EE 360 ELECTRIC Energy

LECTURE 14
DC Generators: Steady State-II

The material covered in this lecture will be as follows:
The material covered in this lecture will be as follows:

1) The no load characteristics of a DC machine.
2) The steady state load characteristics of DC generators

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

⇒ Explain the open circuit characteristics of a DC machine.
Explain the open circuit characteristics of a DC machine.
Understand the voltage current relationship of a DC machine.
Understand the voltage current relationship of a DC machine.

1. No load Characteristics of DC Machines

You may recall that the voltage generated in DC machine is function of both the speed and the flux. It is given by the following equation.

You may recall that the voltage generated in DC machine is function of both the speed and the flux. It is given by the following equation:.

$$E = K_a \phi_m \omega \qquad (1)$$

- By referring to figure 1, we can see that the magnetic field is generated by the field current I_f.

- The flux ϕ is proportional to the field current.

$$\phi = k_f I_f \qquad (2)$$

The K_f factor is calculated from the magnetic circuit using Amperes Law
The K_f factor is calculated from the magnetic circuit using Amperes Law

Figure 1 show the equivalent circuit of DC machines

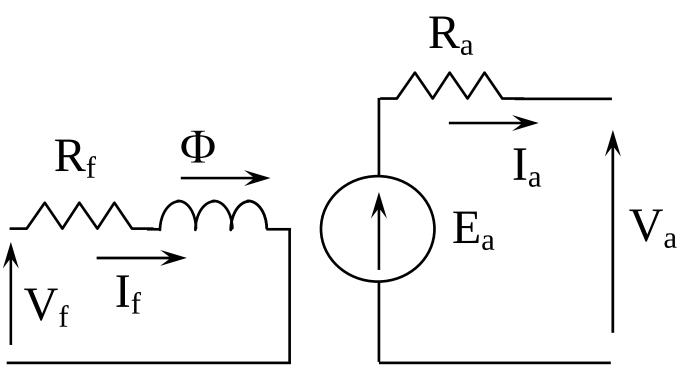


Figure 1 Equivalent Circuit of a DC Machine

- The flux ϕ is proportional to the field current.

The flux ϕ is proportional to the field current

$\phi = k_f I_f$

- The armature generated voltage is give by

$$E_a = K_a \phi_m \omega = K' I_f \omega \qquad (3)$$

Where E_a = armature generated voltage
K_a = machine constant
K' = modified machine constant

The relationship between the generated and the terminal voltages is given by
The relationship between the generated and the terminal voltages is given by

$$E_a = V_a + I_a R_a \qquad (4)$$

Where
V_a= terminal voltage
I_a = armature current
R_a = armature resistance
At no load, the terminal voltage is equal to the generated voltage.
At no load, the terminal voltage is equal to the generated voltage.

$$V_a = E_a = K' I_f \omega \qquad (5)$$

Equation 5 is used to determine the no-load characteristics of DC machines.
Equation 5 is used to determine the no-load characteristics of DC machines.
It is also known as open circuit characteristics.
It is also known as open circuit characteristics.
It is a plot of generated voltage against the field current.
It is a plot of generated voltage against the field current.
This will be explained below.
This will be explained below.
Let us assume that the speed of rotation is constant.
Let us assume that the speed of rotation is constant.
Then, the voltage becomes a function of the field current only.
Then, the voltage becomes a function of the field current only.
The relationship between the voltage and the field current is known as the load characteristic.
The relationship between the voltage and the field current is known as the load characteristic.

Mathematically speaking, the relationship is linear and is represented by a straight line.
Mathematically speaking, the relationship is linear and is represented by a straight line.
However as the filed current (-flux) is increased , the machine core saturates and the voltage tend to increase at a lower rate.
However as the filed current (-flux) is increased , the machine core saturates and the voltage tend to increase at a lower rate.
Once complete saturation is reached, the voltage remains will not increase even if the field current is increased.
Once complete saturation is reached, the voltage remains will not increase even if the field current is increased.
In case of a shunt generator, the generator itself provides its own flux.
In case of a shunt generator, the generator itself provides its own flux.
A small residual voltage is generated because of the presence of a residual flux in the machine core.

A small residual voltage is generated because of the presence of a residual flux in the machine core.
This voltage causes a field current to flow and thus a more flux is produced.

This voltage causes a field current to flow and thus a more flux is produced.

The higher flux produces more generated voltage resulting in higher field current. The process continues till the voltage build up is completed.
The higher flux produces more generated voltage resulting in higher field current. The process continues till the voltage build up is completed.

There are three factors that influence the build up of a voltage in a shunt DC machine.
There are three factors that influence the build up of a voltage in a shunt DC machine.

1. Residual flux: If there is no residual flux the voltage will never build up.
1. Residual flux: If there is no residual flux the voltage will never build up.

2. Critical field Resistance: If the field resistance is greater than a critical value, the voltage would remain at the residual value.
2. Critical field Resistance: If the field resistance is greater than a critical value, the voltage would remain at the residual value.

3. Relative polarity of field winding and the terminal voltage: the field current should produce a flux to aid the residual flux otherwise there will be no voltage buildup.
3. Relative polarity of field winding and the terminal voltage: the field current should produce a flux to aid the residual flux otherwise there will be no voltage buildup.

Reversal of field winding connections or the direction of rotation will cause the voltage to build up.
Reversal of field winding connections or the direction of rotation will cause the voltage to build up.

Figure 2 shows a typical no load characteristics of a DC machine.
Figure 2 shows a typical no load characteristics of a DC machine.

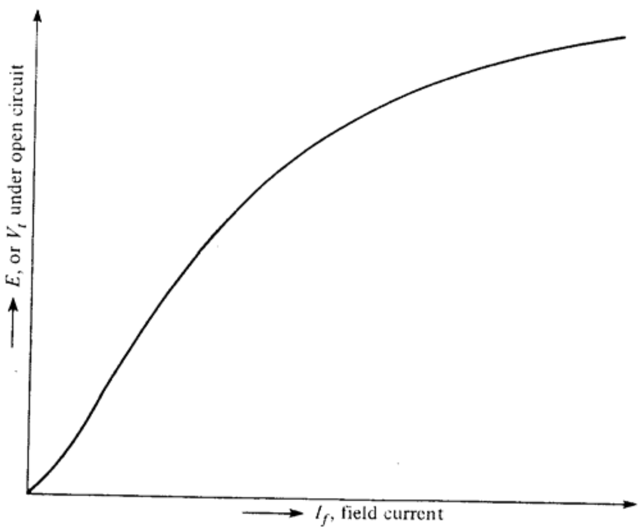


Figure 2 No-Load Characteristics of a DC machine.

Example 1

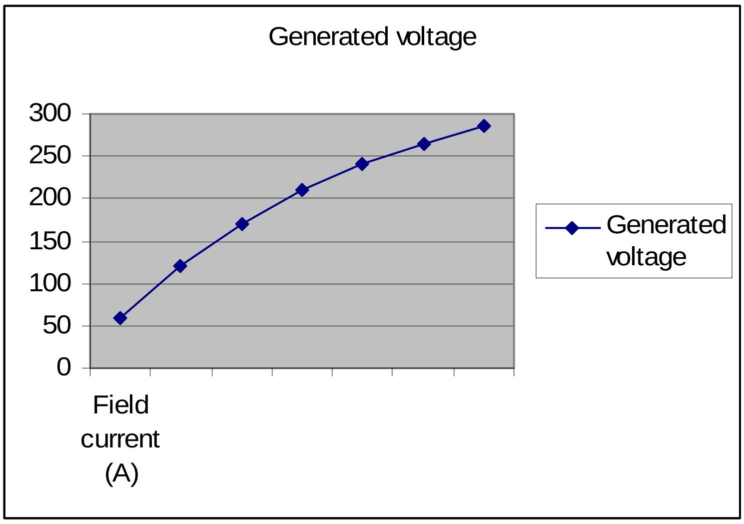
The open-circuit characteristics of a DC generator is given by

E_a (V)	60	120	170	210	240	265	285
I_f (A)	1	2	3	4	5	6	7

The generator runs at 1800 rpm.
1. Plot the open-circuit characteristics.
2. Find the maximum field resistance in order for the voltage to build up.
3. Determine the value of the generated voltage for a field resistance of 48 Ohms and field current of 5 A at speed of 1800 rpm.

Solution

The open circuit characteristics are shown n figure 3.



(b) $R_f = \dfrac{\Delta E_a}{\Delta I_f} = \dfrac{120-60}{2-1} = 60\,\Omega$

(c) E_a = 5x48= 240 V

2. load Characteristics of DC Generators

This is defined as the relationship between the terminal voltage and the load current.
This is defined as the relationship between the terminal voltage and the load current.

The main causes of voltage decrease in a DC generator are:
The main causes of voltage decrease in a DC generator are:

1. Armature resistance drop: It is equal to I_aR_a due to the flow of the current through R_a
1. Armature resistance drop: It is equal to I_aR_a due to the flow of the current through R_a

2. Brush contact drop: the contact between the brush and the commentators has an electrical resistance which will cause a voltage drop. A constant voltage of 2 V is usually assumed as a drop.

2. Brush contact drop: the contact between the brush and the commentators has an electrical resistance which will cause a voltage drop. A constant voltage of 2 V is usually assumed as a drop.

3. Armature reaction voltage drop: The flow of current through the armature winding causes an armature mmf which opposes the main flux. This has a demagnetizing effect which is reflected as a voltage drop.

3. Armature reaction voltage drop: The flow of current through the armature winding causes an armature mmf which has opposes the main flux. This has a demagnetizing effect which is reflected as a voltage drop.

4. Reduction of Terminal voltage in self excited generators: Since the field winding is supplied from generator itself, any reduction in terminal voltage will result in a reduced

field current. This will lead to weakening of flux and thus reduced the terminal voltage further.

4. Reduction of Terminal voltage in self excited generators: Since the field winding is supplied from generator itself, any reduction in terminal voltage will result in a reduced field current. This will lead to weakening of flux and thus reduced the terminal voltage further.

The load characteristics of different types of DC generators are shown in Figure 4.

The load characteristics of different types of DC generators are shown in Figure 4.

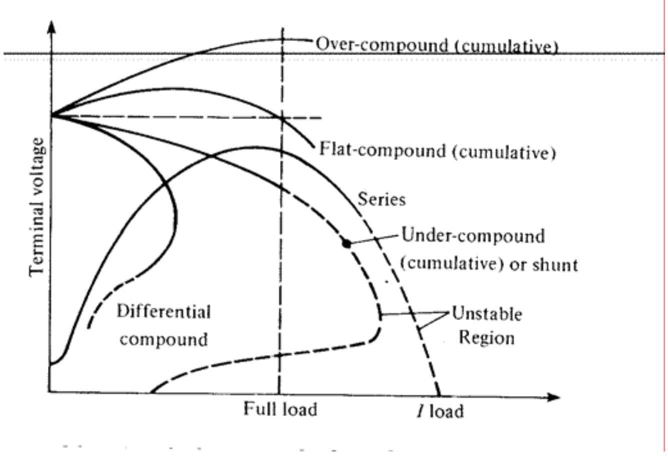


Figure 4 Load Characteristics of DC Generators

The terminal voltage of a DC generator falls as the load current increases.

The terminal voltage of a DC generator falls as the load current increases.

Let us consider the load characteristics of the DC generators in details. Each type of generators exhibits different response.

Let us consider the load characteristics of the DC generators in details. Each type of generators exhibits different response.

The characteristic of a separately excited generator exhibits a drooping shape as a result of the firs three causes.

The characteristic of a separately excited genrator exhibits a drooping shape as a result of the first three causes.

The characteristics of a shunt generator are similar to that of self excited generator but the terminal voltage is lower due to the fourth reason..

The characteristics of a shunt generator are similar to that of self excited generator but the terminal voltage is lower due to the fourth reason..

If the load current is increased beyond a certain value, the voltage may collapse to zero.

If the load current is increased beyond a certain value, the voltage may collapse to zero.

In case of a series generator, the field and load currents are the same. The generated and terminal voltages increase with load current.

In case of a series generator, the field and load currents are the same. The generated and terminal voltages increase with load current.

However beyond a certain value of load (field) current, the machine saturates and the generated voltage does not increase any more.

However beyond a certain value of load (field) current, the machine saturates and the generated voltage does not increase any more.

The terminal voltage collapses towards zero as the load current increases

The terminal voltage collapses towards zero as the load current increases

In case of compound generators, the series and shunt field are either aiding or opposing each other.

In case of compound generators, the series and shunt field are either aiding or opposing each other.

The flux of the two windings may be adjusted to produce a terminal voltage at full load current which is equal, less or greater than the no-load generated voltage.

The flux of the two windings may be adjusted to produce a terminal voltage at full load current which is equal, less or greater than the no-load generated voltage.

Let us now measure the change in the terminal voltage as a result of an increase in the load current.

Let us now measure the change in the terminal voltage as a result of an increase in the load current.

Voltage regulation defines the degree of voltage decrease in a DC generator.

Voltage regulation defines the degree of voltage decrease in a DC generator

It is defined as the percentage change in voltage when the load is removed from the generator terminals. It is expressed by the following equation

$$\text{Voltage Regulation} = \frac{E_a - V_a}{V_a} x 100 \qquad (6)$$

It is defined as the percentage change in voltage when the load is removed from the generator terminals.

$$\text{Voltage Regulation} = \frac{E_a - V_a}{V_a} x 100 \qquad (6)$$

Example 2

A 48-KW 240-V short shunt compound generator has the following parameters

$R_a = 0.03\ \Omega$

$R_s = 0.015\ \Omega$

$R_f = 120.0\ \Omega$

Take 2 V as the total brush contact drop.

(i) Calculate the induced voltage at full load.

(ii) Calculate the voltage regulation at full load.

Solution

The equivalent circuit is shown below

$$I_L = \frac{48x1000}{240} = 200\ A$$

$$I_L R_s = 200 x\ 0.015 = 3V$$

$$V_f = 240 + 3 = 243V$$

$$I_f = \frac{V_f}{R_f} = \frac{243}{120} = 2.025\ A$$

$$I_a = I_L + I_f = 200 + 2.025 = 202.025 A$$

$$I_a R_a = 202.025 x\ 0.03 = 6.0607 A$$

$$E_a = 240 + 6.0607 + 3 + 2 = 251.0607 V$$

(ii) The voltage regulation is given by

Voltage Regulation= $\frac{E_a - V_a}{V_a} x\,100 = \frac{251.0607 - 240}{240} x\,100 = 4.61\%$