EEE108 Electromagnetism and Electromechanics

Lecture 19

DC Generators
Tutorial: Lab 2 Single-phase Transformers

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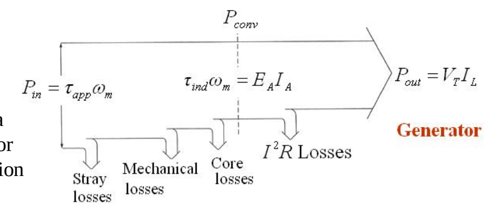
Today

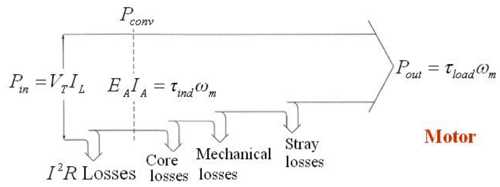
- DC Generators
- Tutorial: Lab 2

DC Generators

From power flow side:

There is no real difference between a generator and a motor except for the direction of power flow.





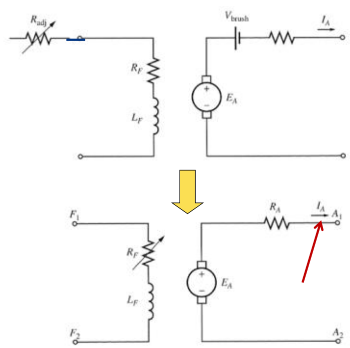
DC Generators

Equivalent Circuit

For any DC machines:

The armature circuit is represented by an ideal voltage source E_A and a resistor R_A. This representation is the Thevenin equivalent of the entire rotor structure, including rotor coils, …

The field coils, which produce the magnetic flux in the generator are represented by inductor L_F and resistor R_F. The resistor R_{adj} represents an external variable resistor used to control the amount of current in the field circuit.



Field Circuit

Armature Circuit

Major Types of DC Generators

The major types of DC generators in general use:

1. The separately excited DC generators
2. The shunt DC generators : the armature coils are connected in parallel with the field coils
3. The series DC generators : the armature coils are connected in series with the field coils
4. The compounded DC generators : the armature coils are connected in series/parallel with the field coils

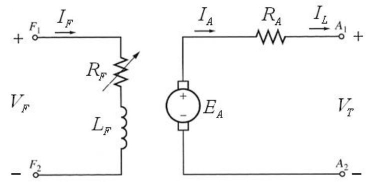
Self-excited DC generators

Separately Excited Generators

Equivalent Circuit

Separately excited DC generators:

The field current is supplied by a separate external DC voltage source



The equivalent circuit of a Separately excited DC generator

$$I_F = V_F/R_F$$

$$V_T = E_A - I_A R_A$$

$$I_L = I_A$$

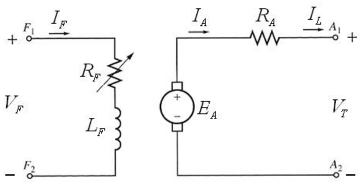
Separately Excited Generators

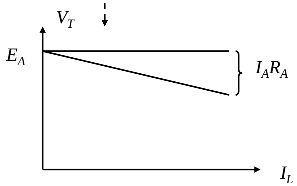
Terminal Characteristic

The terminal characteristic of a separately excited generator is a plot of V_T versus I_L for a constant speed ω.

When load ↑

$$V_T{\downarrow} = E_A - I_A{\uparrow} R_A$$





Separately Excited Generators

Terminal Characteristic

1. Change the speed of rotation: when $\omega\uparrow$

$$V_T{\uparrow} = E_A{\uparrow} - I_A R_A$$

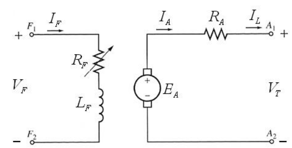
$$E_A{\uparrow} = K\Phi\omega{\uparrow}$$

In many applications, the speed range of the prime mover is quite limited, so the terminal voltage is most commonly controlled by changing the field current (by changing the resistance of the field windings).

2. Change the field current: when $R_F\downarrow$

$$I_F{\uparrow} = V_F/R_F{\downarrow}$$

$$\Phi\uparrow \dashrightarrow E_A\uparrow \dashrightarrow V_T\uparrow$$

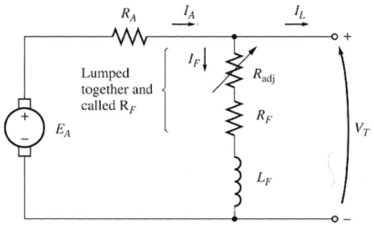


Shunt DC Generators

Equivalent Circuit

A **shunt DC generator**: the armature coils are connected in parallel with the field coils.

A shunt generator has a distinct advantage over the separately excited DC generator: no external power supply is required for the field circuit.



The equivalent circuit of a shunt DC generator

$$I_A = I_F + I_L$$
$$V_T = E_A - I_A R_A$$
$$I_F = V_T / R_F$$

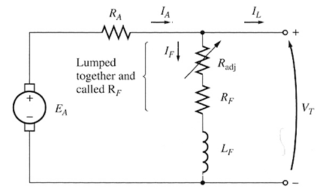
Shunt DC Generators

Terminal Characteristic

$$\boxed{\begin{aligned} I_A &= I_F + I_L \\ V_T &= E_A - I_A R_A \\ I_F &= V_T / R_F \end{aligned}}$$

When load $\uparrow$, then $I_L \uparrow \Rightarrow I_A \uparrow (= I_F + I_L)$

causing $V_T \downarrow (= E_A - I_A R_A)$

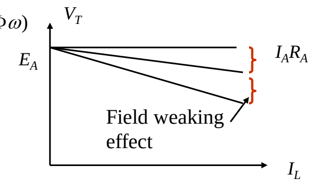


This is the same behaviour observed in a separately excited generator

$V_T \downarrow \Rightarrow I_F \downarrow (= V_T / R_F) \Rightarrow \Phi \downarrow \Rightarrow E_A \downarrow (= K\Phi\omega)$

$E_A \downarrow$ also $\Rightarrow V_T \downarrow (= E_A - I_A R_A)$

The voltage regulation of a shunt generator is worse than that of a separately excited generator.



Shunt DC Generators

Control of Terminal Voltage

1. Change the speed of rotation: when $\omega \uparrow$

$$V_T \uparrow = E_A \uparrow - I_A R_A$$

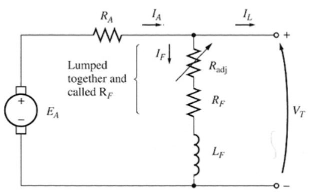
$$E_A \uparrow = K\Phi\omega \uparrow$$

In many applications, the speed range of the prime mover is quite limited, so the terminal voltage is most commonly controlled by changing the field current (by changing the resistance of the field windings).

2. Change the field current: when $R_F \downarrow$

$$I_F \uparrow = V_F / R_F \downarrow$$

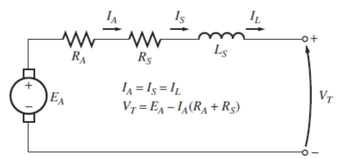
$$\Phi \uparrow \dashrightarrow E_A \uparrow \dashrightarrow V_T \uparrow$$



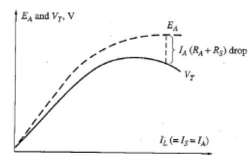
Series DC Generators

A series DC generator is a DC generator whose armature coils are connected in series with the field coils.

Equivalent Circuit



Terminal Characteristic



When load $\uparrow$, then $I_F \uparrow \Rightarrow E_A \uparrow$ and $I_A(R_A + R_S)\uparrow$

From no load, at first the $E_A \uparrow$ more rapidly than $I_A(R_A + R_S)\uparrow$,

so $V_T \uparrow$, after a while, the machine approaches saturation, and E_A

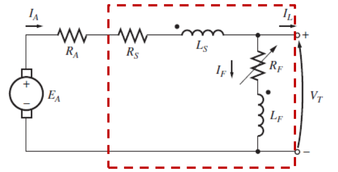
becomes almost constant, then $I_A(R_A + R_S)\uparrow$ is predomiant effect $\Rightarrow V_T \downarrow$.

A series generator would make a bad constant-voltage source.
Series generators are used only in a few specialized applications, such as arc welding.

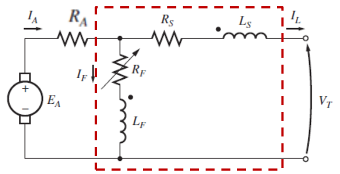
Compounded DC Generators

Equivalent Circuit

A compounded DC generator: the armature coils are connected in series/parallel with the field coils.



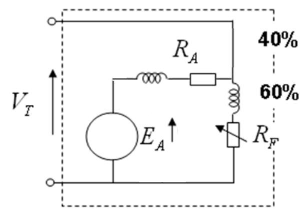
$$I_A = I_F + I_L$$
$$V_T = E_A - I_A(R_A + R_S)$$
$$I_F = V_T / R_F$$

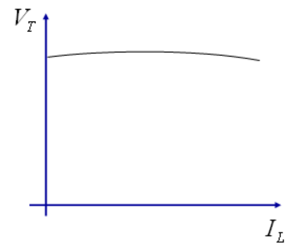


$$I_A = I_F + I_L$$
$$V_T = E_A - I_A R_A - (I_A - I_F) R_S$$
$$I_F = V_T / R_F$$

Compounded DC Generators

Terminal Characteristic





Appropriate choice of the connection point (typically approx. 40:60% of series : parallel) on the field coils creates a nearly constant output voltage vs load current characteristic

DC Generators

Voltage regulation

DC generators are often compared by their voltages regulation.

The voltage regulation is defined by:

$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

VR roughly reflects the shape of a generator's voltage-current characteristic.

DC Generators Summary

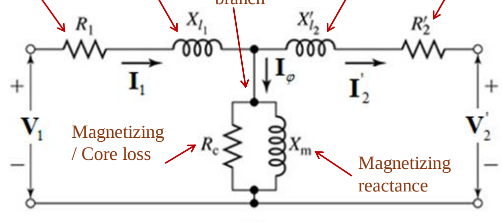
- The main types of DC generators: separately excited, shunt, series, and compounded.
- The output characteristics depend on the different types of generators.
- There are five(four) categories of losses occurring in DC machines.
- Voltage regulation roughly reflects the shape of a generator's voltage-current characteristic.
- Today DC generators have been replaced in many applications by AC power sources and solid-state electronic components.

Tutorial:

Lab 2 Single-phase Transformers

Equivalent Circuits

Equivalent-T Circuit



(d)

$$X_{l_2}^{'} = \left(\frac{N_1}{N_2}\right)^2 X_{l_2}$$

$$R_2^{'} = \left(\frac{N_1}{N_2}\right)^2 R_2$$

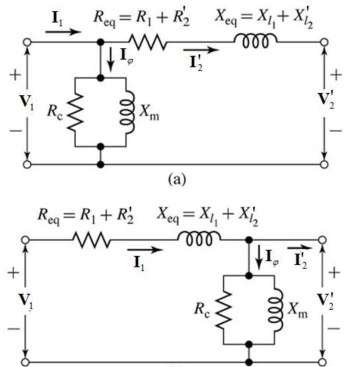
$$V_2^{'} = \frac{N_1}{N_2} V_2$$

secondary voltage (Referred to primary side)

Approximate Equivalent Circuits

In practical engineering applications, the full equivalent circuits are more complex than necessary.

The current in the excitation is much smaller compared to the load current. The excitation branch can be simply moved to either the primary or the secondary terminals, and the primary and secondary impedances are left in series with each other.



(a) (b)

$$X_{l_2}^{'} = \left(\frac{N_1}{N_2}\right)^2 X_{l_2}$$

$$R_2^{'} = \left(\frac{N_1}{N_2}\right)^2 R_2$$

$$V_2^{'} = \frac{N_1}{N_2} V_2 \qquad \mathbf{Z}_{eq} = R_{eq} + jX_{eq}$$

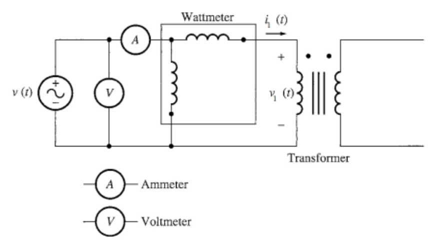
Open-Circuit Test

The values of the inductances and resistances in the transformer model can be determined experimentally. An adequate approximation of these values can be obtained with the ***open-circuit test***, and the ***short-circuit test***.

⇧

No load test

open-circuit test : The transformer's one winding is open-circuited, and its another winding is connected to a full-rated line voltage.



Input voltage, input current, input power are measured.

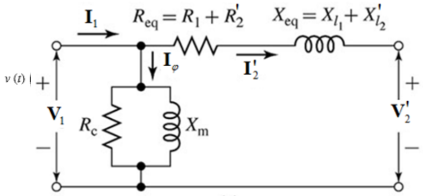
⇩

R_c and X_m

Open-Circuit Test

Input voltage, input current, input power are measured.

R_c and X_m



(a)

Known V_{oc}, I_{oc}, and power P_{oc}, then,

$$R_c = \frac{V_{oc}^2}{P_{oc}}$$

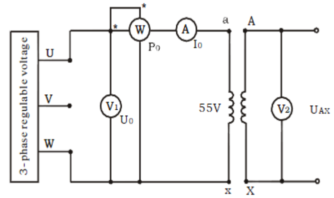
$$Z_{oc} = \frac{V_{oc}}{I_{oc}}, \quad Z_\varphi \approx Z_{oc}$$

$$X_m = \sqrt{Z_\varphi^2 - R_c^2}$$

All the input current will be flowing through the excitation branch of the transformer. The series element R_1 and X_1 are too small in comparison to R_c and X_m to cause a significant voltage drop. Essentially all input voltage is dropped across the excitation branch.

Open-Circuit Test

Autotransformer: the voltage source



Low voltage side High voltage side

1. Switch on the Main power and press “Start” button
2. Turn the autotransformer for $U_0 = 1.2U_N$.
3. Measure several groups of U_0, I_0, P_0 during decreasing the regulable voltage from $1.2U_N$ to $0.3U_N$, record in Table (the test point at $U = U_N$ should be taken). For calculating the transformation ratio, secondary voltage should be measured when U_0 is less than U_N.

No.	Measured data				Calculated data
	U_0(V)	I_0(A)	P_0(W)	U_{AX}(V)	$\cos\varphi_0$

Open-Circuit Test

(1) Transformation ratio calculation

Calculate the ratios according to the experiment data and take the average value as the ratio:

$K = U_{AX}/U_{ax}$

(2) Plotting no load characteristics and calculating excitation parameters

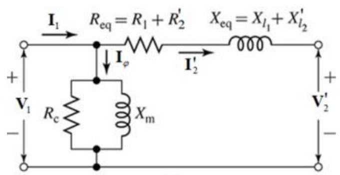
1) Plot no-load characteristics: $U_0 = f(I_0)$, $P_0 = f(U_0)$, $\cos\varphi_0 = f(U_0)$, where $\cos\varphi_0 = \frac{P_0}{U_0 I_0}$.

2) Excitation parameters

Look up values of I_0 and P_0 at $U_0 = U_N$ in the no load characteristic curve, then calculate the excitation parameters according to:

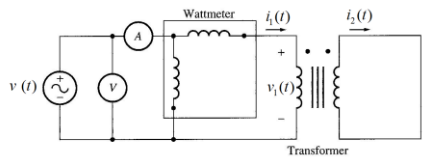
$$r_m = \frac{P_0}{I_0^2}, \quad Z_m = \frac{U_0}{I_0}, \text{ and } X_m = \sqrt{Z_m^2 - r_m^2}$$

$$r_m \rightarrow R_c$$

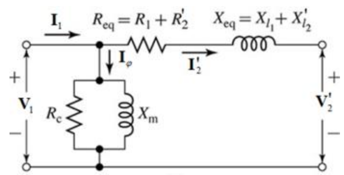


Short-Circuit Test

- One terminals are short circuited, and the another terminals are connected to a fairly low-voltage source.
- The input voltage is adjusted until the current in the short circuited windings is equal to its rated value.



The excitation branch is ignored, because negligible current flows through it due to low input voltage during this test.



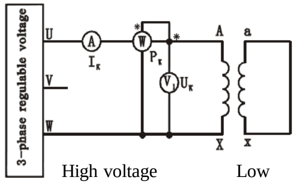
Input voltage, current and power are measured.

R_{eq} and X_{eq}

Lab 2 Single-phase Transformers

Short-Circuit Test

Autotransformer:
the voltage source



High voltage side

Low voltage side

1. Apply an AC power to the circuit;
2. Measure several groups of U_K, I_K, P_K while adjusting the input voltage for a short-circuit current ranging from $0.2I_N$ to $1.1I_N$, then record in Table (the test point at $I_K = I_N$ should be taken).

Room temperature ____ ℃

No.	Measured data				Calculated data
	U_K (V)	I_K (A)	P_K (W)	I_{short} (A)	$\cos\phi_K$

Lab 2 Single-phase Transformers

Short-Circuit Test

Plotting short-circuit characteristics and calculating short-circuit parameters

1) Plot short-circuit characteristics: $U_K = f(I_K)$, $P_K = f(I_K)$ and $\cos\varphi_K = f(I_K)$.

2) Parameters calculation

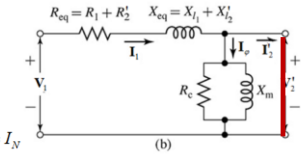
Look up values of U_K and P_K at $I_K = I_N$ in the short circuit characteristics curve, and then calculate the short-circuit parameters at θ (℃):

$$X_K \rightarrow X_{eq}$$
$$r_K \rightarrow R_{eq}$$

$$r_K' = \frac{P_K}{I_K^2}, \quad Z_K' = \frac{U_K}{I_K}, \quad \text{and} \quad X_K' = \sqrt{(Z_K')^2 - (r_K')^2}$$

Equivalent parameters at LV side:

$$r_K = \frac{r_K'}{K^2}, \quad Z_K = \frac{Z_K'}{K^2}, \quad \text{and} \quad X_K = \frac{X_K'}{K^2}$$



Short-circuit loss P_{KN} equals to $I_N^2 r_{K,75°C}$ when $I_K = I_N$

where $r_{K,75°C} = r_{K,\theta}\dfrac{234.5+75}{234.5+\theta}$, 234.5 is the coefficient of copper conductor.

Lab 2 Single-phase Transformers

Lab System

Lab 2 Single-phase Transformers

Lab System

No.	Model	Name	Qty.
1	D33	AC digital/analog V meter	1
2	D32	AC digital/analog A meter	1
3	D34-3	Intelligent P/COSφ meter	1
4	DJ11	Shell-type transformer	1
5	D42	Adjustable resistor	1
6	D51	Waves test & switch	1

The lab-exercise units should be placed in the order of D33, DJ11, D32, D34-3, D51, and D42 from **left** to **right**.

General Information

Operating instructions

(1) Be familiar with relative devices, and master the functions and usage;

(2) Operate in groups of 3 or 4 people for coordinated operation;

(3) Make wiring according to the connection diagram in the wiring rules;

(4) Observe the instruments after starting the machine, once an abnormal phenomenon occurs, cut off the power supply immediately and then try to clear the fault;

(5) Measure parameters according to the operating instructions;

(6) Turn on the power supply system with the instructor's permission, and then renew the experiment field.

General Information

Safety Operation

(1) Never touch a live circuit.

(2) The operation of connecting or disconnecting wires should be performed after power being cut off.

(3) Turn on the power supply with instructor's permission, and cut off the power immediately once a fault occurs.

(4) Check the power meter and ammeter before starting a machine, a short-circuit fault is not allowed.

(5) The main power for control panel should be operated with instructor's permission.

Lab Notes

Lab notes has been uploaded to ICE.

Please print the notes out and read the notes carefully before you enter the Lab room.

Schedule and Groups

Week 11	**May 8, 11:00-15:00 Room 313/315 B4+ (EE) Group A**	**May 8, 15:00-18:00 Room 313/315 B4+ (EE) Group B**
Week 12	**May 15, 11:00-15:00 Room 313/315 B4+ (EE) Group C**	**May 15, 15:00-18:00 Room 313/315 B4+ (EE) Group D**

- Three students are in a group.
- Please check your time and group on ICE.
- Sign your name before the experiment!
- **No signature, no mark!**

Report Submission

The individual report should be submitted by a softcopy (to ICE) before:

- ❖ 5:00pm on May 22, 2018, for students who have the experiment on May 8, 2018 (Groups **A** and **B**)
- ❖ 5:00pm on May 29, 2018, for students who have the experiment on May 15, 2018 (Groups **C** and **D**)

In Lab:

NO FOOD! NO DRINK!

Next

AC Machinery Fundamentals

Thanks for your attendance