24-DC Generators Part 2

Text: 5.9 – 5.16

ECEGR 450
Electromechanical Energy Conversion

Overview

- DC Generator Types
- Separately Excited Generator Model
- Shunt Generator Model
- Series Generator Model
- Compound Generator Model
- Voltage Regulation

DC Generator Types

DC generators can be classified by excitation method

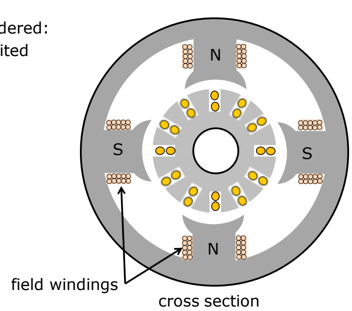
- Separately-Excited
  - Excitation current supplied by external source
  - Field winding or PM
- Self-Excited
  - Excitation current self supplied

DC Generator Types

- Self-excited generators can also be classified based upon how the excitation winding is connected:
  - Series
  - Shunt (parallel)
  - Compound (combination of series and shunt)

Generator Types

- Three types considered:
  - Separately excited
  - Shunt
  - Series
  - Compound

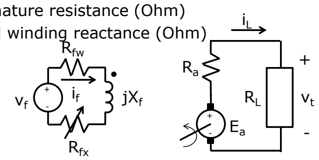


Separately Excited Generator

- DC generator in which a external dc source is used to generate the field current
- External source can be
  - Battery
  - Another DC generator
  - Rectified AC

Separately Excited Generator Model

- Equivalent circuit shown
  - v_t: generator terminal voltage (V)
  - v_f: applied field winding voltage (V)
  - R_{fw}: field winding resistance (Ohm)
  - R_{fx}: adjustable field winding resistance (Ohm)
  - R_a: armature resistance (Ohm)
  - X_f: field winding reactance (Ohm)



field circuit   generator circuit

Separately Excited Generator

- Assume generator is operating in steady state
  - mechanical energy does not change
  - inductance (X_f) behaves a short circuit
- R_{fx} is used to control the field current, and hence the flux

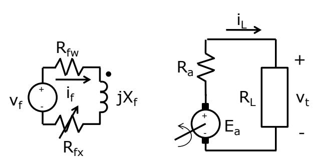
Separately Excited Generator Model

Circuit equations:

$v_f = i_f(R_{fw} + R_{fx}) = i_f R_f$

$E_a = v_t + i_a R_a$

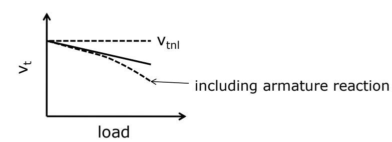
$i_L = i_a$



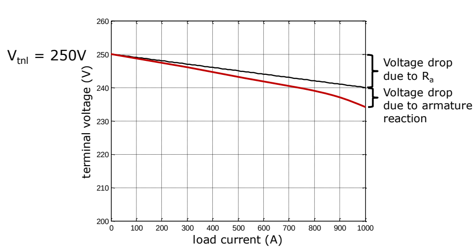
field circuit   generator circuit

Separately Excited Generator

- If i_f and ω_m are constant, then E_a is independent of the armature current
- As load increases (i_L increases), the terminal voltage drops due to R_a
- $V_{tnl} = E_a$ (no load terminal voltage = induced emf)



Separately Excited Generator



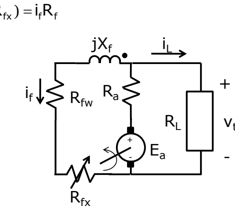
Shunt Generator

- Terminals of the generator are connected to the field winding
- Defining equations:

$v_t = i_f(R_{fw} + R_{fx}) = i_f R_f$

$v_t = E_a - i_a R_a$

$i_a = i_L + i_f$



Shunt Generator

- Under no load $i_a = i_f$
- R_f is usually large since v_t can be large
  - Large number of turns of small gauge
- E_a will be 0 since there is no flux created by field winding ($i_a = 0$)

Dr. Louie 13

Shunt Generator

- However, generally there is residual magnetism in the stator and a small amount of voltage will be induced
  - i_a increases, which increases E_a, which increases i_a, and so on
  - process does not continue forever
  - saturation of the stator limits the process

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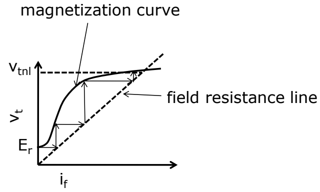
Shunt Generator

Voltage build-up process



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Shunt Generator

- The no-load voltage depends upon the field-circuit resistance
- Smaller resistances increase the rate of build-up
- If the resistance is too large (greater than the "critical resistance") then voltage build-up does not occur
- See Figure 5.24 for an example

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Shunt Generator

- Under no load: $i_a = i_f$
  - V_t is nearly equal to E_a since i_aR_a is small
- As i_l increases
  - i_aR_a increases
  - Armature reaction demagnetization effect increases
- Hence, E_a decreases
  - This further lowers i_f and E_a

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Shunt Generator

- If the load resistance continues to decrease, the load current will also start to decrease
  - due to the decrease in terminal voltage
- If the terminals are shorted, the field current becomes zero, but current still flows due to the residual magnetism E_r

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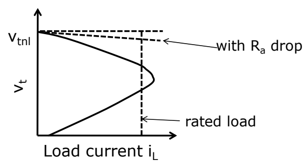
Shunt Generator



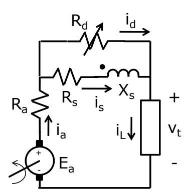
Shunt Generators

- Shunt generators must operate in the saturated region
- Otherwise, an increase in load would appreciably decrease the field current, which would have a large effect on E_a
  - i_f would further drop and so on
- Operation in the saturated region <u>desensitizes</u> the change in flux due to the change in field current

Series Generator

- Field winding is placed in series with armature and external circuit
- A series field diverter resistance (R_d) is used to control the flux
- Defining equations:

$$v_t = E_a - i_a R_a - i_s R_s$$
$$i_a = i_L = i_s + i_d$$
$$i_s R_s = i_d R_d$$

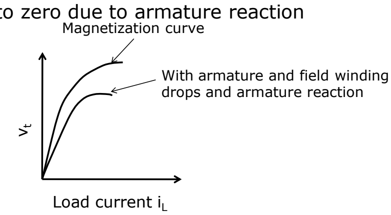


Series Generator

- When under no load, the produced flux in the field is zero
  - E_a is equal to E_r
- As load increases, flux increases
  - E_a increases
- Terminal voltage drops due to series resistance and armature reaction
- <u>E_a and v_t are functions of the load current</u>

Series Generator

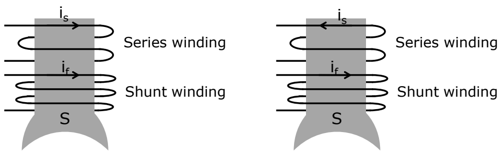
- Note: $i_L = i_a$
- Terminal voltage increases with load current
- As i_L increases, it is possible to drive the terminal voltage to zero due to armature reaction



Compound Generator

- Terminal voltage:
  - Decreases with load in a shunt generator
  - Rises with load in a series generator
- Combine them into a single generator
- Known as a "Compound Generator"
- Several types, depending on how they are wound

Compound Generator



Cumulative (mmfs add)

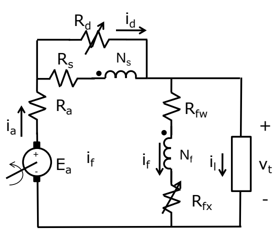
Differential (mmfs subtract)

Compound Generator

- Short-shunt compound:
  - series winding is in between the shunt and load
- Long-shunt compound:
  - Shunt winding connected directly across the load

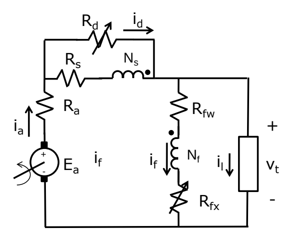
Compound Generator

- A long-shunt cumulative generator



Compound Generator

- A long-shunt differential generator



Compound Generator

- In any configuration:
  - Shunt winding provides the majority of the flux
  - Series winding controls the total flux
- Adjusting the current through the series winding allows for three different degrees of compounding
  - Under-compound
  - Normal compound
  - Over-compound

Compound Generator

- Under-compound generator
  - Full-load voltage is slightly higher than in a shunt generator, but still lower than no-load voltage
  - Voltage regulation is better than in a shunt generator
- Flat-compound generator
  - Full-load voltage is equal to the no-load voltage
  - Voltage regulation is better than in a shunt generator

Compound Generator

- Over-compound generator
  - Full-load voltage is higher than no-load voltage
  - Useful when connected to a long transmission line (to compensate for the voltage drop)
  - Compound generators are usually over-compound
  - See text for more details and comparison of generator types (Figure 5.32)

Voltage Regulation

- In all dc generators, as current (load) increases, the terminal voltage drops
  - Ohmic losses in the armature
  - Armature reaction
- The voltage drop is desired to be minimal
- Voltage Regulation is a metric for quantifying the voltage drop with respect to load

Voltage Regulation

$$VR = \frac{V_{nL} - V_{fL}}{V_{fL}} \times 100$$

- VR: percent voltage regulation (%)
- V_{nL}: terminal voltage under no load (V)
- V_{fL}: terminal voltage under full load (V)

- Ideal voltage regulation is 0%

Summary

- DC generators are less commonly used machines
- DC generators come in several varieties:
  - External (separately excited)
  - Series
  - Shunt
  - Compound
- Residual magnetism is used to "build up" voltage in self-excited generators