required Va to bring the motor back to the desired speed. The GTO thyristor characteristic description is given in Appendix.

2.1 Mathematical Modeling of the Armature Controlled Separately Excited D.C. Motor

Modeling of any kind of electrical machines such is D.C. motor starts with measurements on real model because it is necessary to determine motor parameters. The other possibility is to get the motor parameters from manufacturer or determinate our own parameters if motor prototype is being build. After that motor model can be made by using all mathematical equations that describe the motor [3]. D.C. separately excited motor is the D.C. motor that has a separate D.C. source for the field winding as shown in Figure 2. After configuration of mathematical model, simulation model can be made in Matlab / Simulink. Functioning of D.C. motor can be explained by using two electrical circuits. Exciting (field) circuit creates magnetic flux and an armature circuit, armature current from power source causes appearance of force on motor windings. The motor dynamic characteristics can be obtained from a motor model shown in figure 2 and the equations that are used for this model are the following differential equations as given in [4]. The differential equation of armature circuit is

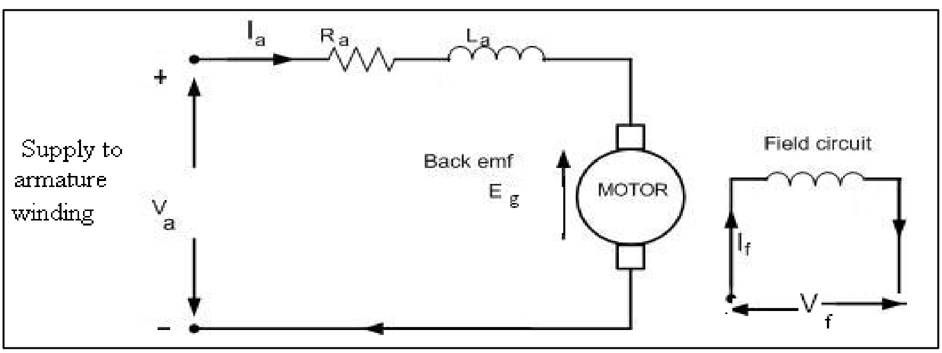


Figure 2: Separately excited D.C. motor model

The armature equation is shown below:

$$V_a = E_b + I_a R_a + L_a\left(\frac{dI_a}{dt}\right) \quad (1)$$

The description for the notations used is given as: V_a is the armature voltage in volts, E_b is the motor back e.m.f. in volts, I_a is the armature current in amperes, R_a is the armature resistance in ohms, L_a is the armature inductance in Henry. Now the torque equation will be given by:

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L \quad (2)$$

Where: T_L is load torque in Nm., T_d is the torque developed in Nm, J is moment of inertia in kg/m², B is friction coefficient of the motor, ω is angular velocity in rad/sec. Assuming absence (negligible) of friction in rotor of motor, it will yield: B = 0 , therefore, new torque equation will be given by:

$$T_d = J\frac{d\omega}{dt} + T_L \quad (3)$$

Taking field flux as Φ and (Back e.m.f. Constant). Equation for back e.m.f. of motor will be:

$$E_b = K\,\Phi\omega \quad (4)$$

Also,

$$T_d = K\,\Phi I_a \quad (5)$$

Where K is a constant. From motor's basic armature equation, after taking Laplace Transform on both sides, we will get: $I_a(s) = \frac{V_a - E_g}{R_a + L_a S}$ Now, taking equation (4) into consideration, we have:

$$I_a(s) = \frac{V_a - K\Phi\omega}{R_a(1+\frac{L_a S}{R_a})} \quad (6)$$

And,

$$\omega(s) = \frac{T_d - T_L}{JS} = \frac{K\Phi I_a - T_L}{JS} \quad (7)$$

Also, the armature time constant will be given by: $T_a = \frac{L_a}{R_a}$ and Figure 3 shows the block model of separately excited D.C. motor

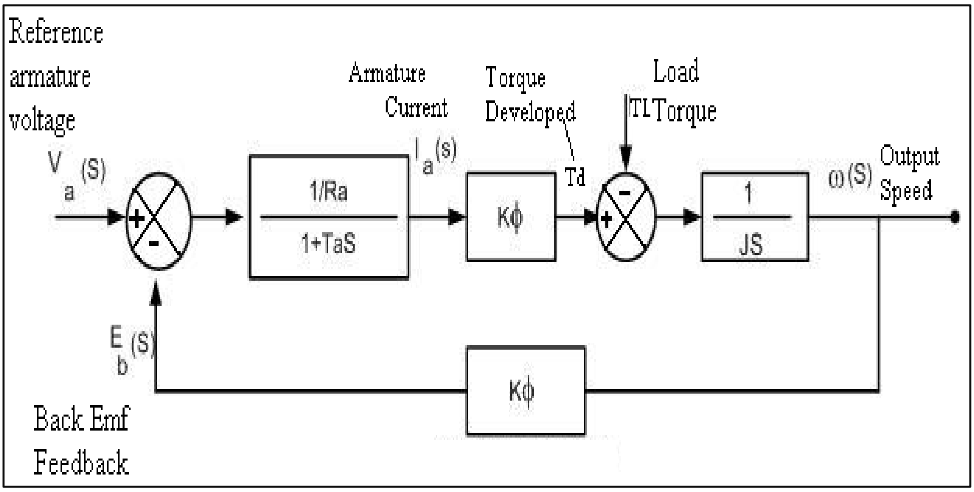


Figure 3: Block Model of Separately Excited D.C. Motor

After simplifying the above motor model, the overall transfer function will be as:

$$\frac{\omega(s)}{V_a(s)} = \frac{\frac{\frac{K\Phi}{R_a}}{JS(1+T_aS)}}{1+\frac{\frac{K^2\Phi^2}{R_a}}{JS(1+T_aS)}} \quad (8)$$

Further simplifying the above transfer function will yield:

$$\frac{\omega(s)}{V_a(s)} = \frac{\frac{1}{K\Phi}}{1+\frac{\frac{K^2\Phi^2}{R_a}}{JS(1+T_aS)}} \quad (9)$$

Assuming $T_m = \frac{JR_a}{(K\Phi)^2}$ as an electromechanical time constant.

Then the above transfer function can be written as below:

$$\frac{\omega(s)}{V_a(s)} = \frac{\frac{1}{K\Phi}}{ST_m(1+ST_a)+1} \tag{10}$$

Let us assume that during starting of motor, load torque $T_L = 0$ and applying full voltage V_a. Also assuming negligible armature inductance, the basic armature equation can be written as:

$$V_a = K\Phi\omega(t) + I_a R_a \tag{11}$$

At the same time Torque equation will be:

$$T_d = J\frac{d\omega}{dt} = K\Phi I_a \tag{12}$$

Putting the value of I_a in above armature equation:

$$V_a = K\Phi\omega(t) + (J\frac{d\omega}{dt})\frac{R_a}{K\Phi} \tag{13}$$

Dividing on both sides by $K\Phi$,

$$\frac{V_a}{K\Phi} = \omega(t) + \frac{JR_a\frac{d\omega}{dt}}{(K\Phi)^2} \tag{14}$$

$\frac{V_a}{K\Phi}$ is the value of motor speed under no load condition. Therefore,

$$\omega(no\ load) = \omega(t) + \frac{JR_a\frac{d\omega}{dt}}{(K\Phi)^2} = \omega(t) + T_m(\frac{d\omega}{dt}) \tag{15}$$

Where, $K\Phi = K_m$ and,

$$T_m = \frac{JR_a}{(K\Phi)^2} = \frac{JR_a}{(K_m)^2} \tag{16}$$

Therefore,

$$J = \frac{T_m(K_m)^2}{R_a} \qquad (17)$$

From motor torque equation, we have:

$$\omega(s) = \frac{K_m I_a(s)}{JS} - \frac{T_L}{JS} \qquad (18)$$

From equations (17) and (18) we have

$$\omega(s) = \frac{\frac{R_a I_a(s)}{K_m} - \frac{T_L R_a}{(K_m)^2}}{T_m S} \qquad (19)$$

Now, Replacing $K\Phi$ by K_m in equation (10), we will get:

$$\frac{\omega(s)}{V_a(s)} = \frac{\frac{1}{K_m}}{1+ST_m+S^2T_aT_m} \qquad (20)$$

Since, the armature time constant T_a is much less than the electromechanical time constant T_m, (T_a<< T_m), Simplifying,

$$1 + ST_m + S^2T_aT_m \approx 1 + S\,(T_a + T_m) + S^2T_aT_m = (1+ST_m)(1+ST_a)$$

The largest time constant will play main role in delaying the system when the transfer function is in time constant form. To compensate that delay due to largest time constant we can use PI controller as speed controller. It is because the zero of the PI controller can be chosen in such a way that this large delay can be cancelled. In Control system term a time delay generally corresponds to a lag and zero means a lead, so the PI controller will try to compensate the whole system. Hence, equation (20) can be written as:

$$\frac{\omega(s)}{V_a(s)} = \frac{\frac{1}{K_m}}{(1+ST_m)(1+ST_a)} \qquad (21)$$

$T_m$and T_a are the time constants of the above system transfer function which will determine the response of the system. Hence the D.C. motor can be replaced by the transfer function obtained in equation (21) in the D.C. drive model shown earlier.

2.2 Chopper-Fed D.C. Motor Drive

A simplified diagram of the simulated chopper-fed D.C. motor drive system is shown in figure 4. The D.C. motor is fed by the D.C. source through a chopper that consists of the GTO thyristor (Th1), and the free-wheeling diode D1. The D.C. motor drives a mechanical load that is characterized by the inertia J, friction coefficient B, and load torque TL (which can be a function of the motor speed). In this diagram, the D.C. motor is represented by its equivalent circuit consisting of inductor La and resistor Ra in series with the counter electromotive force (e.m.f.) E.

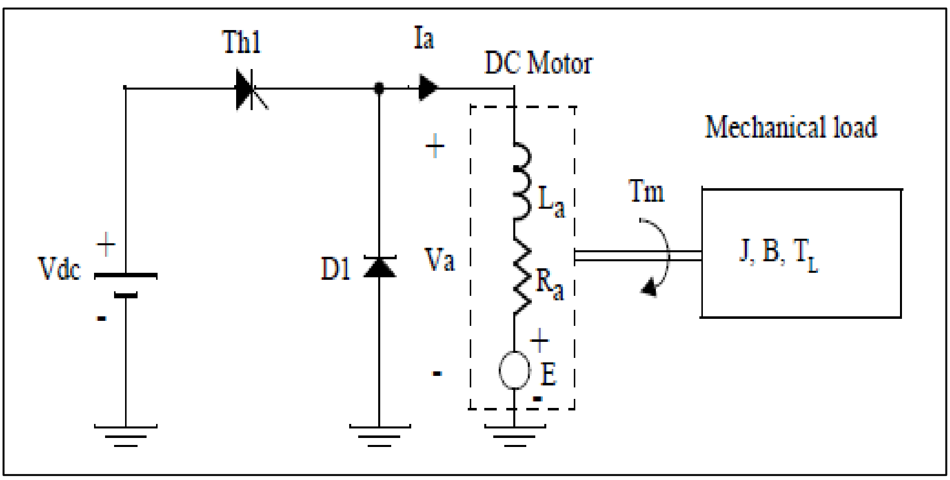


Figure 4: Simplified model of the simulated chopper-fed D.C. motor

Thyristor (Th1) is triggered by a pulse width modulated (PWM) signal to control the average motor voltage. Theoretical waveforms illustrating the chopper operation as shown in figure 5.

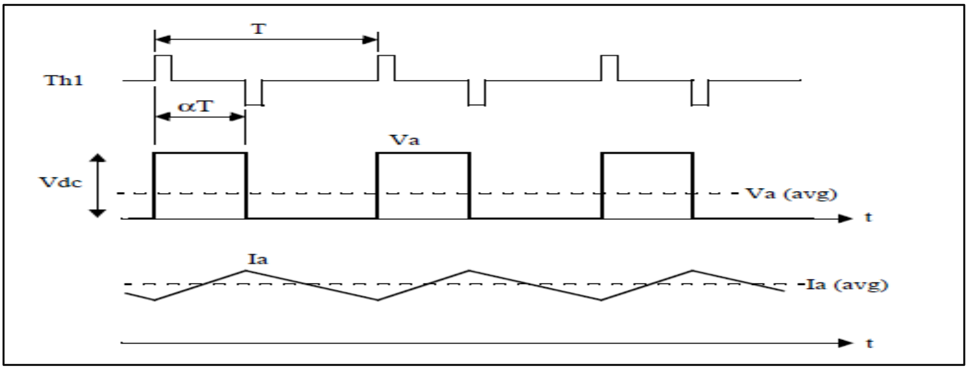


Figure 5: Waveforms illustrating the chopper operation

The equations of the chopper output voltage and current that are used for this model as given in [5]. The average armature voltage is a direct function of the chopper duty cycle α.

$$V_a\,(avg) = \alpha V_{dc} \tag{22}$$

In steady state, the armature average current is equal to

$$\boldsymbol{I_a}\,(avg) = \frac{V_a(avg)-E}{R_a} \tag{23}$$

The peak-to-peak current ripple as given in [5] is

$$\Delta\boldsymbol{i} = \frac{V_{dc}}{R_a}\frac{(1-e^{-\alpha r}+e^{-r}-e^{-(1-\alpha)r})}{1-e^{-r}} \tag{24}$$

where α is the duty cycle and r is the ratio between the chopper period and the D.C. motor electrical time constant.

$$r = \frac{T}{\frac{L_a}{R_a}} \quad (25)$$

2.2.1 Representation of Chopper in Transfer Function Form

Since chopper takes a fixed D.C. input voltage and gives variable D.C. output voltage. It works on the principle Pulse Width Modulation technique [6]. There is no time delay in its operation. Hence, it can be represented by a simple constant gain Kt.

3. Proportional plus Integral Controller Description

The control action of a proportional plus integral controller is defined by following equation as given in [1].

$$u(t)=K_p e(t)+K_i\int_0^t e\,(t)dt \quad (26)$$

where, u(t) is actuating signal, e(t) is error signal, Kp is proportional gain constant, Ki is Integral gain constant. The Laplace transform of the actuating signal incorporating in proportional plus integral control is

$$U(s)=K_p E(s)+K_i\frac{E(s)}{s} \quad (27)$$

The block diagram of closed loop control system with PI control of D.C. motor system is shown in figure 6. The error signal E(s) is fed into two controllers, i.e. (i) Proportional block which does the job of fast-acting correction to produce a change in the output as quickly as the error arises. and (ii) Integral block, this integral action takes a finite time to act but has the capability to minimize the steady-state signal error. The output of PI controller, U(s), is fed to D.C. motor system. The overall output of D.C. drive, may be speed or position, C(s) is feedback to reference input R(s). Error signal can be removed by increasing the value of Kp, Ki. However the feedback of control system is unity. If the gain of the feedback is increased the stability of the system is decreased.

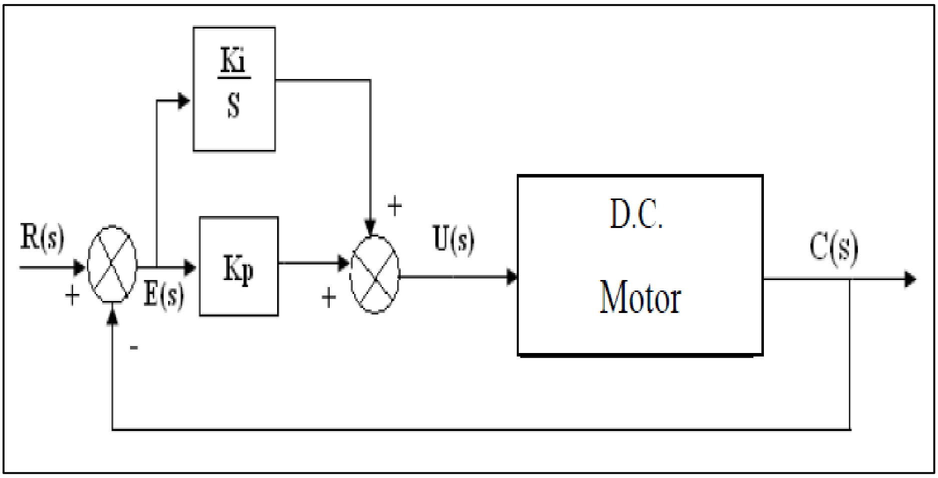


Figure 6: Block diagram of PI control action with D.C. motor

4. Importance of Current Controller in a D.C. drive system

When the machine is made to run from zero speed to a high speed then motor has to go to specified speed. But due to electromechanical time constant, motor will take some time to speed up. But the speed controller used for controlling speed acts very fast. Speed feedback is zero initially. So this will result in full controller output and hence converter (chopper) will give maximum voltage. So a very large current flow at starting time because back e.m.f. is zero at that time which sometime exceeds the motor maximum current limit and can damage the motor windings. Hence there is a need to control current in motor armature. To solve the above problem we can employ a current controller which will take care of motor rated current limit. The applied voltage V_a will now not dependent on the speed error only but also on the current error.

4.1 Current Controller Design

We need to design the current controller for the extreme condition when back e.m.f. is zero that is during starting period because at that time large current flows through the machine. The block model of the D.C. motor drive with current controller is shown in figure 7.

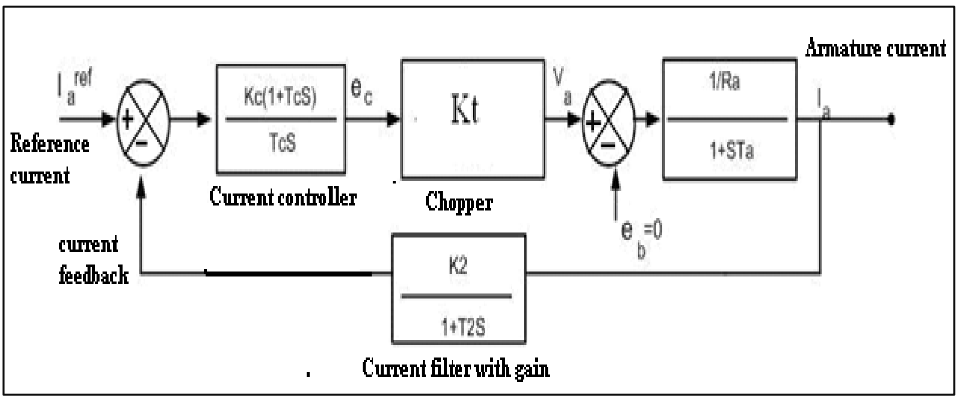


Figure 7: Block model with current controller

The transfer function of the above model:

$$\frac{I_a(s)}{I_a(s)(ref)} = \frac{\frac{K_C(1+T_CS)}{T_CS}(K_t)\frac{\frac{1}{R_a}}{(1+T_aS)}}{1+\frac{K_C(1+T_CS)}{T_CS}(K_t)\frac{\frac{1}{R_a}}{(1+T_aS)}\frac{K_2}{(1+T_2S)}} \quad (28)$$

where

$I_a(s)$ is the feedback current, $I_a(s)(ref)$ is the reference current. Here, T_c (Current Controller Parameter) can be varied as when required. T_c should be chosen such that it cancels the largest time constant in the transfer function in order to reduce order of the

system [8]. Now, the response will be much faster. So, let us assume $T_c = T_a$
Now, putting this value in equation (28)

$$\frac{I_a(s)}{I_a(s)(ref)} = \frac{\frac{K_c K_t (1+T_2 S)}{T_a R_a}}{S(1+T_2 S)+\frac{K_c K_t K_2}{T_a R_a}} \qquad (29)$$

Let $K_0 = \frac{K_c K_t}{T_a R_a}$

$$\frac{I_a(s)}{I_a(s)(ref)} = \frac{K_0(1+T_2 S)}{S^2 T_2+S+K_0 K_2} \qquad (30)$$

Where T_2 corresponds filter lag. Dividing by T_2 on R.H.S:

$$\frac{I_a(s)}{I_a(s)(ref)} = \frac{\frac{K_0}{T_2}(1+T_2 S)}{S^2+\frac{S}{T_2}+\frac{K_0 K_2}{T_2}} \qquad (31)$$

The characteristic Equation:- $S^2 + \frac{S}{T_2} + \frac{K_0 K_2}{T_2} = S^2 + 2\epsilon\omega S + \omega^2$

Here, ω= $\sqrt{\frac{K_0 K_2}{T_2}}$ so $\epsilon = \frac{1}{2T_2\omega} = \frac{1}{2\sqrt{T_2 K_2 K_0}}$

Since, it is a second order system. So, to get a proper response ϵ should be 0.707 as given in [8]

$$K_c = \frac{R_a T_a}{2K_t K_2 T_2} K_0 K_2 = \frac{1}{2T_2}$$

Here, $K_0 = \frac{K_c K_t}{R_a T_a} = \frac{1}{2K_2 T_2}$

Now, from equation 30

$$\frac{I_a(s)}{I_a(s)(ref)} = \frac{\frac{1}{K_2}(1+T_2 S)}{2S^2 T_2^2+2ST_2+1} \qquad (32)$$

We can see that the zero in the above equation may result in an overshoot. Therefore, we will use a time lag filter to cancel its effect. The current loop time constant is much higher than filter time constant. Hence a small delay will not affect much

$$\frac{I_a(s)}{I_a(s)(ref)}(1+ST_2)=\frac{\frac{1}{K_2}(1+T_2S)}{2S^2T_2^2+2ST_2+1} \quad (33)$$

Hence

$$\frac{I_a(s)}{I_a(s)(ref)}=\frac{\frac{1}{K_2}}{2S^2T_2^2+2ST_2+1} \quad (34)$$

4.2 Current Controller Parameters Calculation

Current Filter Time Constant as given in [8], T_2 = 3.5 ms.
Current PI type controller is given by: $\frac{K_c(1+T_cS)}{T_cS}$.
Here, T_c = T_a and $K_c=\frac{R_aT_a}{2K_tK_2T_2}$ $\quad T_a=\frac{L_a}{R_a}$ = $\frac{10\times10^{-3}}{0.5}$ = 20 ms.

For analog circuit maximum controller output is ± 10 Volts as given in [8]. Therefore, K_t = $\frac{240}{10}$ = 24.
Also, K_2 = (10/ maximum current limit) as given in [8], so K_2 = $\frac{10}{30}$ = 0.333.
Now, putting values of $R_a, T_a, K_2, K_2\ and\ T_2$ we get: K_c = 0.194.

5. Speed Control of the D.C. Motor

Under steady state operation, the time derivative is zero and equation 1 can be written as

$$V_a=R_ai_a+E_b \quad (35)$$

And equation 4 can be written as

$$E_b(t)=K_vi_f\omega_m \quad (36)$$

Substituting equation 35 in equation 36 rearrange for ω the result is

$$\omega = \frac{V_a - R_a\ i_f}{K_v\ i_f} \quad (37)$$

From the derivation it can be concluded that the speed of a D.C. motor can be varied by:

1) V_a *is* Voltage Control,
2) *if is Field Control,*
3) *ia (with if fixed) is Demand Torque*

In practice, for speeds less than the base speed (rated), the armature current and field currents are maintained at fixed values (hence constant torque operation), and the armature voltage controls the speed. For speeds higher than the base speed, the armature voltage is maintained at rated value and the field current is varied to control the speed (note the hyperbolic characteristic). As shown in figure 8. However, this way the power developed Pd is maintained constant. This mode is referred to as "field weakening" operation [9].

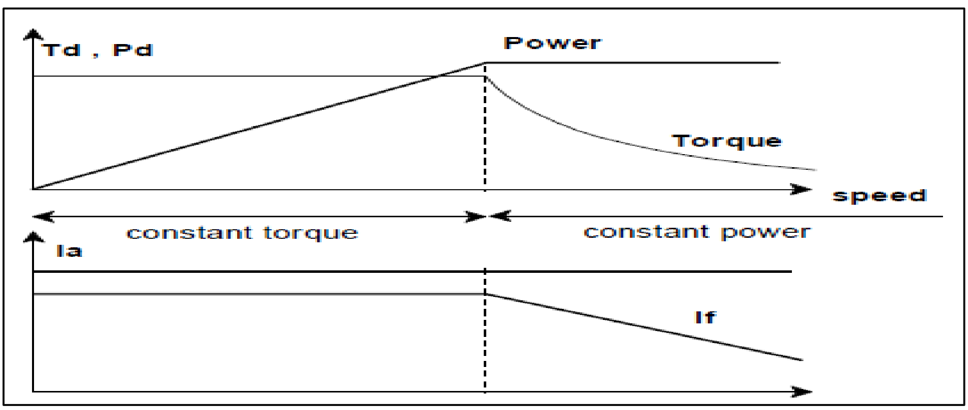


Figure 8: D.C. motor control modes

5.1 Speed Controller Design

The block model of the D.C. motor drive with speed controller is shown in figure 9.

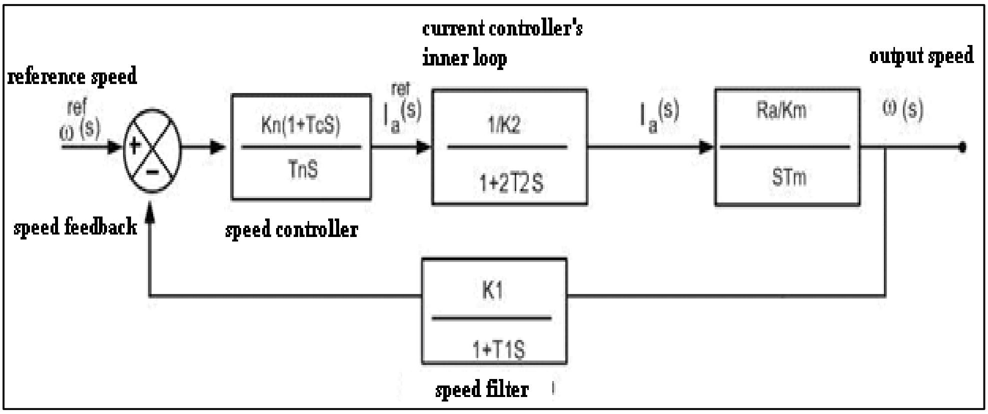


Figure 9: Block model for Speed Controller design

Now, converting the block model in transfer function, we will get:

$$\frac{\omega(s)}{\omega(s)(ref)} = \frac{\frac{\frac{K_n R_a}{K_2 K_m T_m T_n}(1+T_n S)}{(1+2T_2 S)S^2}}{1+\frac{K_n R_a}{K_2 K_m T_m T_n}\frac{(1+T_n S)}{(1+2T_2 S)S^2}\frac{K_1}{(1+T_1 S)}} \quad (38)$$

Here, we have the option to T_n such that it cancels the largest time constant of the transfer
Function, So T_n = $2T_2$
Hence, equation 38 will be written as

$$\frac{\omega(s)}{\omega(s)(ref)} = \frac{K_n R_a(1+T_1 S)}{K_2 K_m T_m T_n(1+T_1 S)+K_n R_a K_1} \quad (39)$$

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

The damping constant is zero in above transfer function because of absence of S term, which results in oscillatory and unstable system.

To optimize this we must get transfer function whose gain is close to unity.

5.2 Speed Controller Parameters Calculation

Speed feedback filter time constant as given in [8], T_1 = 15 ms. The Speed PI type controller is given by: $\frac{K_n(1+T_nS)}{T_nS}$

Here, $T_n = 4\,(T_1 + 2\,T_2) = 4\,(15 + 7) = 88$ ms.

Also $K_n = \frac{T_m K_m K_2}{2K_1 R_a (T_1+2T_2)}$, $K_1 = \frac{10}{Rated\ speed} = \frac{10}{120} = 0.083$,

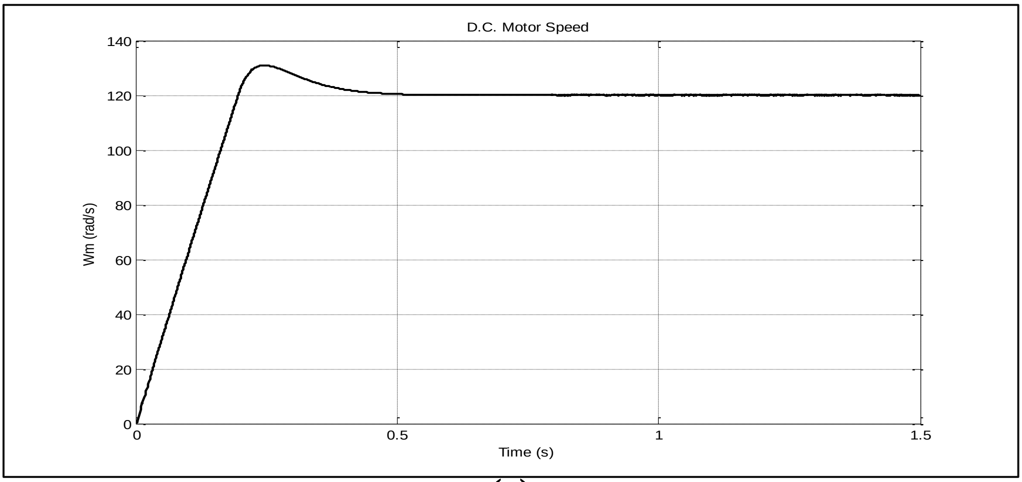
$T_m = \frac{JR_a}{K_m^2} = \frac{0.05\times0.5}{1.23^2} = 16.5$ ms.

Now, $K_n = \frac{16.5\times1.23\times0.333}{2\times0.083\times0.5\times22} = 3.7$

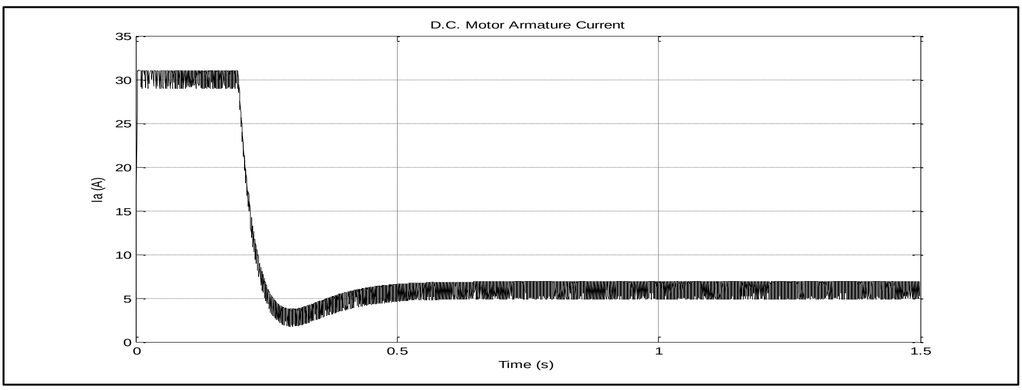
6. Simulation Results

6.1 Simulation of the D.C. Drive Starting

This test simulates the starting transient of the D.C. drive. The inertia of the mechanical load is small (5 N.m.) in order to bring out the details of the chopper commutation. The speed reference is stepped from 0 to 120 rad/s at t = 0.0 s. The transient responses of speed and current for the starting of the D.C. motor drive are shown in figure 10.



(a)

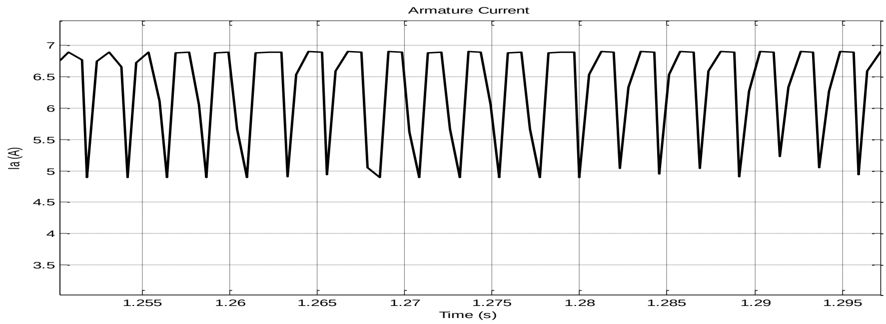


(b)

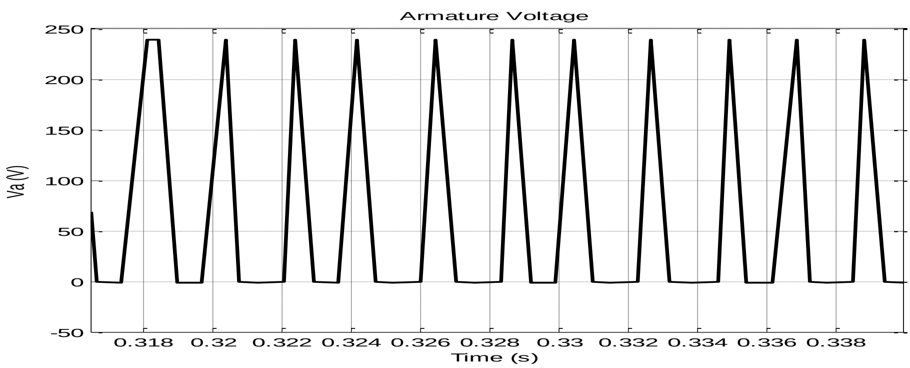
Figure 10: Starting transient of the D.C. motor drive (a) speed and (b) armature current

6.2 Steady – State Current and Voltage Waveforms

The D.C. motor current and voltage waveforms obtained at the end of the starting simulation are shown in figure 11.



(a)

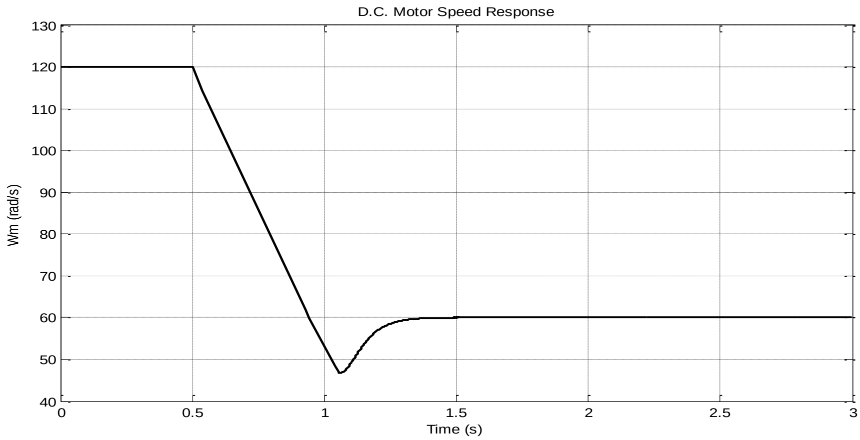


(b)

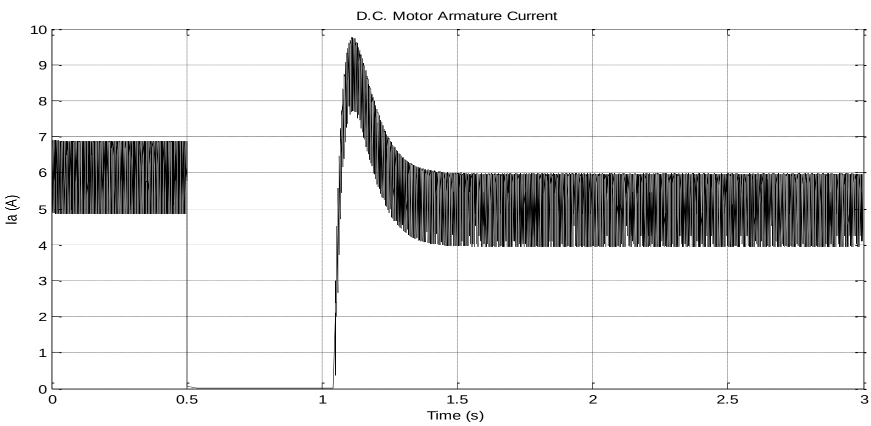
Figure 11: Steady-state (a) motor current and (b) voltage

6.3 D.C. Motor Drive Speed Regulation

In this simulation the speed reference steps from 120 rad/s to 60 rad/s at t = 0.5 s, with keeping the applied torque reference as 5 N.m., figure 12 shows the response of the D.C. motor to the change in speed.



(a)

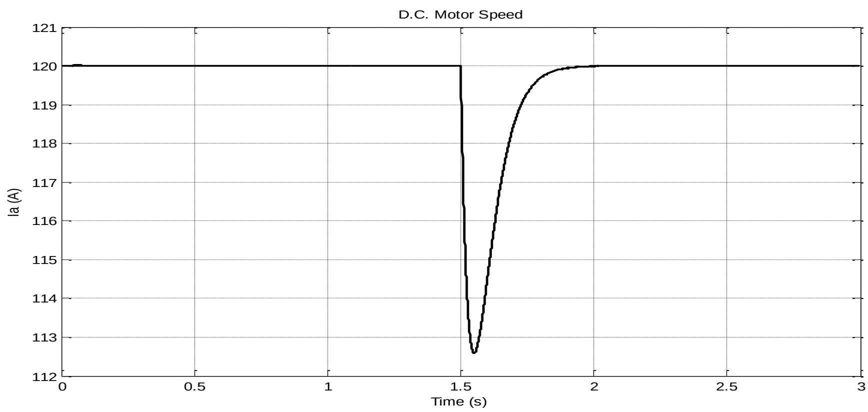


(b)

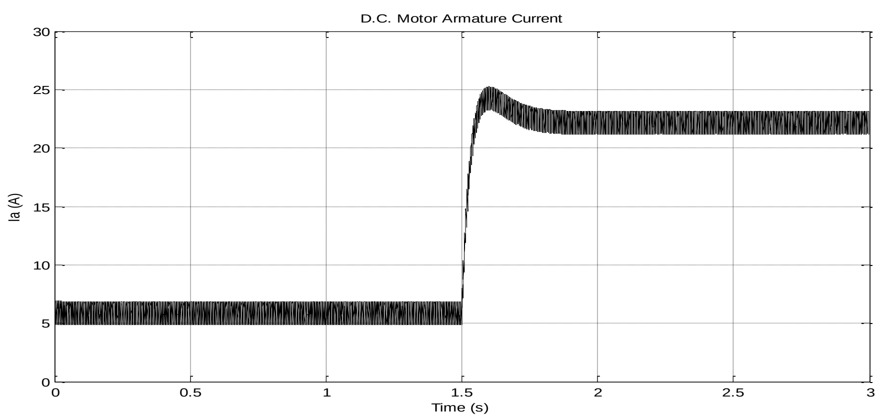
Figure 12: D.C. motor drive response to speed change, (a) speed transient and (b) armature current transient.

6.4D.C. Motor Drive Response to Load Torque Change

In this simulation the load torque steps from 5 N.m. to 25 N.m. at t = 1.5 s and the speed reference is 120 rad/s. Figure 13 shows the response of the D.C. motor drive to the change in load torque.



(a)

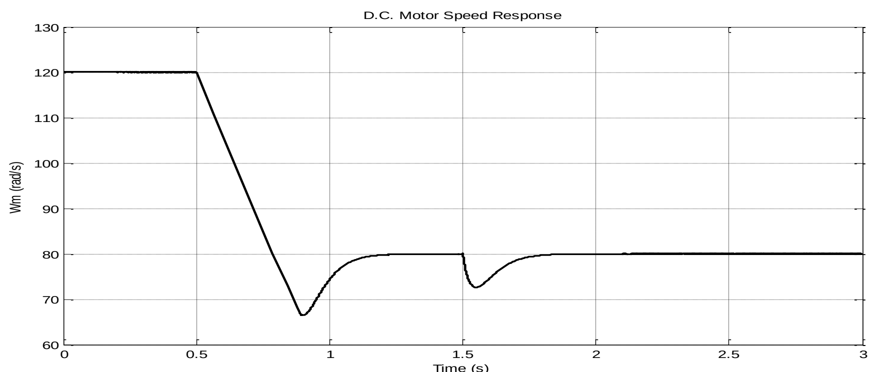


(b)

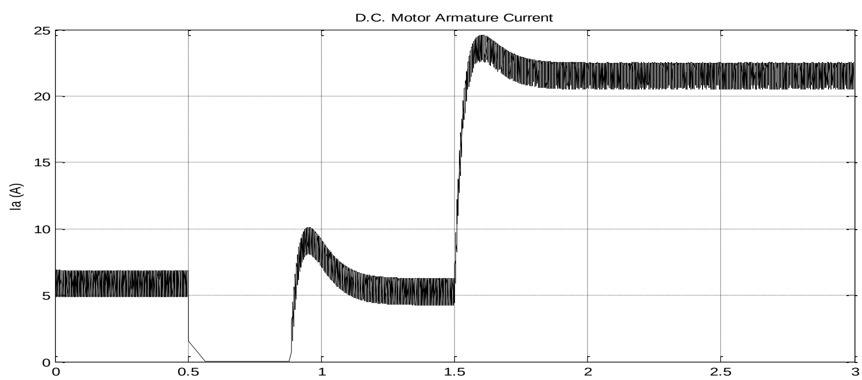
Figure 13: D.C. motor drive response to load torque change, (a) speed transient and (b) armature current transient.

6.5 Dynamic Transient Performance of the D.C. Motor Drive

In this simulation the dynamic performance of the D.C. motor drive is tested by applying two successive transient changing of operating conditions i.e. a step change in speed reference at t = 0.5 s (from 120 rad/s to 80 rad/s) and a step change in load torque at t = 1.5 s (from 5 N.m to 25 N.m.). The response of the D.C. motor drive to these successive changes is shown in figure 14.



(a)



(b)

Figure 14: Dynamic transient of the D.C. motor drive, (a) speed transient and (b) armature current transient.

6.6 Armature controlled D.C. Motor Drive

6.6.1 Simulation with Reference Speed of 120 rad/s and Reference Torque of 5 N.m

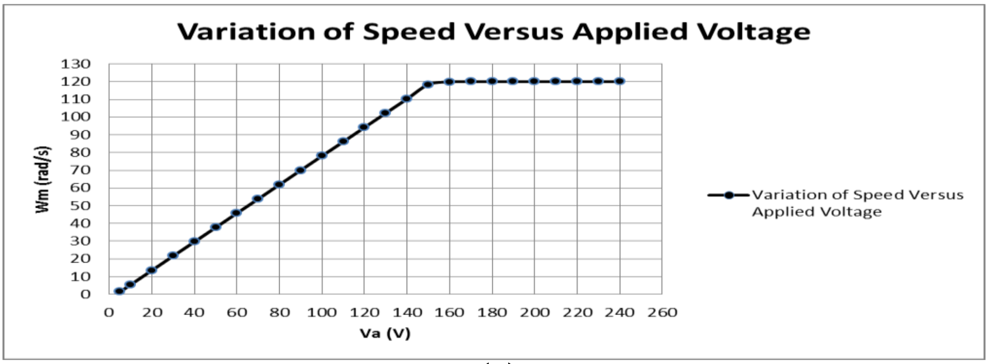
In this simulation the voltage that is applied to the D.C. motor drive is varied. The speed reference of 120 rad/s and torque reference of 5 N.m are used in this simulation. The D.C. motor speed, armature current and the torque are calculated for each value of the applied voltage as shown in table 1. Figure 15 shows the variation of the D.C. motor parameters versus voltage variation.

Table 1: Variation of motor parameters with applied voltage

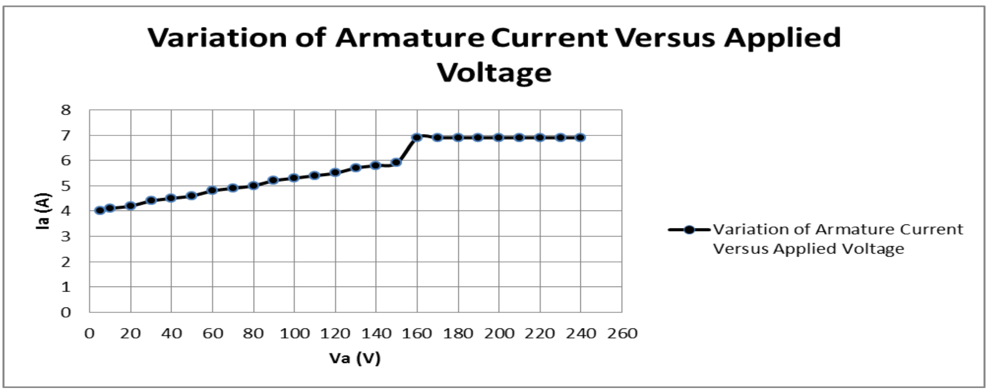
Va (V)	5	10	20	30	40	50	60	70	80	90	100	110
ω (rad/s)	1.4	5.4	13.5	21.6	29.6	37.7	45.8	53.8	61.9	70	78.1	86.1
I_a (A)	4	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5	5.2	5.3	5.4
T_m (N.m)	5	5.1	5.2	5.4	5.5	5.7	5.9	6	6.1	6.3	6.5	6.7

Va (V)	120	130	140	150	160	170	180	190	200	210	220
ω (rad/s)	94.2	102.3	110.3	118.4	120	120	120	120	120	120	120
Ia (A)	5.5	5.7	5.8	5.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Tm (N.m)	6.7	6.9	7.2	7.3	8.5	8.5	8.5	8.5	8.5	8.5	8.5

Va (V)	230	240
ω (rad/s)	120	120
Ia (A)	6.9	6.9
Tm (N.m)	8.5	8.5



(a)



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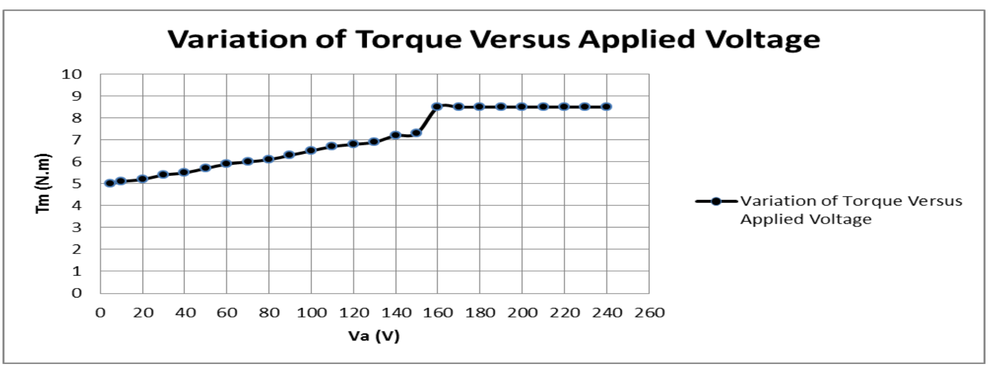


(c)

Figure 15: Variation of (a) speed, (b) armature current and (c) motor torque.

6.6.2 Simulation with Reference Speed of 120 rad/s and Torque of 15 N.m.

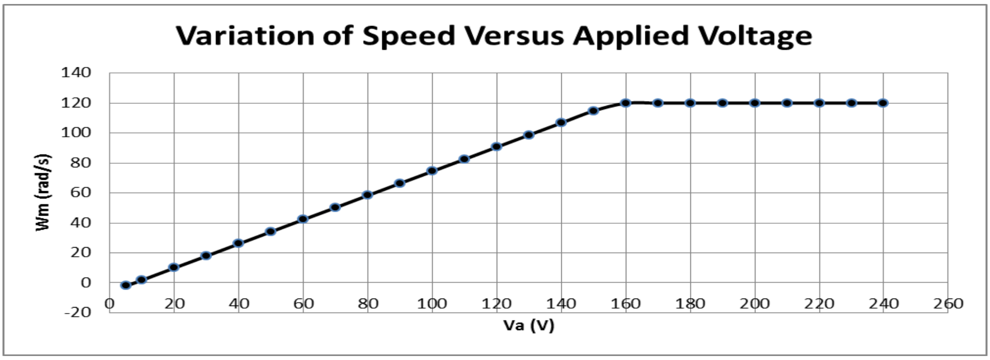
In this simulation the voltage that is applied to the D.C. motor drive is varied. The speed reference of 120 rad/s and torque reference of 15 N.m are used in this simulation. The D.C. motor speed, armature current and the torque are calculated for each value of the applied voltage as shown in table 2. Figure 16 shows the variation of the D.C. motor parameters versus voltage variation.

Table 2 Variation of motor parameters with applied voltage

Va (V)	5	10	20	30	40	50	60	70	80	90	100	110
ω(rad/s)	-2.1	1.8	9.9	17.9	26	34.1	42.2	50.2	58.3	66.4	74.4	82.5
Ia (A)	12.1	12.2	12.3	12.4	12.6	12.7	12.8	13	13.1	13.2	13.4	13.5
Tm(N.m.)	14.9	15	15.1	15.3	15.5	15.6	15.8	16	16.1	16.3	16.4	16.6

Va (V)	120	130	140	150	160	170	180	190	200	210	220
ω (rad/s)	90.6	98.7	106.7	114.8	119.9	120	120	120	120	120	120
Ia (A)	13.6	13.8	13.9	14	14.7	14.8	14.8	14.8	14.8	14.8	14.8
Tm (N.m)	16.8	16.9	17.1	17.2	18	18	18	18	18	18	18

Va (V)	230	240
ω (rad/s)	120	120
Ia (A)	14.8	14.8
Tm (N.m)	18	18



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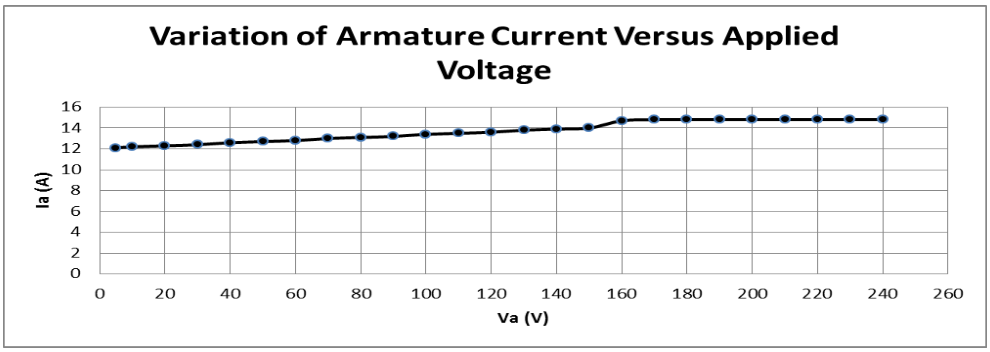

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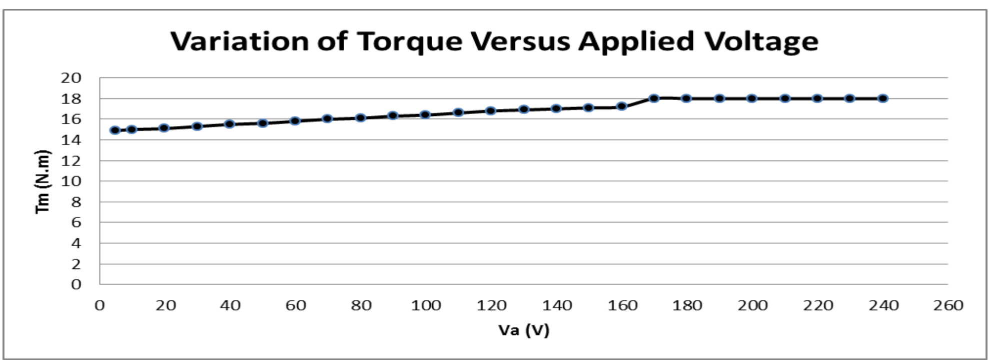


(c)

Figure 16: Variation of (a) speed, (b) armature current and (c) motor torque.

6.6.3 Simulation with Reference Speed of 120 rad/s and Torque of 25 N.m.

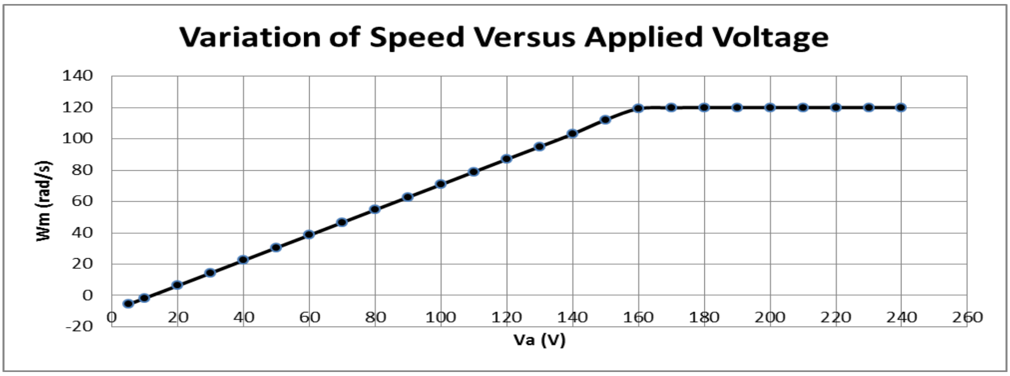
In this simulation the voltage that is applied to the D.C. motor drive is varied. The speed reference of 120 rad/s and torque reference of 25 N.m. are used in this simulation. The D.C. motor speed, armature current and the torque are calculated for each value of the applied voltage as shown in table 3. Figure 17 shows the variation of the D.C. motor parameters versus voltage variation.

Table 3 Variation of motor parameters with applied voltage

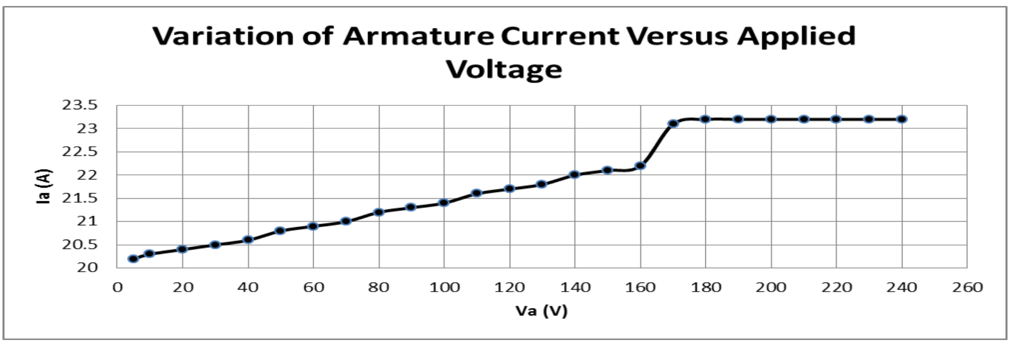
Va (V)	5	10	20	30	40	50	60	70	80	90	100	110
ω(rad/s)	-5.7	-1.7	6.3	14.3	22.4	30.5	38.5	46.6	54.7	62.8	70.8	78.9
Ia (A)	20.2	20.3	20.4	20.5	20.6	20.8	20.9	21	21.2	21.3	21.4	21.6
Tm(N.m.)	24.8	24.9	25.1	25.2	25.4	25.6	15.8	25.9	26	26.2	26.4	26.5

Va (V)	120	130	140	150	160	170	180	190	200	210	220
ω(rad/s)	87	95	103.1	111.2	119.3	119.9	120	120	120	120	120
Ia (A)	21.7	21.8	22	22.1	22.2	23.1	23.2	23.2	23.2	23.2	23.2
Tm(N.m)	26.7	26.9	27	27.2	27.3	28.1	28.3	28.3	28.3	28.3	28.3

Va (V)	230	240
ω (rad/s)	120	120
Ia (A)	23.2	23.2
Tm (N.m)	28.3	28.3



(a)



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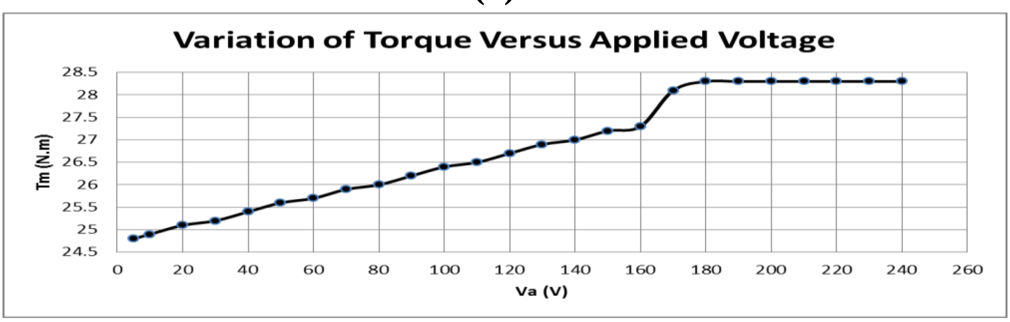


(c)

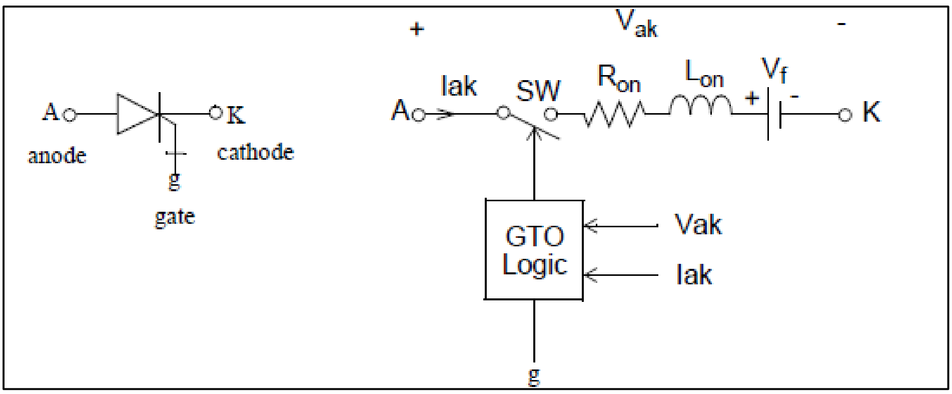
Figure 17: Variation of (a) speed, (b) armature current and (c) motor torque.

7. Conclusion

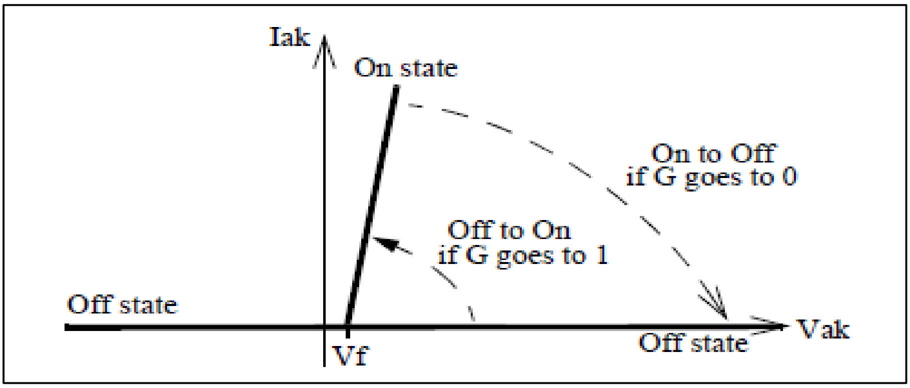
The speed of a D.C. motor has been successfully controlled by using Chopper as a converter and Proportional-Integral type Speed and Current controller based on closed loop system model. Initially a simplified closed loop model for speed control of D.C. motor is considered and requirement of current controller is studied. Then a generalized modeling of dc motor is done. After that a complete layout of D.C. drive system is obtained. Then designing of current and speed controller is done. A D.C. motor specification is taken and corresponding parameters are found out from derived design approach. The simulation results under varying reference speed and varying load are obtained. In 6.6, the shown simulation is of motor speed control by varying the motor armature voltage for the range of speed less and up to the rated speed (constant torque operation) with keeping the field current at fixed value. In (6.6.1, 6.6.2 and 6.6.3) the armature current variations are (41.1%, 18.2% and 12.9%) for applied load torques of (5, 15 and 25) N.m respectively and for the range of speed between (5 and 120) rad/s as shown in tables (1, 2 and 3) and figures (15, 16 and 17) respectively.

Appendix

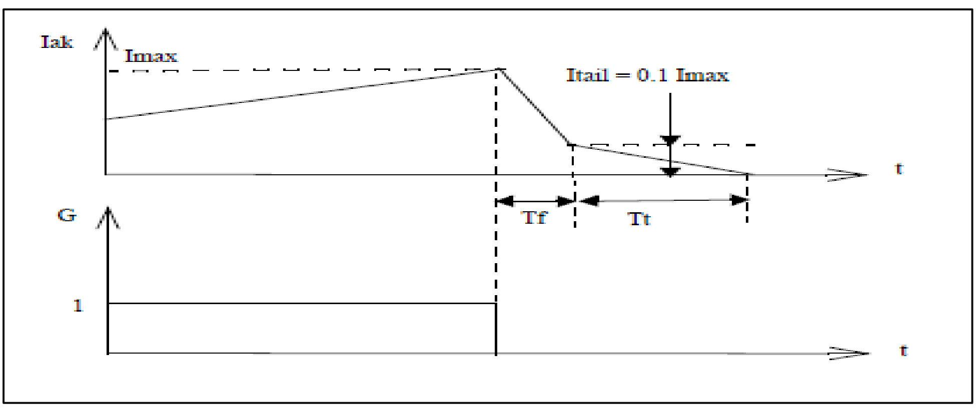
The gate turn off (GTO) thyristor is a semiconductor device that can be turned on and off via a gate signal. The GTO can be turned on by a positive gate signal (g > 0). The GTO can be turned off at any time by a gate signal equal to 0. The GTO is simulated as a resistor R_{on}, an inductor L_{on}, and a D.C. voltage source V_f connected in series with a switch. The switch is controlled by a logical signal depending on the voltage V_{ak} , current I_{ak}, and the gate signal g.



The V_f, R_{on}, and L_{on} parameters are the forward voltage drop while in conduction, the forward conducting resistance, and the inductance of the device. The GTO block also contains a series R_s-C_s snubber circuit that can be connected in parallel with the GTO device (between terminal ports A and K). The GTO on when the anode-cathode voltage is greater than V_f and a positive pulse signal is present at the gate input (g > 0). When the gate signal is set to 0, the GTO starts to block but its current does not stop instantaneously.



Because the current extinction process of a GTO contributes to the turnoff losses, the turnoff characteristic is built into the model. The current decrease is approximated by two segments. When the gate signal becomes 0, the current I_{ak} first decreases from the value I_{max} (value of I_{ak} when the GTO starts to open) to $I_{max}/10$, during the fall time (T_f), and then from $I_{max}/10$ to 0 during the tail time (T_t). The GTO turns off when the current I_{ak} becomes 0. The latching and holding currents are not considered [10].



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تحسين الاداء الديناميكي لمحرك التيار المستمر ذو التغذيه المنفصله للفيض المغناطيسي و بالسيطره على المنتج

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المستخلص

في هذا البحث قد تم تحسين الاداء الديناميكي (اداء تنظيم السرعه حسب تغير عزم الحمل) لمحرك التيار المستمر ذو التغذيه المنفصله لملفات الفيض المغناطيسي. المحرك تم تغذيته من قبل مصدر تيار مستمر و من خلال المقطع من نوع GTO و ثنائي الدوران الحر. المحرك يسوق حمل ميكانيكي ذو عزم قصور ذاتي J و معامل احتكاك B وعزم T_L. ان تحسين الاداء قد تم باستعمال حلقة سيطرة السرعه والتي تستخدم المسيطر من النوع التناسبي التكاملي وهذه الحلقه تنتج اشارة المقارنه لحلقة سيطرة التيار و هذا المسيطر ايضا من النوع التناسبي التكاملي و الذى بدوره يقوم بمقارنة تيار المحرك الفعلي مع اشارة تيار المقارنه و ان ناتج المقارنه تكون اشارة القدح للمقطع GTO وذلك لجعل تيار المحرك بتتبع اشارة المقارنه. المحاكاة لسواقة التيار المستمر هذه قد تمت باستعمال برنامج الماتلاب.

الكلمات الرئيسية: مقطع، مسيطر تناسبي تكاملي، محرك تيار مستمر، مسيطر سرعه، مسيطر تيار.