EE 360 ELECTRIC Energy

LECTURE 16
DC Motors-II

The material covered in this lecture will be as follows:
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1) The speed control of DC motors
2) The staring methods of DC motors
3) The losses and efficiency of DC machines

At the end of this lecture you should be able to:

To control the speed of DC motors
To control the speed of DC motors
To understand how DC motors are started.
To understand how DC motors are started .
Calculate losses and efficiency of DC machines.
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1. Speed Control of DC Motors

The speed equation of DC motors is given below.

$$\omega = \frac{V_a - I_a R_a}{K_a \phi_m} \qquad (1)$$

The speed of a DC motor is influenced by three factors:
The speed of a DC motor is influenced by three factors:
a. field flux, ϕ_m
b. armature resistance, R_a
c. armature applied voltage, V_a

The most common methods of speed-control are
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1. Shunt-field-rheostat control
2. Armature-circuit –resistance control
3. Armature-terminal–voltage control

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1.1 Shunt-field-rheostat control

Let us keep the armature voltage and resistance constant. Thus the numerator of equation 1 is replaced by a constant.
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The motor speed changes in inverse proportion to the flux as shown in equation 2

$$\omega = \frac{K}{K_a \phi_m} \qquad (2)$$

To control the flux, we can insert a rheostat R_f in series with the shunt filed of the motor.
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Figure 1 shows a typical shunt motor with field rheostat.

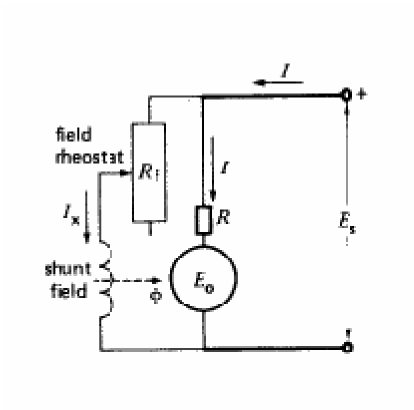

Figure 1 Field Rheostat Speed Control.

If the field rheostat is increased, the field current decreases resulting in lower flux.
If the field rheostat is increased, the field current decreases resulting in lower flux.
A lower flux means higher speed.
A lower flux means higher speed.
This will result in higher speed.
This will result in higher speed.
But the torque may also decease as the it is function of the flux, $T = k_a \phi_m I_a$.
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This method is referred to as constant horse-power method (P=Tω).
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The method is widely used when speed higher that the rated speed is required.
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1.2. Armature Resistance Control

This method is used when lower speed is required.
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The effective armature resistance is increased. This will increase the armature drop.
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The numerator of equation 1 is reduced (. $\omega = \frac{V_a - I_a(R_a + R_{ext})}{K_a \phi_m}$ **).** Thus lower speed is achieved.
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1.3. Applied Armature Voltage Control

This method is very versatile and has become quite attractive with the use of solid-state devices that provide smooth voltage control.
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Any change in the applied voltage is manifested as a change in speed.
Any change in the applied voltage is manifested as a change in speed.
An increase in the applied voltage will result in an increase in speed even though the flux may also increase.
An increase in the applied voltage will result in an increase in speed even though the flux may also increase
A decrease in the applied voltage will result in a decrease in speed even though the flux may also decrease.
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Example 1

A 240-V DC shunt DC motor has an armature resistance of 0.25 Ω and a field resistance of 120 Ω. At full load the armature draws a current of 40 A and the speed is 1100 rpm.
(i) Find the developed torque
(ii) The field rheostat is adjusted so that the field resistance is 150 Ω. Find the new operating speed if the torque and the armature current remain constant.

Solution

The generated emf is given by

$$E_a = V_a - I_a R_a = 240 - 40x\,0.25 = 230\,V$$

The speed $\omega = \dfrac{2\pi N}{60} = \dfrac{2\pi x\,1100}{60} = 115.192\,rad/\sec$

(i) The developed torque

$$P_{dev} = E_a I_a = 230x\,40 = 9200\,W$$

$$T_{dev} = \frac{P_{dev}}{\omega} = \frac{9200}{115.19} = 79.87\,N-m$$

(ii) New Speed

The initial field resistance R_{f1} = 120 Ω
The new field resistance R_{f2} = 150 Ω

The initial field current $I_{f1} = \dfrac{V_t}{R_{f1}} = \dfrac{240}{120} = 2A$

The new field current $I_{f2} = \dfrac{V_t}{R_{f2}} = \dfrac{240}{150} = 1.6A$

The armature current remains the same. This means that the generated emf is the same for the two operating conditions

$$E_{a1} = E_{a2}$$

$$K_a I_{f1}\omega_1 = K_a I_{f2}\omega_2$$

$$\omega_2 = \left(\frac{I_{f1}}{I_{f2}}\right)\omega_1 = \left(\frac{2}{1.6}\right)115.192 = 143.99\,rad/\sec$$

The new speed in rpm $N_2 = \dfrac{\omega_2 x\,60}{2\pi} = 1375\,rpm$

2. Starting of DC Shunt Motors

When a shunt motor is started from stationary position, the speed is very low.
When a shunt motor is started from stationary position, the speed is very low.
The generated back emf is almost zero ($E_a = K_a\phi_m\omega \approx 0$).
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The armature current is limited only by the armature resistance

$$I_a = \frac{V_a - E_a}{R_a} = \frac{V_a - 0}{R_a} = \frac{V_a}{R_a} \qquad (3)$$

This may result in extremely high and dangerous currents.
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High currents can burn the machine armature or damage commutators and brushes .
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Thus there is a need to limit the starting current of DC motors.
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Two methods are widely used to limit the starting current of DC motors:
Two methods are widely used to limit the starting current of DC motors:

a. Insert an external resistance in the armature circuit.
b. Apply a reduced voltage at starting.

Insert an external resistance in the armature circuit.
Apply a reduced voltage at starting.

The first method implies increased losses but only during the starting period.
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The second method requires a variable voltage supply. This is now possible through the use of solid-state devices.
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The external resistance is inserted into the armature at starting.
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The armature current at starting is given by 4.
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$$I_a = \frac{V_a}{(R_a + R_{ext})} \qquad (4)$$

As the motor accelerates, the external resistance is gradually removed from the armature circuit.
As the motor accelerates, the external resistance is gradually removed from the armature circuit.
Figure 2 shows a typical four-step starter of a shunt DC motor.

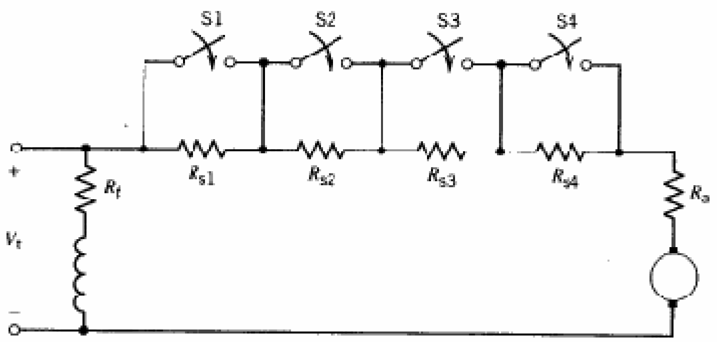

Figure 2 DC motor starter.

Example 2

A 10 HP 220-V 1000 rpm DC shunt motor has a full load current of 40 A. The motor is started by a four-point starter. The armature resistance is 0.3406 Ω and the resistances of the steps in the starting resistor are 1.375, 0.694, and 0.3406 Ω in the order in which they are cut out . When the armature current has dropped to its rated value, the starter is switched to its next point. This means eliminating a step at time of the resistor. Find:

(i) the initial and final value of the armature current at each step.

(ii) the corresponding speed at each step.

Solution

Step # 1 Resistance in armature circuit, R_{t1}= 1.375+0.694+0.39+0.3406 =2.75 Ω

Step # 2 Total resistance in armature circuit, R_{t2}= 0.694+0.39+0.39 =1.375 Ω

Step # 3 Total resistance in armature circuit, R_{t3}= 0.3406+0.3406 =0.6812 Ω

Step # 4 Total resistance in armature circuit, R_{t4} =0.3406 Ω

1. At starting, the generated back emf, E_a, is zero. All the resistance is in circuit. The starting armature current I_{st}

$$I_{st} = \frac{V_a - E_a}{R_{t1}} = \frac{V_a - 0}{R_{t1}} = \frac{220}{2.75} = 80.0A$$

When the armature drops to its rated value of 40 A, the corresponding emf is

$$E_{a1} = V_a - I_a R_a = 220 - 40x\ 2.75 = 110V$$

When the motor delivers rated load at rated speed of 1000 rpm, the emf

$$E_a = V_a - I_a R_a = 220 - 40x\ 0.3406 = 206.376V$$

Thus the speed corresponding to en emf (E_{a1}), 110 is

$$N_1 = \frac{E_{a1}}{E_a} xN_{full} = \frac{110}{206.376} x\,1000 = 533\ rpm$$

2. The 1.375 Ohm is cut of the circuit. The remaining resistance is R_{t2}= 1.375 Ω
The speed at this stage is 533 rpm and the emf is still 110

$$I_{st} = \frac{V_a - E_{a1}}{R_{t2}} = \frac{220 - 110}{1.375} = 80A$$

When the armature drops to its rated value of 40 A, the corresponding emf is

$$E_{a2} = V_a - I_a R_a = 220 - 40x\,1.375 = 165.5V$$

Thus the speed corresponding to en emf (E_{a2}), 165.5 is

$$N_2 = \frac{E_{a2}}{E_a} xN_{full} = \frac{165.5}{206.376} x\,1000 = 801.9\,rpm$$

3. The remaining resistance is R_{t3}= 0.6812 Ω
The speed at this stage is 801.9 rpm and the emf is still 165.5 V.

$$I_{st} = \frac{V_a - E_{a2}}{R_{t2}} = \frac{220 - 165.5}{0.6812} = 80A$$

When the armature drops to its rated value of 40 A, the corresponding emf is

$$E_{a3} = V_a - I_a R_a = 220 - 40x\,0.6812 = 192.75V$$

Thus the speed corresponding to en emf (E_{a3}), 192.75 is

$$N_3 = \frac{E_{a3}}{E_a} x N_{full} = \frac{192.75}{206.376} x\,1000 = 933.97\,rpm$$

4. The remaining resistance is R_{t4}= 0.3406 Ω

The speed at this stage is 923.6 rpm and the emf is still 192.75 V.

$$I_{st} = \frac{V_a - E_{a3}}{R_{t2}} = \frac{220 - 192.75}{0.3406} = 80A$$

When the armature drops to its rated value of 40 A, the corresponding emf is

$$E_{a4} = V_a - I_a R_a = 220 - 40x\,0.3406 = 206.376V$$

Thus the speed corresponding to en emf (E_{a3}), 204.4 is

$$N_4 = \frac{E_{a4}}{E_a} x N_{full} = \frac{206.376}{206.376} x\,1000 = 1000\,rpm$$

Table 1 provides a summary of the results

step	Initial Current (A)	Final Current(A)	Speed (rpm)
1	80	40	533
2	80	40	801.9
3	80	40	933.97
4	80	40	1000

3. Efficiency of DC machines

The efficiency of the DC machine, whether motor or generator, is expressed as

The efficiency of the DC machine, whether motor or generator, is expressed as

$$Efficieny = \frac{output}{input} = \frac{Input - losses}{input} \quad 1 - \frac{losses}{input} \qquad \textbf{(5)}$$

The losses in a DC machine are made of the following components:

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a. Electrical or copper losses

These are the losses in the armature and field windings. The losses depend of the load and armature currents. They are classified as variable losses. These include

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Armature copper losses $P_a = I_a^2 R_a$

Shunt field losses $P_f = I_f^2 R_f$

Series field losses $P_s = I_a^2 R_s$

Brush Losses (depending on brush voltage drop) $P_b = 2I_a$

b. Magnetic or core losses

These are hysteresis and eddy current losses. They occur in the magnetic circuits of the stator and armature .

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They are constant and are independent of the load.

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c. Mechanical losses

These are the friction and windage losses.

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Friction losses are incurred in bearing, brushes etc.

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Windage losses are due to friction between rotating parts and the air inside the machine.

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d. Stray load losses

These are losses that are unaccounted for.

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When the core and mechanical losses are lumped together, they are referred to as rotational losses.

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Example 3

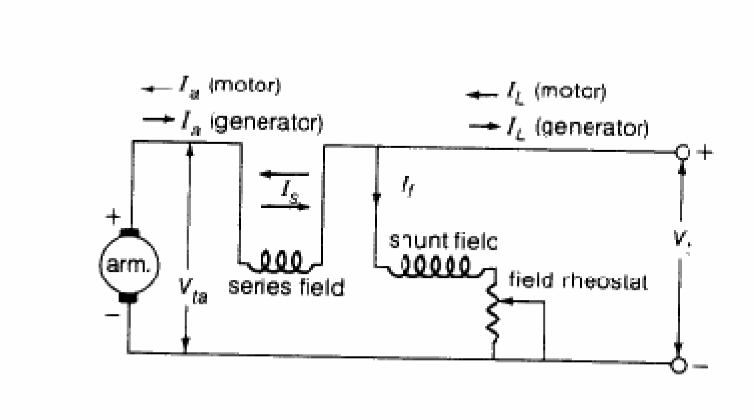
Compute the efficiency of 100 kW, 250-V, 6-pole, 1000 rpm long shunt compound generator. The generator has the following parameters

Armature resistance	R_a	= 0.015 Ω
Series field resistance	R_s	= 0.010 Ω
Shunt field resistance	R_f	= 100.0 Ω
Total rotational losses		= 4000 W

Assume a stray losses to be 1% of the output and a brush drop of 2 volts.

Solution

Figure 3 show the compound machine with the details



Total resistance in armature circuit (R_A) = $R_a + R_s = 0.015 + 0.010 = 0.025\ \Omega$

Field current I_f $= \dfrac{V_t}{R_f} = \dfrac{250}{100} = 2.5\ A$

Load current I_L $= \frac{P_{out}}{V_t} = \frac{100000}{250} = 400\ A$

Armature current $I_a = I_L + I_f$ = 400+2.5 = 402.5 A

Machine Losses in Watts are :

Rotational losses			=4000
Armature Copper losses =	$I_a^2(R_A) = (402.5)^2 x\ (0.025)$		$= 4050$
Brush losses	= 2 Ia	=2x 402.5	= 805
Shunt field losses	= I_fx V_t	=2.5x250	= 625
Stray losses	= 0.01x100,000		= 1000
Total Losses			= 10,480
Input	=100,000+10,480		= 110480 W

Efficiency $\eta = 1 - \frac{losses}{input} = 1 - \frac{10480}{110480} = 0.905 = 90.5\%$