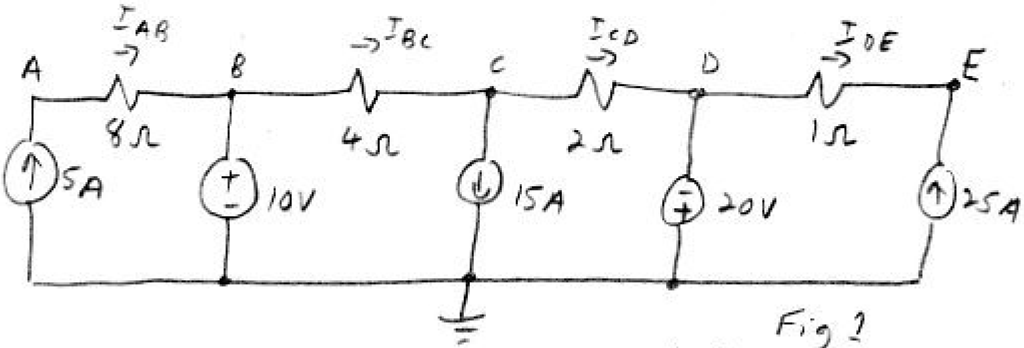
325 Final Exam Fall 2005 Solutions

#1



Note: problems may be slightly different from actual exam

Fig 1

(a) Use the node voltage method and Ohm's Law to find V_A, V_B, V_C, V_D, V_E.

(b) Use the mesh current method to find I_{AB}, I_{BC}, I_{CD}, I_{DE}.

(c) Find the power dissipated in each resistor.

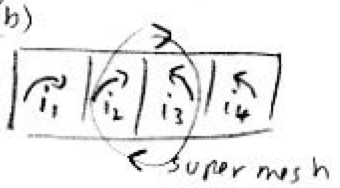
(d) From part (c) what can you conclude about the sources?

Soln (a) $V_A = V_B + IR = 10V + 5 \times 8 = \underline{\underline{50V}}$, $V_B = \underline{\underline{10V}}$ (given)

Node C: $\frac{V_c - 10}{4} + 15 + \frac{V_c - (-20)}{2} = 0 \Rightarrow V_c = \underline{\underline{-30V}}$

$V_D = \underline{\underline{-20V}}$ (given), $V_E = V_D + I_{ED} R = -20V + 25 \times 1 = \underline{\underline{5V}}$

(b)



$i_1 = \underline{5A}$ (given) (1)

super: $-10 + 4i_2 - 2i_3 - 20 = 0$

$4i_2 - 2i_3 = 30$ (2)

inside super constraint: $i_2 + i_3 = 15A \Rightarrow i_3 = 15 - i_2$ (3)

plug (3) → (2): $4i_2 - 30 + 2i_2 = 30 \Rightarrow i_2 = \frac{60}{6} = \underline{10A}$ (4)

plug (4) → (3): $i_3 = 15 - 10 = \underline{5A}$ (5), $i_4 = 25A$ (given) (6)

∴ From (1): $I_{AB} = \underline{\underline{5A}}$ (4): $I_{BC} = \underline{\underline{10A}}$ (5): $I_{CD} = \underline{\underline{-5A}}$ (6): $I_{DE} = \underline{\underline{-25A}}$

Check: $\frac{V_A - V_B}{8} = \frac{50-10}{8} = 5A$ ✓, $\frac{V_B - V_C}{4} = \frac{10+30}{4} = 10A$ ✓, $\frac{V_C - V_D}{2} = \frac{-30+20}{2} = -5A$ ✓, $\frac{V_D - V_E}{1} = -25A$ ✓

(c) $P_8 = I^2 R = 5^2 \times 8 = \underline{\underline{200W}}$ $P_4 = 10^2 \times 4 = \underline{\underline{400W}}$ $P_2 = 5^2 \times 2 = \underline{\underline{50W}}$, $P_1 = 25^2 \times 1 = \underline{\underline{625W}}$

(d) $\left| \Sigma P_{sources} \right| = \Sigma P_R = 1275W$ is the total or net power generated by the combined five sources.

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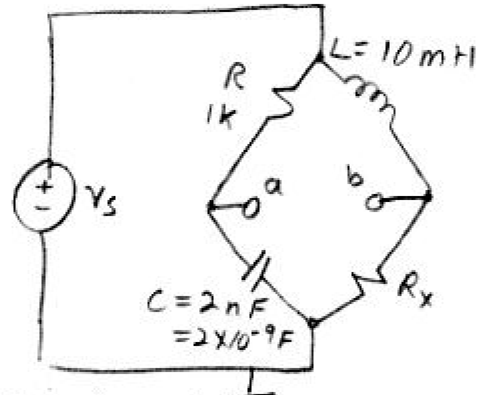
1 #2

(a) Find R_x in circuit of Fig 2 to balance the bridge (ie $\bar{V}_{ab} = 0$).

(b) For R_x found in part (a), find $v_b(t)$.

(c) For R_x found in part (a) find power loss in L, C, R_x.



$v_s = 10\cos(5\times10^5 t)$

Fig 2

Soln (a) volt div: $\bar{V}_a = \dfrac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R}\bar{V}_s = \dfrac{1}{1 + j\omega RC}\bar{V}_s$ (1)

volt div: $\bar{V}_b = \dfrac{R_x}{R_x + j\omega L}\bar{V}_s = \dfrac{1}{1 + \frac{j\omega L}{R_x}}\bar{V}_s$ (2)

$\bar{V}_a = \bar{V}_b \Rightarrow$ (1) = (2) $\Rightarrow \omega RC = \dfrac{\omega L}{R_x} \Rightarrow R_x = \dfrac{L}{RC} = \dfrac{10\times10^{-3}}{10^3\times2\times10^{-9}}$

$= \underline{\underline{5k\Omega}}$

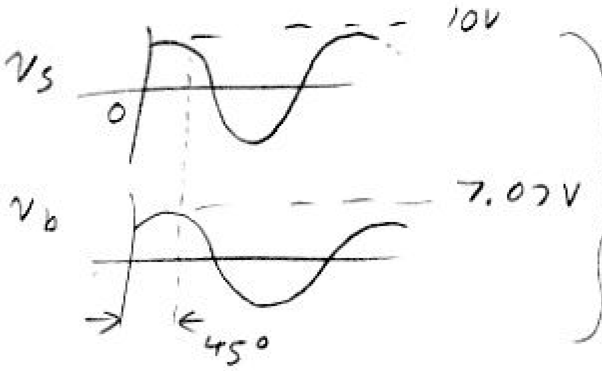
(b) From (2) $\bar{V}_b = \dfrac{1}{1 + j\frac{5\times10^5\times10\times10^{-3}}{5000}}\bar{V}_s = \dfrac{1}{1+j}\bar{V}_s$

$= 10\angle0^\circ / \sqrt{2}\angle45^\circ$

$= \frac{10}{\sqrt{2}}\angle{-45^\circ}$

$\therefore v_b(t) = \underline{\underline{7.07\cos(5\times10^5 t - 45^\circ)}}$

$\therefore$



not required

(c) L, C only store/release energy temporarily: $\underline{\underline{P_{avg} = 0}}$.

$P_x = I_{rms}^2 R_x = \left(\dfrac{7.07V}{\sqrt{2}\ 5K}\right)^2 \times 5k = (1mA\ rms)^2 \times 5k = \underline{\underline{5mW}}$

or $P_x = V_{x\,rms}^2 / R_x = (5V)^2/5k = \frac{25}{5k} = 5mW$ ✓

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#3 In Fig 3 switch open long time, prior to $t=0$.

(a) sketch $i_L(t)$ for all t.

(b) Find change in inductor energy between $t=0$ and $t\to\infty$. Does inductor energy increase or decrease?

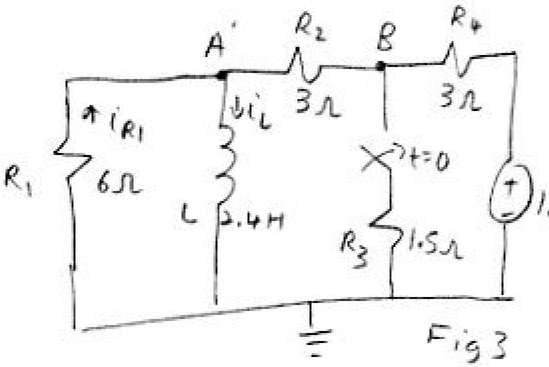


Fig 3

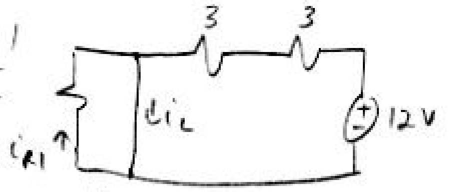
(c) Sketch $i_{R1}(t)$ for all t.

Hint: ans < 1J

(d) Find change in R1 energy between $t=0$ and $t\to\infty$, where does this energy go?

(a) Step 1

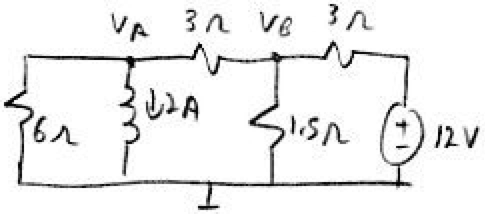
$t=0^-$



$i_L(0^-) = \frac{12}{6\Omega} = \underline{\underline{2A}}$ $\quad i_{R1}(0^-) = \underline{\underline{0}}$

Step 2

$t=0^+$



$i_L(0^+) = i_L(0^-) = \underline{\underline{2\,A}}$

Node A: $\frac{V_A}{6} + 2 + \frac{V_A - V_B}{3} = 0$

$6\times$: $\quad 3V_A - 2V_B = -12 \quad (1)$

Node B: $\frac{V_B - V_A}{3} + \frac{V_B}{1.5} + \frac{V_B - 12}{3} = 0$

$3\times$: $\quad -V_A + 4V_B = 12 \quad (2)$

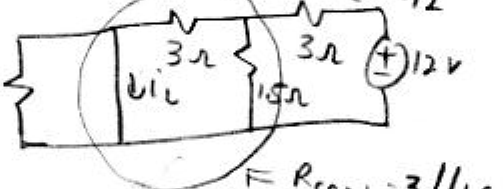
$(1)\times 2$: $\quad 6V_A - 4V_B = -24 \quad (3)$

$(2)+(3)$: $\quad 5V_A = -12 \Rightarrow V_A = -2.4V$

$\therefore i_{R1}(0^+) = \frac{-V_A}{R} = \frac{2.4}{6} = \underline{\underline{0.4\,A}}$

Step 3

$t\to\infty$



$R_{comb} = 3 // 1.5 = 1\Omega$

$i_{12} = \frac{12V}{(3+1)\Omega} = 3\,A$

Current Div: $i_L(\infty) = 3A \times \frac{1.5}{4.5} = \underline{\underline{1\,A}}$

$i_{R1}(\infty) = \underline{\underline{0}}$

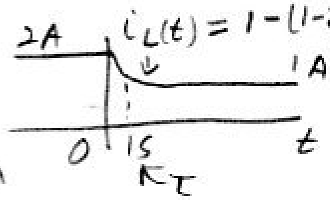
Step 4

Req

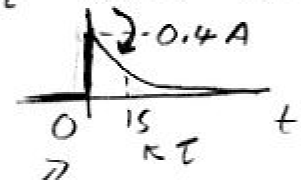
$R_{eq} = [(3//1.5)+3]//6 = 4//6 = \underline{\underline{2.4\Omega}}$

$\therefore \tau = L/R_{eq} = 1\,\text{sec.}$

$i_L(t) = 1-(1-2)e^{-\frac{t}{\tau}}$



$i_{R1}(t) = .4e^{-\frac{t}{1s}}$



$\Delta W = \Delta \frac{1}{2} L I^2$

$= \frac{1}{2} \times 2.4H (1^2 - 2^2)$

$= 1.2J - 4.8J$

$= -3.6\,J$

$\therefore$ inductor energy decreases by 3.6 Joules.

$\Delta W = \int p\,dt$

$= \int_0^\infty I_R^2 R\,dt$

$= \int_0^\infty (0.4e^{-t})^2 R\,dt$

$= 0.4^2 \times 6\Omega \left[-\frac{e^{-2t}}{2}\right]_0^\infty$

$= 0.4^2 \times 6 \times \frac{1}{2}$

$= 0.48\,J$

Heat in R1.

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#4

For circuit of Fig 4,

(a) find v_o if S1 and S2 are closed,

(b) find v_o if S1 and S2 are open,

(c) find v_o if S1 is open and S2 is closed,

(d) For part (a), roughly sketch $v_o(t)$ if $v_s(t) = 2\sin(\omega t)$ V.

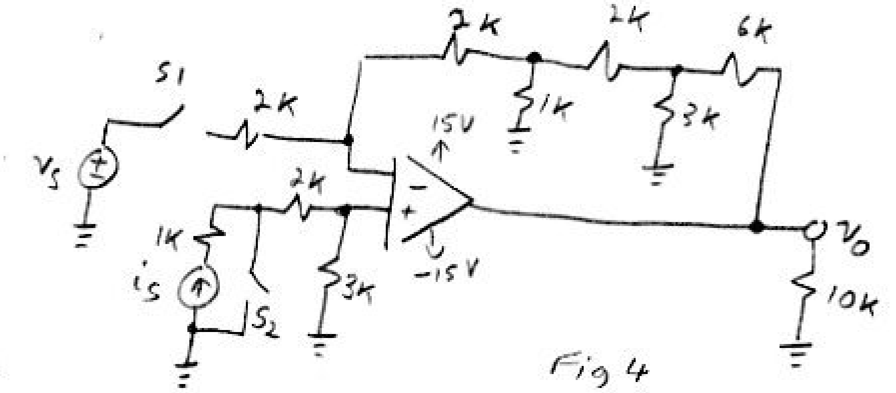
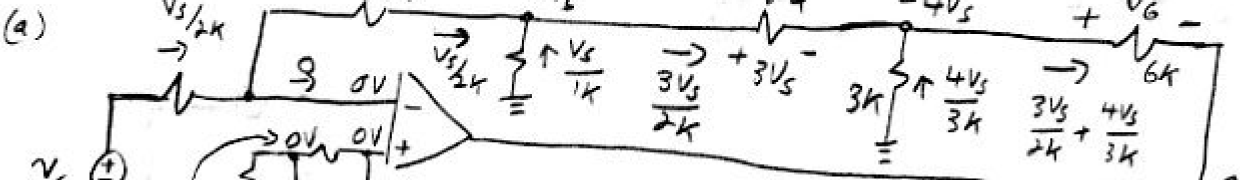


Fig 4

Soln (a)



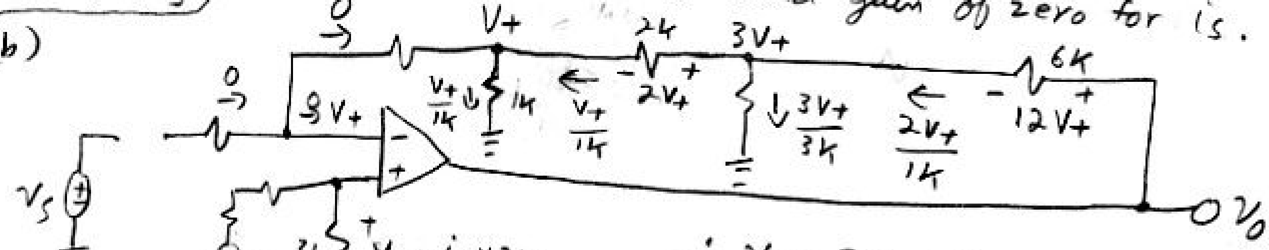
$$V_6 = \left(\frac{3V_s}{2k} + \frac{4V_s}{3k}\right) \times 6k = 9V_s + 8V_s = 17V_s$$

$$v_o = -4V_s - V_6 = -4V_s - 17V_s = \underline{\underline{-21V_s}}$$

ie this circuit has gain of -21 for v_s and gain of zero for i_s.

Note! For parts (a) an (b) Node Method also works

(b)



$V_+ = i_s \times 3k$

↖ start here

$$\therefore\ v_o = 3V_+ + 12V_+ = 15V_+$$

$$\Rightarrow v_o = 15(i_s \times 3k) = \underline{\underline{45k\ i_s}}$$

ie this circuit has gain = zero for v_s and gain $45K\ \frac{V}{A}$ for i_s.

(c) In this case all resistors have zero current $\therefore$ $\underline{v_o = 0V}$
Except for 1k in series with i_s,

(d) For gain $= -21 \Rightarrow v_o(t) = -41\sin(\omega t)$ V, but Op-Amp ±15V power supply will limit out voltage max ≃ 14V.

$\therefore$ v_s  $\Rightarrow$ v_o 

Aside: S1 closed, S2 open
Superposition does not work
since in (b) S1 can't zero Vs.

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#5 (a) For the diode characteristic shown in Fig 5, find the diode equivalent circuit corresponding to each line segment (lable i_D and v_D in each equivalent circuit).
Note $1\mu A = 10^{-6}$ A.

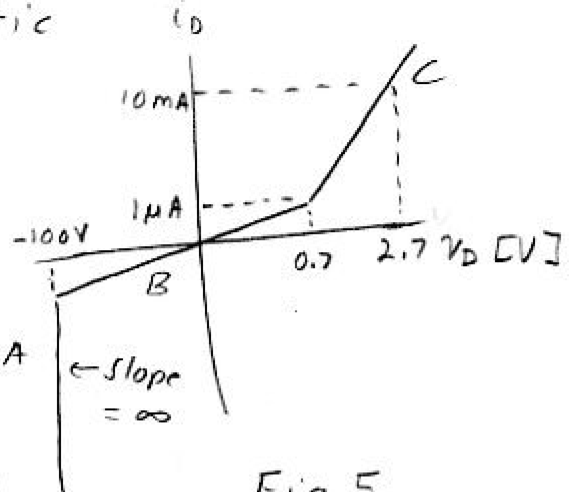


Fig 5

(b) i) Find I_1 and I_2 in Fig 5-1.
ii) " " " " " 5-2.
iii) " " " " " " 5-3.
} All diodes characterized as in part (a).

Hint in each case at least one current is order μA.

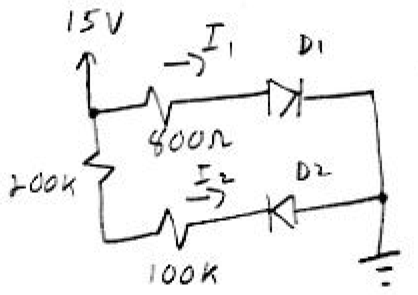


Fig 5-1

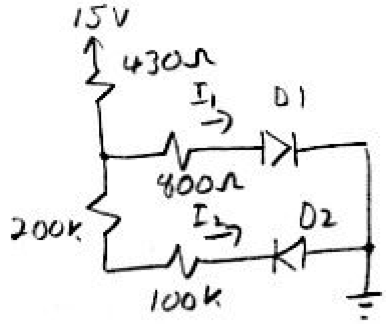


Fig 5-2

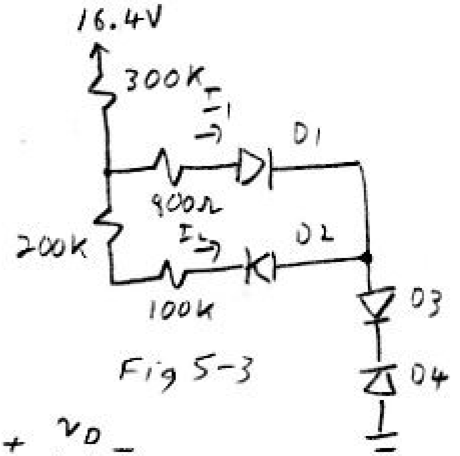
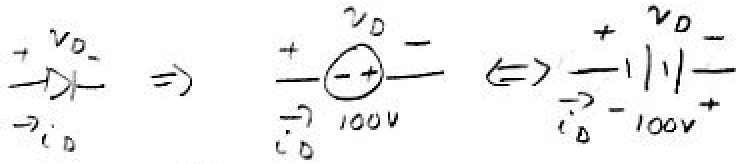


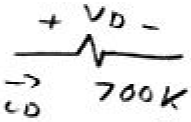
Fig 5-3

Soln (a) (A)

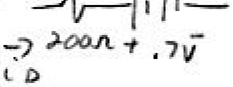


$Req_A = 0$

(B) $Req_B = \frac{\Delta V}{\Delta I} = \frac{.7V}{1\mu A} = 700k\,\Omega \Rightarrow$



(C) $Req_C = \frac{\Delta V}{\Delta I} = \frac{2V}{10mA - 1\mu A} = 200\Omega$ $\quad V_{on} \simeq 0.7V \Rightarrow$



(b) D1 on D2 off $I_1 = \frac{15V - .7V}{400 + 200} = \underline{14.3\text{ mA}}$ $\quad I_2 = \frac{15V}{(100+200+700)K} = \underline{15\mu A}$

ii D1 on D2 off $I_2 << I_1 \Rightarrow I_1 = \frac{15V - 0.7V}{400 + 200 + 430} = \underline{10\text{ mA}}$ $\quad I_2 = \frac{10.7V}{1000K} = \underline{10.7\mu A}$ ← $15V - 10mA \times 430$

iii D1, D3 on D2, D4 off $I_{300K} = \frac{16.4V - (0.7 + 0.7)V}{300k + 700k} = 15\mu A$ (D1+D3; top R → 300k; 700k ← D4)

$I_2 \simeq \frac{0.7V}{(200+100+700)K} = \underline{0.7\mu A}$ (0.7V ← D1) (more exact: 0.715μA) $\quad I_1 = 15\mu A - 0.7\mu A = \underline{14.3\mu A}$

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#6 (a) A shunt connected (ie field winding and armature are connected in parallel) DC machine is observed to have the following operating conditions.

Shaft Power: $P_{dev} = 30HP$ (recall $1HP = 746W$)

Friction Power: $P_{rot} = 0$

Terminal Voltage: $V_T = V_A = V_F = 230V$

Armature Current: $I_A = 100A$

Field Current: $I_F = 5A$

Shaft speed: $n = 4500 rpm$

Is the machine operating as a motor or generator? Explain. Hint: use power,

(b) Find i) Arm R, R_A ii) Arm EMF, E_A iii) Shaft torque, T_{dev} iv) Efficiency η.

(c) Same machine is now operated having $V_T = 230V$, $n = 4687rpm$. Is operation as a motor or generator? Explain. Hint: opposite of (a).

(d) Find i) E_A, ii) I_A, iii) T_{dev} iv) η and explain change in η compared to (b).

Soln (a) $V_T I_A = 230 \times 100 = 23000W > P_{dev} = 30 \times 746 = 22380W$ ∴ motor

(b) $I_A^2 R_A = 100^2 R_A = 23000 - 22380 = 620W \Rightarrow \underline{R_A = 0.062\Omega}$

$E_A = V_T - I_A R_A = 230 - 100 \times 0.062 = \underline{223.8V}$ ← or $E_A I_A = P_{dev}$

$P_{dev} = 22380 = T_{dev}\omega = T_{dev} \times \frac{2\pi}{60}(4500) = T_{dev}(471.24 \frac{rad}{s}) \Rightarrow \underline{T_{dev} = 47.5 Nm}$

$\eta = \frac{P_{out}}{P_{in} \text{ or } V_T I_L} = \frac{P_{dev} - P_{rot}}{P_{Arm} + P_{field}} = \frac{22380W}{23000 + 230 \times 5} = \frac{22380}{23000 + 1150} = \underline{92.67\%}$

(c) $E_A = K\phi\omega \Rightarrow E_{A new} = E_{A old} \times \frac{n_{new}}{n_{old}} = 223.8 \times \frac{4687}{4500} = \underline{233.1V}$ ← $> V_T$ ∴ gen or from power see generator

(d) $E_A = 233.1V$, $I_A = \frac{233.1 - 230}{R_A} = \frac{3.1V}{.062\Omega} = \underline{50A}$ ← -50A acceptable too.

$P_{dev} = E_A I_A = 233.1 \times 50 = 11655W = T_{dev}\omega = T_{dev} \times \frac{2\pi}{60} 4687 = T_{dev} \times 490.82 \frac{rad}{s}$

∴ $11655W = T_{dev}(490.82) \Rightarrow \underline{T_{dev} = 23.746 Nm}$

lower η ∵ lower power, same field losses

$\eta = \frac{P_{out}}{P_{in}} = \frac{V_T I_A - V_T I_F}{E_A I_A + P_{rot}} = \frac{230 \times 50 - 230 \times 5}{11655 + 0} = \frac{11500 - 1150}{11655} = \frac{10350}{11655} = \underline{88.8\%}$