ET 332a
Dc Motors, Generators and Energy Conversion Devices

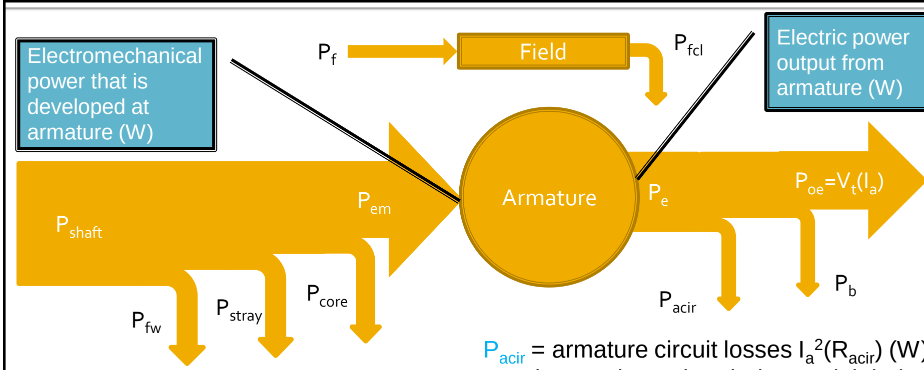
Lesson 9: Power Balance and Efficiency in Dc Generators

Learning Objectives

After this presentation you will be able to:

- Identify the sources of power loss in separately excited dc generators and compute their values
- Balance the input and output power of a separately excited dc generator.
- Compute generator efficiency
- Explain how changing generator load affects efficiency
- Explain how the generator/motor and motor generator transition takes place in dc machines

Power Balance for Dc Generators



P_{shaft} = total mechanical power developed at shaft (W)
P_{fw} = friction and windage losses (W) (from test)
P_{stray} = stray load losses (W) (from test)
P_{core} = core losses (W) (from test)

P_{acir} = armature circuit losses $I_a^2(R_{acir})$ (W)
P_b = losses due to brush drop $V_b(I_a)$ (W)
P_{oe} = electric power output at terminals (W)
P_f = power delivered to the field circuit
P_{fcl} = field-circuit losses, $I_f^2(R_c)$ (W)

3

Power Balance in Armature

Electric power developed at the armature is equal to the electromechancial power delivered from the shaft.

$$P_{em} = P_e$$
$$T \cdot \omega = E_a \cdot I_a$$

To find P_e, add electrical losses to output electric power, P_{oe}

$$P_e = P_{oe} + P_{acir} + P_b$$

In terms of armature circuit variables the above is:

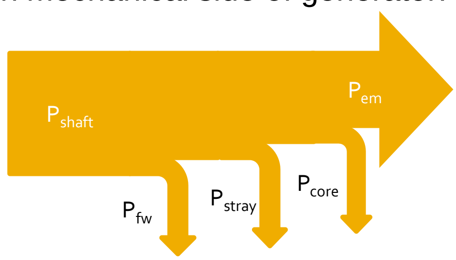
$$P_e = V_t \cdot I_a + I_a^2 \cdot R_{acir} + V_b \cdot I_a$$

Where V_b = 0.5 for metal-graphite brushes
= 2.0 for electrographitic and graphite brushes

4

Power Balance in Armature

On mechanical side of generator:



Find shaft power input by equating P_e and P_{em} and then adding mechanical losses

$$P_{shaft} = P_{em} + P_{fw} + P_{stray} + P_{core}$$

Find electromechanical power in armature by subtracting mechanical losses from shaft power

$$P_{em} = P_{shaft} - P_{fw} - P_{stray} - P_{core}$$

5

Machine Efficiency

Ratio of output power to input power determines efficiency of dc generator

Mathematically $\eta = \frac{P_{out}}{P_{in}} \cdot 100\,\%$ or $\eta = \frac{P_{out}}{P_{out} + P_{losses}} \cdot 100\,\%$

Where: η = machine efficiency
P_{out} = machine output power
P_{in} = machine input power
P_{losses} = total mechanical and electrical losses

For generator operation :

$$P_{out} = P_{oe} = V_t \cdot I_a$$
$$P_{in} = P_{shaft}$$

Units must be the same (Watts or HP)

6

Efficiency Example

Example: A 25 kW, 120 V, 1800 rpm separately excited generator is delivering rated current. The stray losses of the generator are found from test to be 1.5% of the rated output. The total core, friction, and windage losses are 2.0% of rated output. R_{acir} =0.0280 Ω Neglect the losses of the field circuit. Assume graphite brushes.

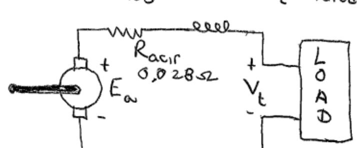
a.) Find the power in HP that the prime mover must develop at rated speed to drive the generator
b.) Find the efficiency of the machine operating at rated load.
c.) Find the efficiency of the machine when operating at 0% 25%, 50% and 75% of rated output. Assume that rated terminal voltage is maintained at the generator output as the load varies.
d.) Plot the % efficiency vs the % load and comment on the result

7

Efficiency Example Solution

$P_{rated} = 25\ kW$ $V_{rated} = 120V$ $V_t = V_{rated} = 120$

$P_{rated} = P_{oe}$ $R_{acir} = 0.028\Omega$



At Rated Output $I_a = \dfrac{P_{rated}}{V_t}$ $I_a = \dfrac{25,000W}{120V} = 208.3A$

Find losses due to Brushes and armature R

$$P_{acir} = I_a^2 R_{acir} = (208.3)^2 (0.028\Omega) = 1214.9\ W$$

$$P_b = V_b I_a = 2(208.3) = 416.6\ W$$

$$P_e = P_{oe} + P_{acir} + P_b = 25,000\ W + 1214.9\ W + 416.6\ W = 26,631.5\ W$$

8

Example Solution Continued

Remember $P_e = P_{em}$ in armature

Add mechanical losses $P_{em} = P_e$

$$P_{mech} = P_{em} + P_{fw} + P_{stray} + P_{core}$$

$$P_{stray} = \frac{1.5\%}{100\%}(25{,}000) = 375\ \text{w} \qquad P_{core} + P_{fw} = \frac{2.0\%}{100\%}(25{,}000) = 500\ \text{W}$$

$$P_{mech} = 26{,}631.5 + 375 + 500\ \text{W} = 27506.3\ \text{Watt}$$

$$\text{a)} \quad P_{HP} = \frac{27{,}506.3\ \text{W}}{746\ \text{W/HP}} = \underline{36.87\ \text{HP}}\ \underline{\text{ANS}}$$

Now compute the efficiency at full load

$$\text{b.)} \quad \eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_{oe}}{P_{mech}} \times 100\% = \frac{25{,}000\ \text{W}}{27506.3\ \text{W}} \times 100\% = \underline{90.89\%}$$

9

Efficiency Example: 0 % Output

Compute the efficiency at 0% output power

at 0% Load $I_a = 0$ So $P_{acIR} = 0$ $R_{acIR} = 0$ ARMATURE LOSSES

$$P_b = 2I_a = 2(0) = 0 \text{ brush losses}$$

$$P_{oe} = 0 \qquad V_t I_a = 0$$

Mechanical Losses Still Present $P_{rated} = 25{,}000\ \text{W}$

2.0% Rated $\quad P_{fw} + P_{CORE} = 25{,}000\,(0.02) = \underline{500\ \text{W}}$

1.5% Rated $\quad P_{stray} = 25{,}000\,(0.015) = \underline{375\ \text{W}}$

Electrical Output of Armature $\qquad P_{em} = P_e = 0$

$$P_e = P_{oe} + P_b + P_{acIR} = \underline{0\ \text{watts}}$$

10

Efficiency Example: 0% Output

Total Mechanical Power Developed is power necessary to overcome mechanical losses.

$$P_{Mechloss} = P_{fw} + P_{stray} + P_{core}$$

$$P_{Mechloss} = 500 + 375\ W = \underline{875\ W}$$

Shaft power required of prime mover to overcome mechanical losses

$$P_{HP} = \frac{875\ W}{746\ W/HP} = \underline{1.173\ HP}$$

Now compute the efficiency with 0% output

$$\%\eta = \frac{P_{oe}}{P_{mech}} \times 100\% = \frac{0}{875\ W} \times 100\% = \underline{0\%}$$

11

Efficiency Example 25, 50, 75%

Now compute the efficiencies for the other load levels

At 25% Rated Load $\quad P_{oe} = \frac{25\%}{100\%}(25{,}000) = 6250\ W$

$$I_a = \frac{P_{oe}}{V_t} \quad V_t = 120\ V \quad I_a = \frac{6250\ W}{120\ V} = 52.08\ A$$

$$P_{acir} = I_a^2 R_{acir} = (52.08\ A)^2 (0.028\ \Omega) = 75.95\ W$$

$$P_b = 2(I_a) = 2(52.08\ A) = 104.16\ W$$

From previous calculations $\quad P_{fw} + P_{core} = \underline{500\ W} \quad P_{stray} = \underline{375\ W}$

12

Efficiency Example 25, 50, 75%

Electric power developed

$P_e = P_{oe} + P_{acIR} + P_b$

$P_e = 6250 + 75.95 + 104.16\ W$

$P_e = \underline{6430.11}\ \underline{watts}$

$P_{em} = P_e$

armature mechanical power = armature electric power.

$P_{mech} = P_{em} + P_{stray} + P_{fw} + P_{core}$

$P_{mech} = 6430.11 + 375 + 500\ W = \underline{7305.11}\ W$

Prime mover required horsepower

$P_{HP} = \frac{P_{mech}}{746\ W/HP} = \frac{7305.11\ W}{746\ W/HP} = \underline{9.79\ Hp}$

$\eta = \frac{P_{oe}}{P_{mech}} \times 100\% = \frac{6250\ W}{7305.11} \times 100\%$

$\eta = \underline{85.56\ \%}$

Efficiency Example 50, 75%

Now compute efficiencies for 50 and 75% loading

At 50% And 75% Rated load

$P_{oe_{50}} = \frac{50\%}{100\%} 25{,}000 = \underline{12{,}500}\ W.$ $\quad I_{a50} = \frac{P_{oe_{50}}}{V_t} = \frac{12{,}500}{120} = \underline{104.2\ A}$

$P_{oe_{75}} = \frac{75\%}{100\%} 25{,}000 = \underline{18{,}750}\ W$ $\quad I_{a75} = \frac{P_{oe75}}{V_t} = \frac{18750}{120} = \underline{156.25A}$

Power Loss at 50 and 75% Rated

$P_{b50} = 2(104.2\ A) = \underline{208.3W}$ $\quad P_{acIR50} = (104.2)^2(0.028) = \underline{304.01\ W}$

$P_{b75} = 2(156.25A) = \underline{312.5W}$ $\quad P_{acIR75} = (156.25)^2(0.028) = \underline{683.6\ W}$

Finally compute the total power losses for 50 and 75% load

Efficiency Example 50, 75%

Electric power values in armature

$P_{e50} = 12{,}500 + 208.3 + 304.1\ \text{W}$

$P_{e50} = \underline{13012.4}\ \text{W}$

$P_{e75} = 18{,}750 + 312.5 + 683.6\ \text{W}$

$P_{e75} = \underline{19{,}746.1}\ \text{W}$

Add fixed losses between armature and shaft to get the required shaft power

$P_{shaft50} = 13012.4 + 875\ \text{W}$

$P_{shaft50} = 13887.4\ \text{W}$

Prime mover Hp 50%

$P_{HP} = \dfrac{13887.4\ \text{W}}{746\ \text{W/HP}} = \underline{18.62\ \text{HP}}$

$P_{shaft75} = 19746.1 + 875\ \text{W}$

$P_{shaft75} = 20{,}621.1\ \text{W}$

Prime Mover Hp 75%

$P_{HP} = \dfrac{20{,}621.1\ \text{W}}{746\ \text{W/HP}} = \underline{27.64\ \text{HP}}$

15

Compute Efficiencies at 50 and 75%

$\eta_{50} = \dfrac{12500\ \text{W}}{13887.9\ \text{W}} \times 100\%$

$\eta_{50} = 90.00\ \%$

$\eta_{75} = \dfrac{18{,}750\ \text{W}}{20{,}621.1\ \text{W}} \times 100\%$

$\eta_{75} = 90.93\ \%$

Power losses related to I_a are called load losses since they relate to the generator loading

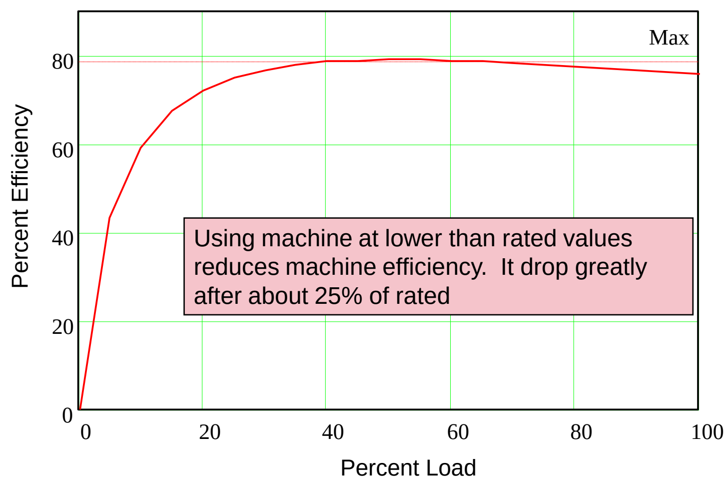
Maximum efficiency occurs when the fixed losses equal the load losses.

16

Plot of Efficiency vs Percent Rated Load

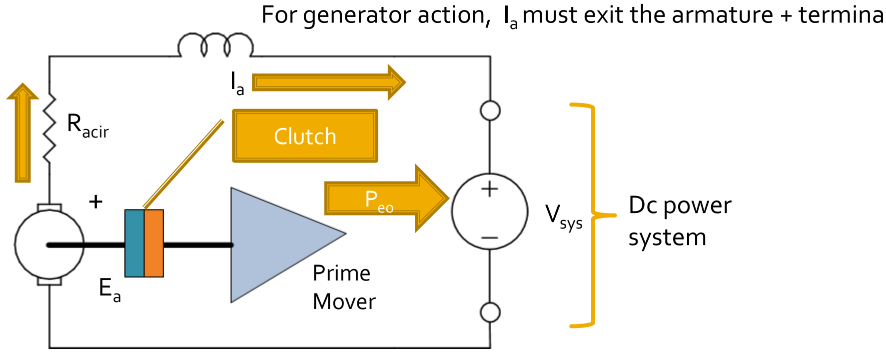
Typical Efficiency curve

Percentage of rating used is called the load factor of an electrical device.



Generator-to-Motor and Motor-to Generator Transitions

For generator action, I_a must exit the armature + terminal

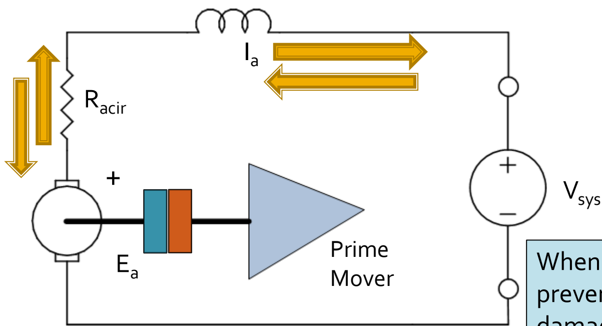


If $E_a > V_{sys}$, then I_a leaves the machine for generator action and power is delivered to system

If $E_a = V_{sys}$, then I_a =o a power is delivered to system but generator action

Generator-to-Motor and Motor-to Generator Transitions

For motor action, current must enter the positive terminal of the machine: $V_{sys} > E_a$



When current enters, clutch opens preventing opposing torque from damaging prime mover

Mechanical power delivered to load depends on the needs of the load. With no mechanical power load, the electric power drawn is only that necessary to overcome electrical and mechanical losses

19

End Lesson 9: Power Balance and Efficiency in Dc Generators

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20