# PROJECT- RESISTANCE STARTING OF A DC SHUNT MOTOR

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- # Introduction-

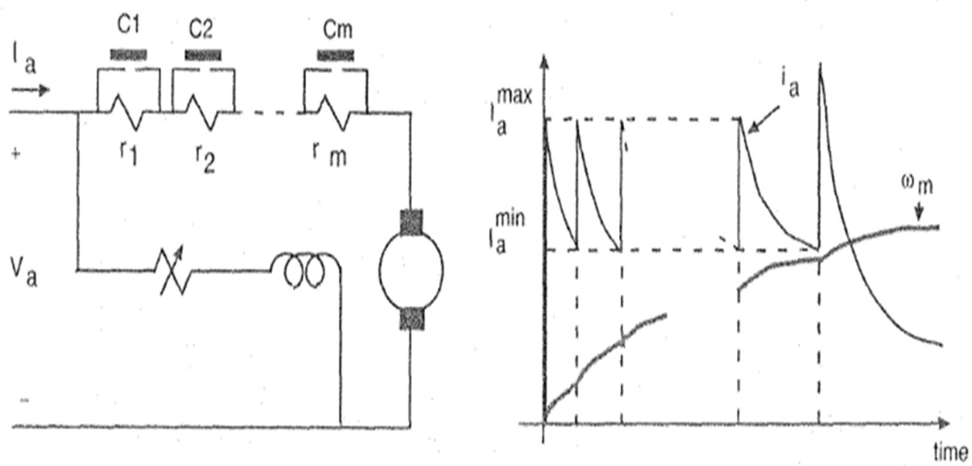
Basic operational voltage equation of a DC motor is given as
$E = E_b + I_a R_a$ and hence, $I_a = (E - E_b) / R_a$
Now, when the motor is at rest, obviously, the back emf $E_b = 0$.
Hence, armature current at the moment of starting can be given as
$I_a = E / R_a$. In practical DC machines, armature resistance is basically very low, generally about 0.5 Ω. Therefore, a large current flows through the armature during starting. This current is large enough to damage the armature circuit.
Due to this excessive starting current -

1. the fuses may blow out and the armature winding and/or commutator brush arrangement may get damaged.
2. very high starting torque will be produced (as torque is directly proportional to the armature current), and this high starting torque may cause huge centrifugal force which may throw off the armature winding.
3. other loads connected to the same source may experience a dip in the terminal voltage.

A large DC motor will pick up speed rather slowly due to its large rotor inertia. Hence, building up the back emf slowly causing the level of high starting current maintained for quite some time. This may cause severe damage. To avoid this, a suitable **DC motor starter** must be used. Very small dc motors, however, may be started directly by connecting them to the supply with the help of a contactor or a switch. It does not result in any harm because they gather speed quickly due to small rotor inertia. In this case, the large starting current will die down quickly due to fast rise of back emf.

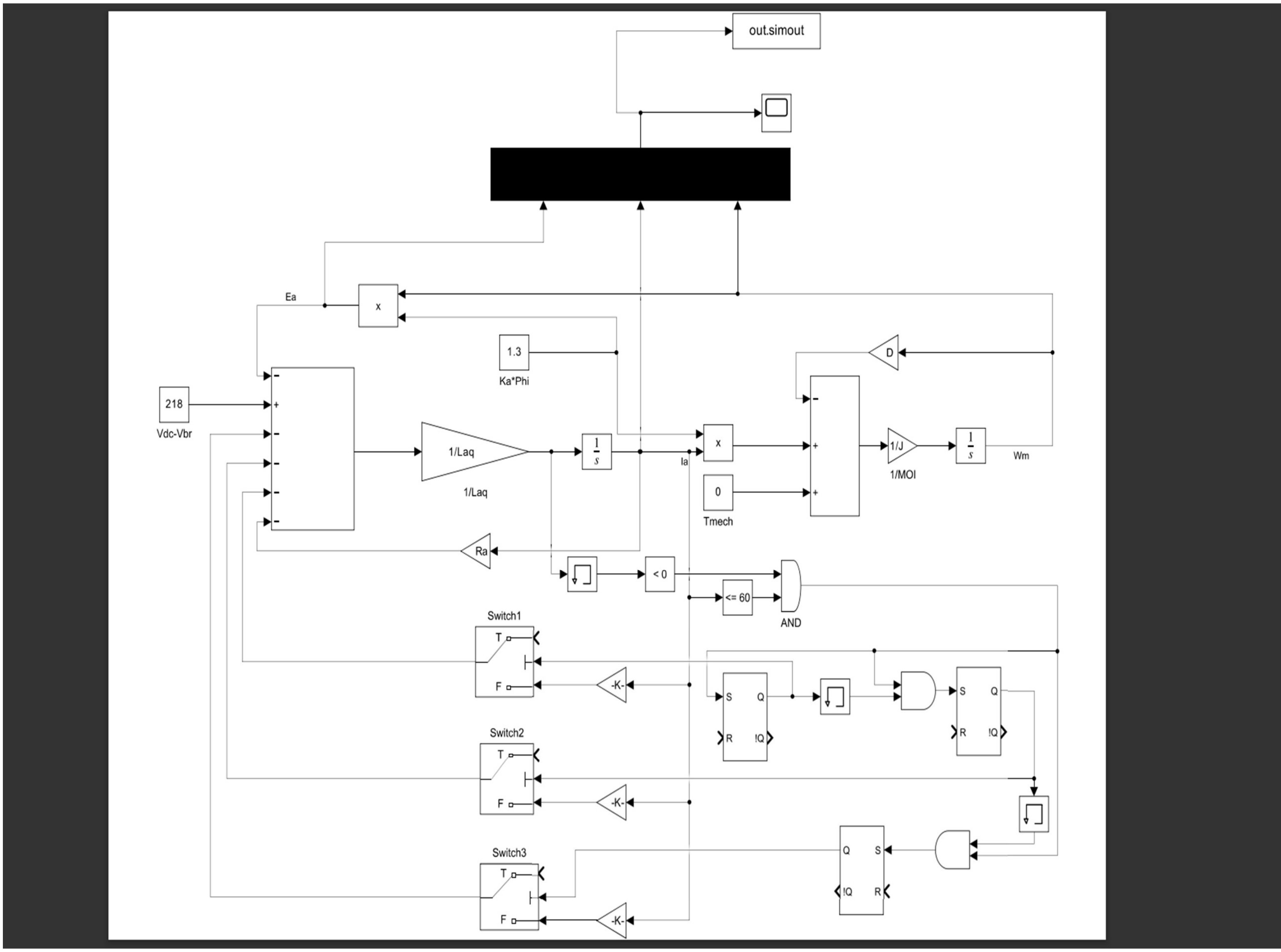
# Resistance Starting

External resistors may be temporarily inserted into the armature circuit during starting to reduce the starting current. These resistors can be manually or automatically shorted out as the motor accelerates. Figure shows a simple starting circuit with m external starting resistor segments that are successively shorted out by contactors as the machine accelerates up to speed. It also shows the waveforms of the armature current and rotor speed during starting.



- System Design/Project Development-

- We simulate the following method to start the dc motor in Simulink software. The symbols, notations and other parameters used to describe the process and methodology can be referred from the Simulink model drawn at the end of page.




-Simulink modelling of the project.

For this project, we will assume that the field excitation of the dc motor has reached the desired steady-state value before energizing the armature circuit to start the motor. The internal emf, $E_a$, of the armature is assumed to be proportional to the product of the field flux, $\phi$, and the motor speed, $\omega_m$, that is

$$E_a = k_a \phi \omega_m \qquad V \tag{8.53}$$

The electromagnetic torque developed by the motor is given by

$$T_{em} = k_a \phi I_a \qquad N.m \tag{8.54}$$

where $I_a$ is the current of the armature.

When the rotor is at or near standstill, $\omega_m$ and also $E_a$ will be zero. In resistance starting, the motor is started with a fixed dc supply voltage, and starting resistors are inserted during the starting period to keep the armature current within some safe limits. The upper current limit is often decided by the ability to commutate properly, and the lower limit is to maintain acceptable acceleration or run-up time.

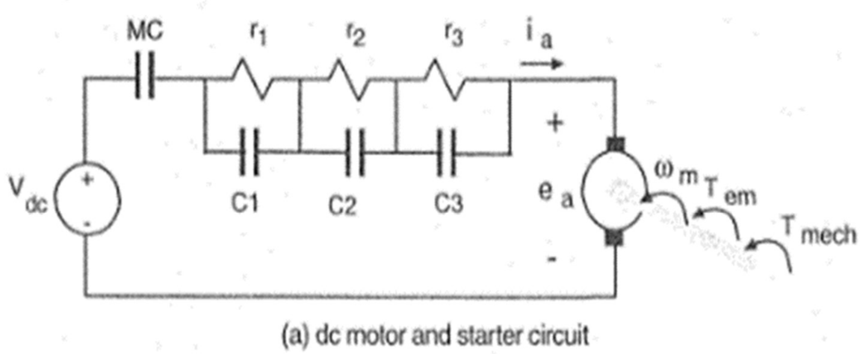
The KVL equation of the armature circuit is

$$V_a = I_a R_t + L_{aq}\frac{dI_a}{dt} + E_a + V_{brush} \qquad V \tag{8.55}$$

where $R_t$, the total resistance in the armature circuit circuit, is the sum of the starter resistance and the armature winding resistance, $R_a$, and $V_{brush}$ is the voltage drop across the brushes on the commutator. The equation of motion of the rotor is obtained by equating the net accelerating torque to the inertia torque on the rotor, that is

$$T_{em} + T_{mech} - D_\omega \omega_m = J\frac{d\omega_m}{dt} \qquad N.m \tag{8.56}$$

where $T_{mech}$ is the externally applied torque in the direction of rotation, $D_\omega$, the damping coefficient, and $J$, the inertia of the rotor. The above two equations can be rewritten into integral form, that is




(a) dc motor and starter circuit

**Figure 8.31** Starting of a dc motor under fixed excitation.

$$
\begin{aligned}
I_a(t) &= \frac{1}{L_{aq}} \int_0^t (V_{dc} - V_{brush} - I_a R_t - E_a)dt + I_a(0) \qquad A \\
\omega_m(t) &= \frac{1}{J} \int_0^t (T_{em} + T_{mech} - D_\omega \omega_m) + \omega_m(0) \qquad rad/s
\end{aligned}
\tag{8.57}
$$

During starting, the switching of the three resistor segments in $s2$ is being triggered by the crossing of $I_a$ below the threshold value of $I_a^{min}$. The contacts, $C1$, $C2$, and $C3$, are initially open. When the main contact, $MC$, is closed to start the motor, the initial starting current drawn will be limited to its upper value, $I_a^{max}$, by all of the starting resistors. As the rotor increases in speed, the back emf, $E_a$, will correspondingly increase with speed, causing the armature current to decrease. When the starting current decreases to the lower limit, $I_a^{min}$, contact $C1$ closes to short out the first starting resistance segment, $r_1$. When $r_1$ is shorted, the armature current rises again and the torque, $T_{em}$, increases along with it, accelerating the rotor to a higher speed. As the back emf, $E_a$, increases with speed, the armature current will again decrease. When the armature current decreases again to the lower limit, the next starting resistor segment, $r_2$, will be shorted out by the contact, $C2$. In this way, the rotor accelerates further and the same process is repeated until the last starting resistance segment, $r_3$, is shorted out, leaving only the armature winding resistance as the rotor accelerates on to full speed.

The sequential logic for starting is implemented in Fig. 8.31b by detecting the condition when $I_a$ decreases down to $I_a^{min}$. The logic signal drives a derivative module, producing a pulse input to a set of SR latches connected to operate like a counter. The outputs of the three latches are used to switch off the resistive drops of the three switchable starting resistor segments. The SR latches can be obtained from the **extras/Flip Flops** block library. The logic and relational operator modules are taken from the **Nonlinear** block library. Memory modules, from the **Nonlinear** block library, are used for different purposes: the module placed before the relational operator module is used to break an algebraic loop, whereas the modules placed between latches are used to create a short delay to get the latches to operate as desired. The switches, C1, C2, and C3, will pass input 1 through if their input 2 is greater or equal to an adjustable threshold, otherwise they pass input 3 through.

If we choose Iamax=100A, Iamin=60A;

$$\begin{aligned} E_a(t_1) &= V_{dc} - V_{brush} - I_a^{min}(R_a + r_1 + r_2 + r_3) \\ &= V_{dc} - V_{brush} - I_a^{max}(R_a + r_2 + r_3) \end{aligned} \tag{8.59}$$

At the instant of shorting out the next section of the starting resistor, we have

$$\begin{aligned} E_a(t_2) &= V_{dc} - V_{brush} - I_a^{min}(R_a + r_2 + r_3) \\ &= V_{dc} - V_{brush} - I_a^{max}(R_a + r_3) \end{aligned} \tag{8.60}$$

At the instant of shorting out the last section of the starting resistor, we have

$$E_a(t_2) = V_{dc} - V_{brush} - I_a^{min}(R_a + r_3) = V_{dc} - V_{brush} - I_a^{max} R_a \tag{8.61}$$

From Eq. 8.58, we obtain

$$(R_a + r_1 + r_2 + r_3) = \frac{V_{dc} - V_{brush}}{I_a^{max}} \quad \Omega \tag{8.62}$$

And from Eqs. 8.59 to 8.61, we obtain

$$\begin{aligned} (R_a + r_2 + r_3) &= \frac{I_a^{min}}{I_a^{max}}(R_a + r_1 + r_2 + r_3) \\ (R_a + r_3) &= \frac{I_a^{min}}{I_a^{max}}(R_a + r_2 + r_3) \\ (R_a) &= \frac{I_a^{min}}{I_a^{max}}(R_a + r_3) \end{aligned} \tag{8.63}$$

With $I_a^{max} = 100A$ and $I_a^{min} = 60A$, the values of the three starting resistance segments are

$$\begin{aligned} r_1 &= 0.872\ \Omega \\ r_2 &= 0.523\ \Omega \\ r_3 &= 0.313\ \Omega \end{aligned} \tag{8.64}$$

# Method to eliminate resistances serially as Ia reaches Iamin(60A here) –

We check if rate of change of current is negative , and given this condition as soon as the current goes below 60 A , the AND gate outputs 1, which in turn sets the output of SR latch to 1 hence the switch passes zero instead of Ia*r value, this output is not reflected to the next SR latch due to one step delay of the memory unit . The successive latches give Output =1 serially after the current hits the 60A marks for the second and third time and thus the second and third resistances are also sorted.

- Implementation- The following value of the parameters used in the model of 10KW, 220V , 1490 rev/minute separately excited dc motor are as follows-

Armature resistace, Ra=0.3 ohm

Armature coil inductance , Laq=12mH

Brush drop, Vb=2V

Rated Current=50A

Flux*Ka , KaPhi = 1.3

Inertia of rotor and load assembly , J=2.5 kgm^2

Damping coefficient Dw=0

Here we take Iamax=100A , Iamin= 60A ;

- Results –Following three parameters were plotted-

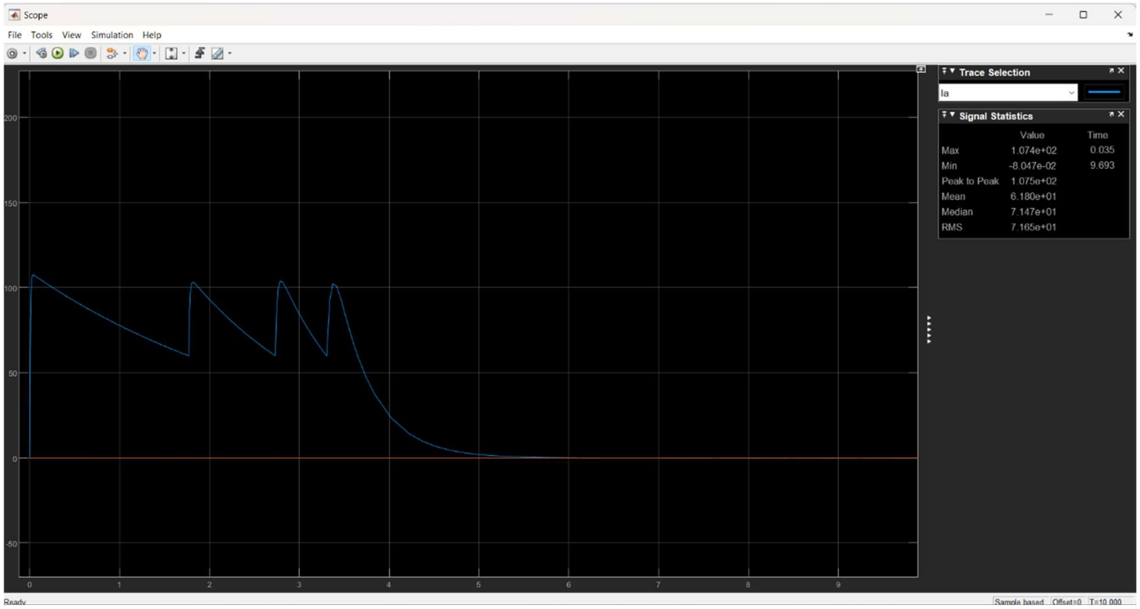
1- Armature current(Ia) vs time.
2- 2- Rotor Speed(Wm) vs time.
3- 3- Back emf (Eb) vs time.

Unit of Ia- Ampere

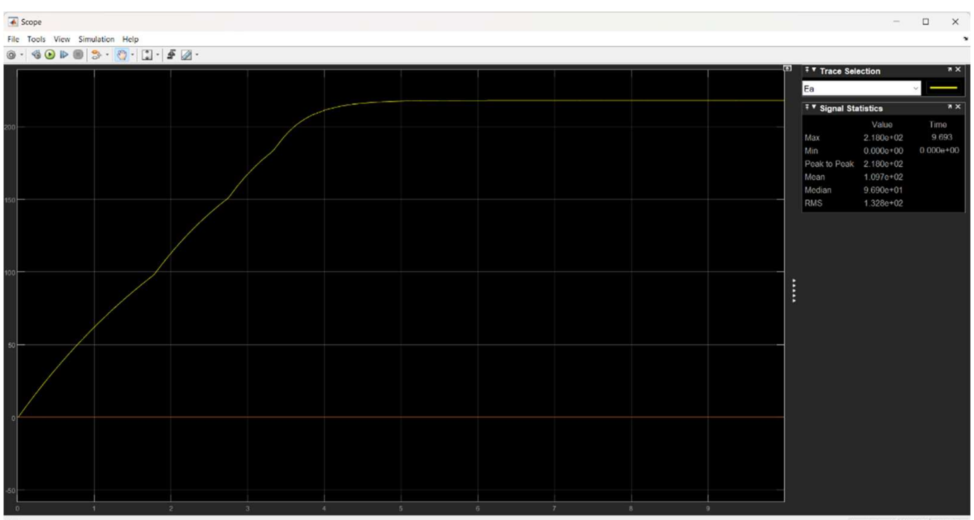
Unit of Wm- Radian/sec

Unit of Eb- Volt

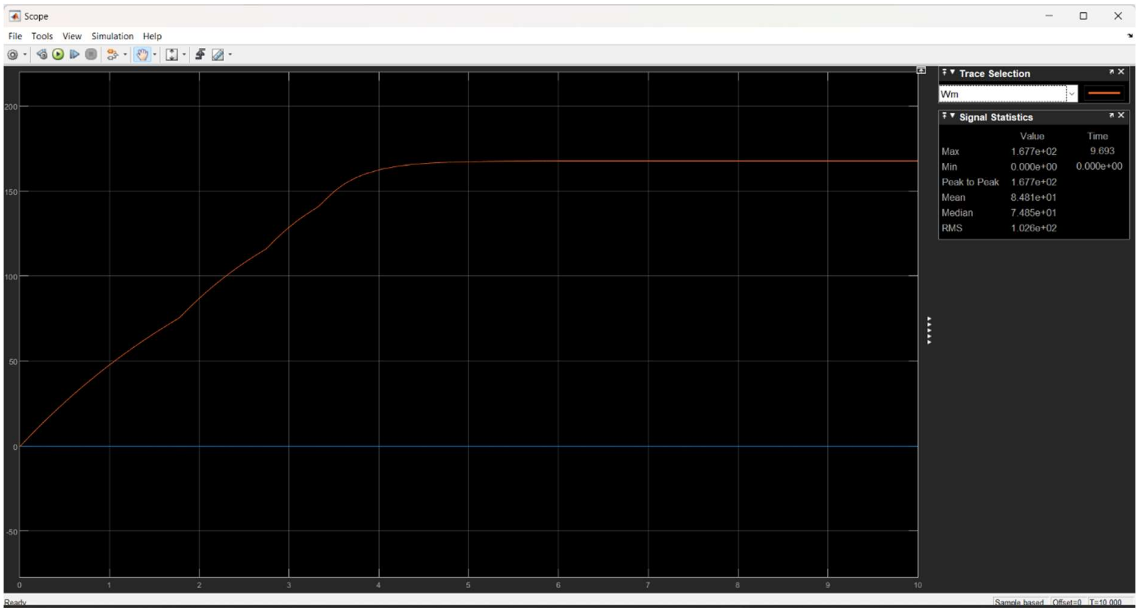
- Ia vs Time




- Ea vs Time



# -Wm vs Time




# -All curves together