EE 360 ELECTRIC Energy

LECTURE 12
DC Generators: Steady State-I

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

1) Equivalent Circuit of DC generators
2) Classification of DC Machines..
3) Performance equations

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

⇒ Represent a DC machine by an equivalent circuit.
Represent a DC machine by an equivalent circuit.
Understand how to use performance equations to calculate voltage and current in a DC generator.

Understand how to use performance equations to calculate voltage and current in a DC generator

1. DC Machine Classifications

DC machines are classified according the method of excitation or supply of the field winding
DC machines are classified according the method of excitation or supply of the field winding

a. **Separately excited machines**: the field winding (excitation) receives its supply from a separate source.
Separately excited machines: the field winding (excitation) receives its supply from a separate source.

b. Self excited machines: the field winding is excited from the machine itself.
The self excited machines are classified further depending on the method of connection to the armature winding

1. Shunt connected: field winding is connected across (shunt or parallel) the armature.
Shunt connected: field winding is connected across (shunt or parallel) the armature.

2. Series connected: field winding is connected in series with the armature.
Series connected: field winding is connected in series with the armature.

3. Compound connected: two field windings are used. One is connected in shunt across the armature while the second is in series with the armature.

Compound connected: two field windings are used. One is connected in shunt across the armature while the second is in series with the armature.

The compound machine is classified further into cumulative and differential machine depending on whether the fields are additive or subtractive respectively.
The compound machine is classified further into cumulative and differential machine depending on whether the fields are additive or subtractive respectively.

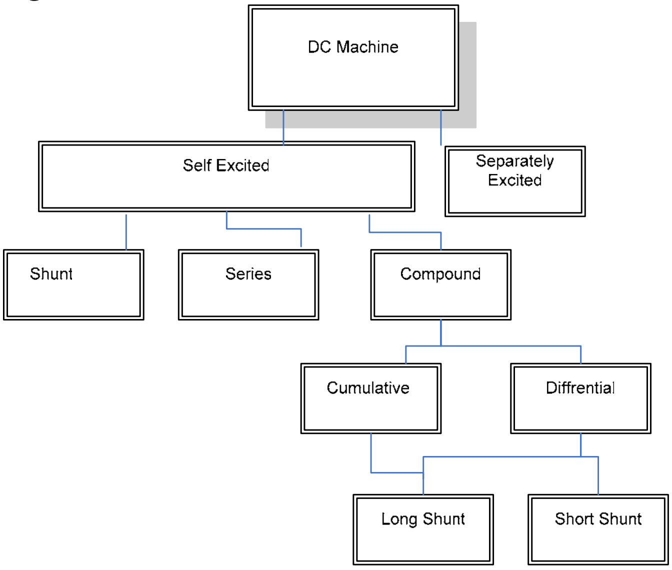
Further classifications of the compound machine are:

Further classifications of the compound machine are:

1. Long shunt: The shunt field is across both the armature and series field.
Long shunt: The shunt field is across both the armature and series field.

2. Short Shunt: The shunt field is across the armature only followed by the series field.
Short Shunt: The shunt field is across the armature only followed by the series field.

Figure 1 shows a Chart of the classification of the DC machines.



2. Equivalent Circuit of DC Machines

An equivalent circuit is the electrical representation of the DC machine.
An equivalent circuit is the electrical representation of the DC machine.

It is used to assess the machine performance.
It is used to assess the machine performance.

The equivalent circuit of the DC machine is made of an armature representation and representation together with the field winding.

The equivalent circuit of the DC machine is made of an armature representation and representation together with the field winding.

1. The DC machine can be represented by a voltage source and a resistance connected in series. The armature winding has a resistance, Ra.

   The DC machine can be represented by a voltage source and a resistance connected in series. The armature winding has a resistance, Ra.

2. The field circuit is represented by a winding that generates the magnetic field and a resistance connected in series. The field winding has resistance R_f.

   The field circuit is represented by a winding that generates the magnetic field and a resistance connected in series. The field winding has resistance R_f.

   You recall that in lecture 12 we developed two equations for voltage and torque.
   You recall that in lecture 12 we developed two equations for voltage and torque.

The generated voltage is give by

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

Equation 1 shows the voltage generated is function of the magnetic flux and the speed of rotation.
Equation 1 shows the voltage generated is function of the magnetic flux and the speed of rotation.

The torque is given by

$$T \Leftrightarrow k\,\phi I \quad (2)$$

Equation 2 shows that the machine torque is function of the magnetic flux and the current drawn by the machine.
Equation 2 shows that the machine torque is function of the magnetic flux and the current drawn by the machine.
In this lecture we shall concentrate on the DC generator and its steady state performance
In this lecture we shall concentrate on the DC generator and its steady state performance

- By referring to figure 2, we can see that the magnetic field is generated by the field current I_f.
- The flux ϕ is proportional to the field current.

$$\phi = k_f I_f \quad (3)$$

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 2 show the equivalent circuit of DC machines

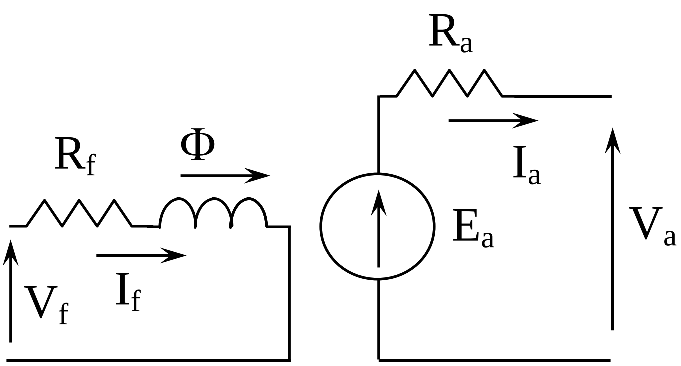


Figure 2 Equivalent Circuit of a DC Machine

- 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

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

Where E_a = armature generated voltage
K_a = machine constant
K' = modified machine constant
The question is "What is the machine constant and how to determine it
The question is "What is the machine constant and how to determine it

In order to define the machine constant, it is important to understand few points.
In order to define the machine constant, it is important to understand few points.

We will derive the generated voltage in slight different manner.
We will derive the generated voltage in slight different manner.

The armature winding is made of many conductors
The armature winding is made of many conductors

The conductors are arranged in coils. The coils are arranged in a number of parallel paths according to the method of winding.

The conductors are arranged in coils. The coils are arranged in a number of parallel paths according to the method of winding.

There are two types of windings: lap and wave windings
There are two types of windings: lap and wave windings

The lap winding is arranged such that the number of parallel paths is always equal to the number of poles.

The lap winding is arranged such that the number of parallel paths is always equal to the number of poles.

The wave winding is arranged such that the number of parallel paths is always equal to 2 irrespective of the number of poles.
The wave winding is arranged such that the number of parallel paths is always equal to 2 irrespective of the number of poles.

Let us define the following variables
Let us define the following variables

Z= no. of armature conductors
P= no. of poles
a= no. parallel paths
 = 2 for wave winding
 = P for lap winding.
$\phi =$ flux per pole
N = speed in rpm

The flux cut by one conductors in one rotation $= \phi P$

The flux cut by one conductors in N rotations $= \phi PN$

The flux cut per second by one conductors $= \dfrac{\phi PN}{60}$

Number of conductors in series $= \dfrac{Z}{a}$

The flux cut per second by $\dfrac{Z}{a}$ conductors $= \dfrac{\phi PN}{60}(\dfrac{Z}{a})$

This is the voltage generated in the armature E $= \dfrac{\phi PN}{60}(\dfrac{Z}{a})$

Let us express the speed in radian per second $\omega = \dfrac{2\pi N}{60}$

Thus the voltage generated in the armature E $= \dfrac{\phi P\omega}{2\pi}(\dfrac{Z}{a})$

The relations is re-arranged such that E $= (\frac{ZP}{2\pi a})\phi\omega$

Finally, the armature voltage E $= K_a \phi\omega$

Where K_a = machine constant $= \frac{ZP}{2\pi a}$

Example 1

Find the voltage induced in a DC machine that has flux per pole = 20 mWb. It has 4 poles and it is rotating at 1800 rpm. The machine winding is lap wound.

Solution

For lap winding the number of parallel paths a=4

$$\omega = \frac{2\pi N}{60} = \frac{2\pi x\, 1800}{60} = 188.48\ rad/\sec$$

Where $K_a = \frac{ZP}{2\pi a} = \frac{800x\ 4}{2\pi x\ 4} = 127.323$

The armature induced voltage E = $K_a \phi\omega = 127.323x\ 20x\, 10^{-3}x\, 188.48 = 479.96\ V$

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
In addition, the field voltage is related to the voltage by equation 5.

$$V_f = I_f R_f \qquad (5)$$

Where
V_f= field voltage
I_f = field current
R_f = field resistance

Example 2

Find the terminal voltage of a separately excited DC generator as illustrated in figure 8 with following data:

V_f= 240 volts
R_f = 120 Ohms
I_a = 80 A
R_a = 0.02 Ohms
N= 1800 rpm
K' = modified machine constant= 1.5 V-sec /A

Solution

The speed in radian per second

$$\omega = \frac{2\pi N}{60} = \frac{2\pi x\,1800}{60} = 188.48\ rad\ /\sec$$

$$I_f = \frac{V_f}{R_f} = \frac{240}{120} = 2A$$

$$E_a = KI_f\,\omega = 1.5x\ 2x\,188.49 = 565.48V$$

The terminal voltage is given by

$$V_a = E_a - I_aR_a = 565.48 - 80x\ 0.02 = 563.88V$$

3. Types of DC Machines

The connection of the armature circuit to the field winding is dictated by the type of DC Machine.

The connection of the armature circuit to the field winding is dictated by the type of DC Machine.

1. **Separately excited machine (Figure 3)**
   - The armature winding supplies the load.
   - The armature winding supplies the load.
   -
   - The field winding is supplied by a separate DC source whose voltage is variable.
   - The field winding is supplied by a separate DC source whose voltage is variable.

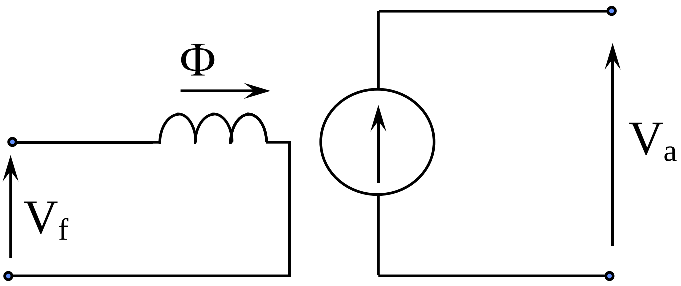


Figure 3 Separately Excited Machine

2. **Shunt DC Machine (Figure 4)**

The armature and field windings are connected in parallel.

The armature and field windings are connected in parallel.

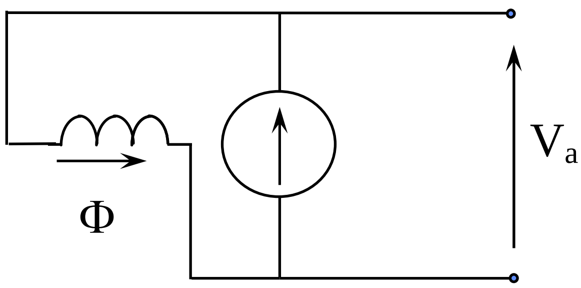


Figure 4 Shunt DC Machine

3. **Series DC Machine (Figure 5)**

   The armature and field winding are connected in series.

   The armature and field winding are connected in series.

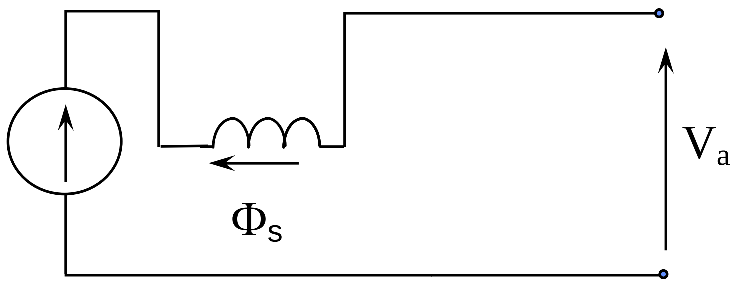


Figure 5 Series DC Machine

4. **Compound DC machine**.

The machine has two field windings: One connected in series; the other in parallel.

The machine has two field windings: One connected in series; the other in parallel

a. **Short Shunt :** The shunt field is across the armature only followed by the series field.

Short Shunt : The shunt field is across the armature only followed by the series field.

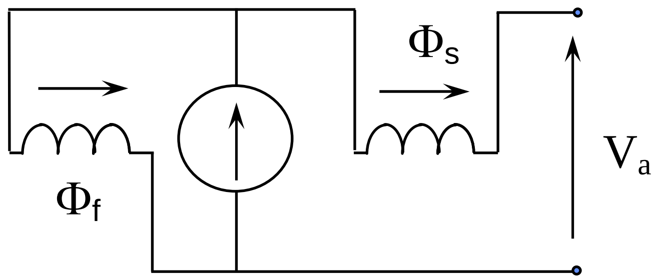


Figure 6 Short Shunt Compound s DC Machine

b. Long Shunt: The shunt field is across both the armature and series field.

Long Shunt: The shunt field is across both the armature and series field.

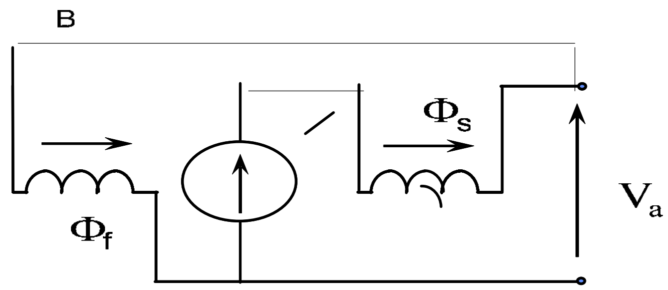


Figure 7 Long Shunt Compound DC Machine