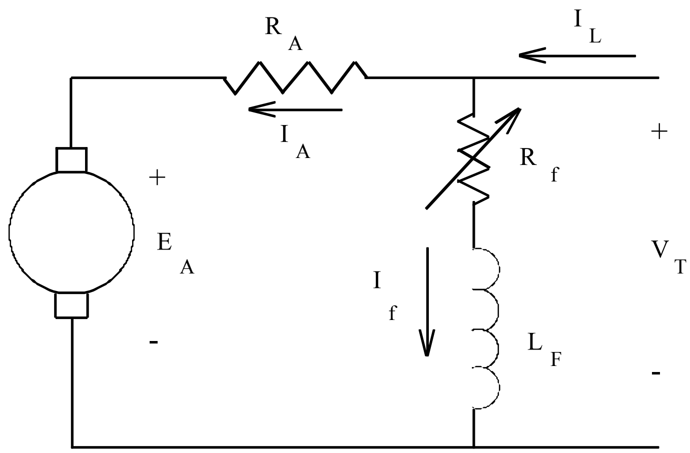
Sample Exam Solution

1. A 230V, shunt excited DC motor has R_A =0.05 Ω and R_f=75 Ω. The motor draws a line current, I_L, of 7 A when lightly loaded and turning at 1120 RPM. With the machine loaded such that the line current is 46 A, answer the following. Assume the iron is linear (i.e. no saturation in E_A vs. I_f curve).



$rev := 2\cdot\pi rad \qquad Ra := 0.05ohm \qquad Rf := 75ohm \qquad IL := 7A \qquad n1 := 1120\frac{rev}{min}$

$Vt := 230V \qquad Inew := 46A$

A. Find speed in RPM

$If := \frac{Vt}{Rf} \qquad If = 3.067\,A$

$Ia\_light := IL - If \qquad Ia\_light = 3.933\,A$

$Ealight := Vt - Ia\_light\cdot Ra \qquad Ealight = 229.803\,V$

$Ia\_2 := Inew - If \qquad Ia\_2 = 42.933\,A$

$Ea\_2 := Vt - Ia\_2\cdot Ra \qquad Ea\_2 = 227.853\,V$

Since constant field flux: $\frac{Ea1}{n1} = \frac{Ea2}{n2} \qquad n2 := \frac{Ea\_2\cdot n1}{Ealight} \qquad n2 = 1110\frac{rev}{min}$

B. Find induced torque

Use: $\tau = \frac{P}{\omega}$ $P2 := Ea\_2 \cdot Ia\_2$ $P2 = 9.783\,kW$

$\omega := 1110 \cdot \frac{(2 \cdot \pi)}{60sec}$ $\omega = 116.239\,\frac{rad}{sec}$

$\tau := \frac{P2}{\omega}$ $\tau = 84.159\,N \cdot m$

C Suppose the field current is increased to 100Ω, find the speed if the line current stays at 46 A.

$Ifnew := \frac{Vt}{100ohm}$ $Ifnew = 2.3\,A$

$Ia\_3 := Inew - Ifnew$ $Ia\_3 = 43.7\,A$

$Ea\_3 := Vt - Ia\_3 \cdot Ra$ $Ea\_3 = 227.815\,V$

Now we need a more complicated relation to find the new speed.

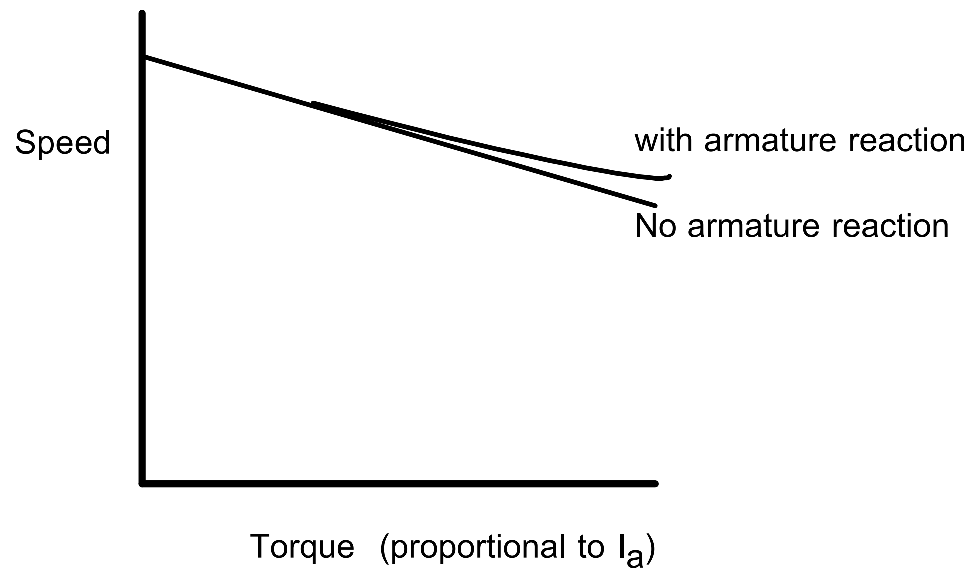
$Ea = K_a \cdot \phi \cdot \omega = K \cdot I_f \cdot n$ the new constant K includes the machine conditions to produce flu from I_f, and the conversion of speed to RPM from rad/sec

$Kp := \frac{Ealight}{If \cdot n1}$ $Kp = 0.639\,H$

$n3 := \frac{Ea\_3}{Kp \cdot Ifnew}$ $n3 = 1480\,\frac{rev}{min}$

D If the machine experiences armature reaction, how would this impact the torque speed characteristic? Explain and sketch an approximate characteristic.

Armature reaction results in a weakening of the field. If one looks at part (c), the field flux was decreased and the motor sped up. Armature reaction will do the same thing, but now the effect of the field weakening increases with armature current (or Torque). Recall that armature reaction is caused by flux induced around the armature windings due to the armature current. So as Ia increass, the motor won't slow down as much.



2. A cumulatively compounded generator with interpoles (to correct armature reaction) is to b used as a compounded motor. If no changes are made to the internal connections, will the motor be cumulatively compounded or differentially compounded? Explain.

- It will be differentially compounded. Reversing the direction of the current reverses the direction of the flux produced by the series winding, so now it opposes the flux from the shunt field.

Will the polarity on the interpoles be correct? Explain why or why not

- The polarity of the interpoles will be correct. The interpoles are also effectively a series winding. But they are used to counteract the armature reaction flux produced by the armature current. Since the armature current reversed direction, the armature reaction flux also reversed polarity, so the flux from the interpole will be correct.

Will the direction of rotation be the same as or opposite to the direction in which it was driven as a generator?

- The machine will probably rotate in the same direction. However, it does depend somewh on the relative strength of the series and shunt fields. If the series field is the dominant fiel could possibly reverse.

- ***A question like this will probably not be on the exam.***

3. Short Answer (5 points each). Write your answers on a separate sheet of paper.

A. How does a dc generator with a shunt field produce the induced voltage, E_a when it is first started up?

Are there any pitfalls with this technique? How are they resolved?

Solution: The residual flux in the magnetic material in the poles and rotor core will produce a l voltage on the armature windings when the machine is turning at rated speed ($E_a = K\phi\omega$). The small voltage will drive a small current through the field winding, which will increase E_a, whic turn increases the current in the field, and so on. This process of voltage buildup is sometimes referred to as "bootstrapping" the generator. This voltage build-up is most effective if the gener is started without an electrical load. The residual flux is from magnetic domains that are still al from the last time the field was energized.

Pitfalls could result from the following:

1. If the core is completely demagnetized, then there is no residual flux, and E_a starts out at 0 and stays at 0. No voltage buildup will occur.
2. If the field resistance is too large, insufficient field current will flow to build the voltage up can also be a problem if the trapped flux is too small.
3. If the residual flux has the opposite polarity what is desired (usually results if the generator run in the opposite direction.
4. If the application for the generator does not allow it to be started with no load, then the fielc current may be diverted to the load

Possible solutions:

- In the first 3 cases, the best solution would be to start the using an external field and use contacts or switches to transfer it to a shunt self excited connection after the flux had built u sufficiently. This could be accomplished with a relatively small dc supply.
- If the generator must supply a load all of the time, a series field or a compounded arrangem would be more effective. This set up still depends on residual flux, to produce the initial E_a

B. What is armature reaction? How does it impact the output of a dc generator?

Solution Armature reaction is caused by flux induced by flux flowing armature windings. Sinc this flux forms a loop around the winding, or a set of windings, the flux will add to the flux produced by the external field in part of the winding and oppose it at the other side of the wind (set of windings). The generator output will be impacted in the following ways:

1. Induced voltage will be higher under the parts of the pole face where the armature reaction flux adds and lower where it cancels the field flux.

2. In addition, the areas where the flux adds will will usually show some saturation effects, wl will lower the voltage produced.
3. As a result, the average DC voltage will tend to roll off faster as load increases than would normally be expected.

C. A diesel engine is used to turn the rotor on a dc generator. If the operator increases the rotor speed what happens to the output voltage? Explain.

Solution The output voltage will increase if the field flux stays constant, based on $E_a = K\phi\omega_m$ For a separately excited generator (or one with a linear field characteristic) we see:

$$\frac{Ea1}{n1} = \frac{Ea2}{n2}$$

In a self excited generator will see a non-linear variation, since flux will vary as a result of chai in E_a.

D. What are the mechanisms that cause no-load losses to occur in a separately excited dc motoı (with the field energized)? Are there additional losses under load? What causes these additiona losses?

Solution: The no load losses consist of rotational losses (friction and windage). When the fiel energized, there will be eddy current and hysteresis losses as well. When the machine is loaded there will be additional losses due to armature I^2R losses and brush losses. Stray load losses wi also increase.

E. What happens to a shunt field dc motor when the field current is interrupted? Why? Is this a problem with a series field motor, why or why not?

The rotor will overspeed. The rotor speed will increase until one of the following happens: (1) circuit protection trips the dc supply on overcurrent (or overspeed protection if any), (2) the rot reaches a max speed at the limit of the current, or (3) the rotor flies apart:

$$E_a = K\cdot\phi\cdot\omega_m \qquad I_a = \frac{\tau}{K\cdot\phi}$$

$$\omega_m = \frac{E_a}{K\cdot\phi} = \frac{V_t - R_a\cdot I_a}{K\cdot\phi} = \frac{V}{(K\cdot\phi)} - \frac{R_a\cdot\tau}{(K\cdot\phi)^2}$$

So if I_f goes to zero, we divide by zero.

The runaway rotor speed problem does not occur in a series field motor, since interrupting th current also interrupts the stator current (and therefore torque productions goes to zero).

F. Is torque induced on the rotor of a dc generator when it supplies an electrical load? Explain? there is torque induced, how does it relate to the mechanical torque applied by the prime mover

Solution: Yes, there is torque induced on the rotor. When the generator is loaded, there will current in the armature windings. Any conductor carrying current in the presence of a magnetic field will have torque induced on it. The induced torque will oppose the mechanical torque applied to turn the generator (slowing the generator down as load increases).

4. The open circuit characteristic for a 6 pole dc generator rated at 500 V and 500 kW is given below. The characteristic was measured at a speed of 1000 RPM. R_A=0.02Ω (counting brush drop).

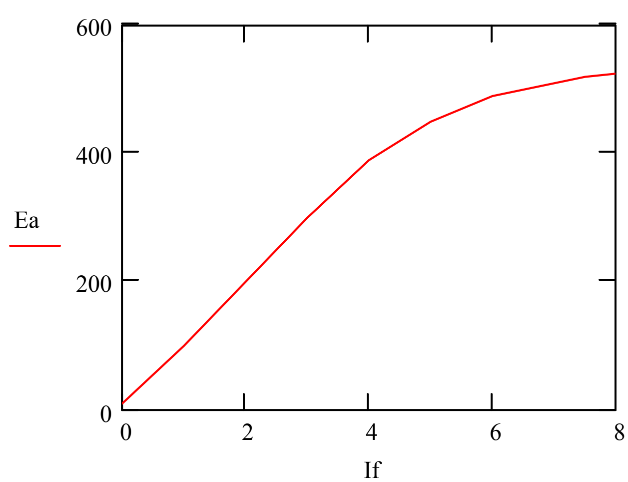
$Vrated := 500V$

$nrated := 1000 \frac{rev}{min}$

$Ra := 0.02ohm$

$$If := \begin{pmatrix} 0A \\ 1A \\ 2A \\ 3A \\ 4A \\ 5A \\ 6A \\ 6.5A \\ 7A \\ 7.5A \\ 8A \end{pmatrix} \qquad Ea := \begin{pmatrix} 10V \\ 100V \\ 200V \\ 300V \\ 390V \\ 450V \\ 490V \\ 500V \\ 510V \\ 520V \\ 525V \end{pmatrix}$$

No load, so this is equal to Vt



A Calculate the shunt resistance ($R_F + R_{adj}$) required to produce rated terminal voltage when the machine is unloaded.

When unloaded: $Vt = Ea$

$Vt := Vrated \qquad Vt = 500\,V$

On the curve above this corresponds to $Ifr := 6.5A$

$$Rtot := \frac{Vt}{Ifr} \qquad Rtot = 76.923\,\Omega$$

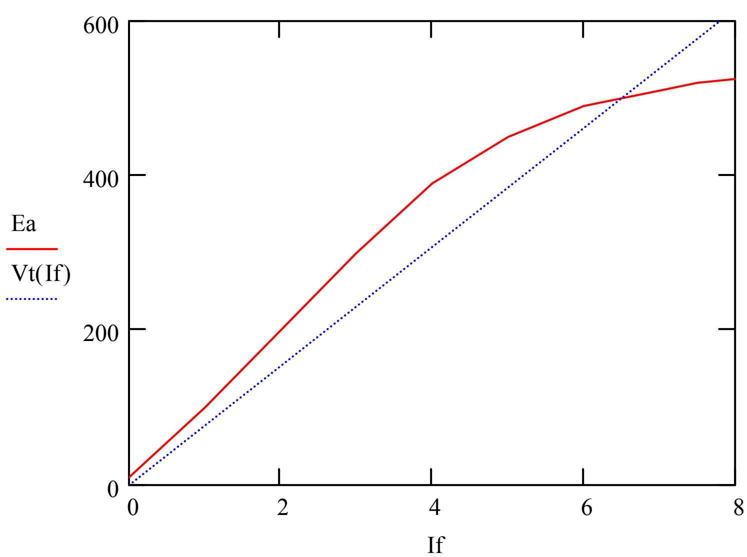
B Using the shunt resistance calculated in part **A**, calculate the terminal voltage when the armature current is 1000A and the speed is 1000 RPM (ignore armature reaction).

We have: $Vdrop := Rtot \cdot 1000A$

The speed stays the same, so the curve above applies.

Graphically plot: $V_t = I_f \cdot Rtot$ and Ea versus flux from above.

$Vt(If) := If \cdot Rtot$



Find the point where the curves are 20 V apart. This is at approximately:

$E_a = 490V$

$V_t = 470V$

C Why does the magnetization curve given with this problem flatten out as the field current is increased? How would the curve differ if calculated at a different rotor speed?

- The curve flattens out due to magnetic saturation or the magnetic material in the core of tl field poles (and so a smaller extent, saturation in the rotor too).
- Calculating the curve at a different speed scales it linearly. Recall: $V_t = E_a$ since no load curve.

$$\frac{Ea1}{n1} = \frac{Ea2}{n2}$$