EE101: Electrical Science
End-Sem Exam. Solution

Attempt all questions. Marks are as shown.
Maximum Marks = 50

1. In the circuit shown in Fig. 1, the Zener diode has zener voltage V_z = 4.8 V. Its maximum power dissipation should be limited to 100 mW and it requires a minimum current of 1 mA for zener operation.

Calculate the range of the source voltage V_s that can be used. **[5]**

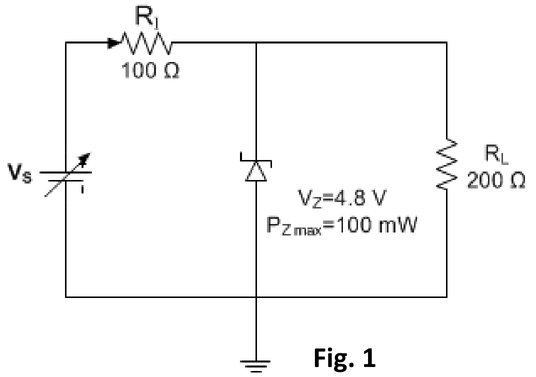


Fig. 1

$I_{Z,\,max}$ = 100/4.8 = 20.83 mA **[1]**

I_{RL}=4.8/0.2=24mA

$I_{R1,\,max}$= 44.83 mA **[1]**
$V_{S,\,max}$ = 4.8+(44.83)(0.1) = 9.3 V **[1]**

$I_{R1,\,min}$ = 1+I_{RL}= 25 mA **[1]**
$V_{S,\,min}$ = (25)(0.1)+4.8 = 7.3 V **[1]** $7.3 \le V_S \le 9.3$

2. Find the bias point (Q-point) of the transistor in the circuit shown in Fig. 2. Assume that the transistor has β=20 when it is working in the active region and $V_{CE,\ sat}$ =0.1 V when it is in saturation. **[5]**

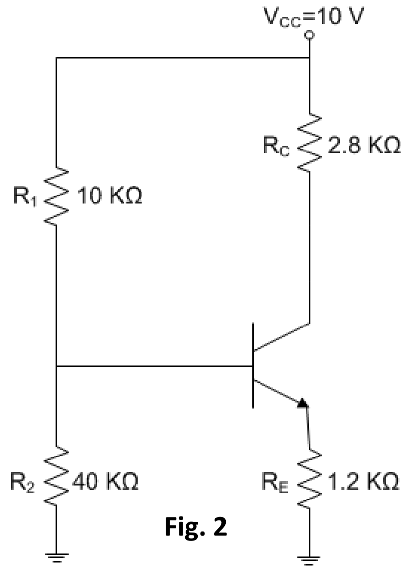


Fig. 2

V_B = 40*10/50 = 8 V R_B =10*40/50 = 8 KΩ

It can be shown that the transistor cannot be in the active region.
(No marks for showing this.)

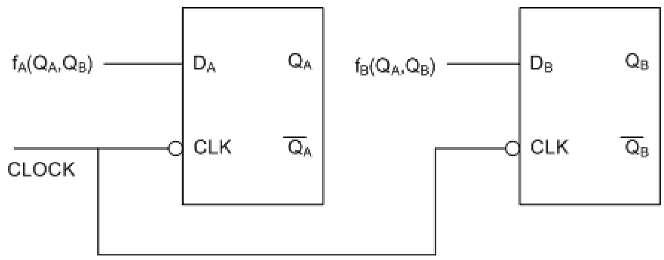
$I_BR_B + (I_B+I_C)R_E = V_B-0.7$ $9.2I_B+1.2I_C = 7.3$ **[1]**
$I_CR_C +(I_B+I_C)R_E = 10-V_{CE,\,Sat}$ $1.2I_B + 4I_C =9.9$ **[1]**

Solving, I_B=0.49 mA, I_C=2.33 mA **[1+1]**

I_C=2.33<βI_B=9.8 confirming that the transistor is indeed in saturation. **[1]**

3. Use D flip flops (and logic gates, as required) to construct a 2-bit counter which counts in the Gray-code sequence, i.e. 00, 01, 11, 10, 00, ….. **[5]**

The circuit will be as shown, where $f_A(Q_A, Q_B)$ and $f_B(Q_A, Q_B)$ are to be determined and implemented. (Note that any clock triggering may be used.)

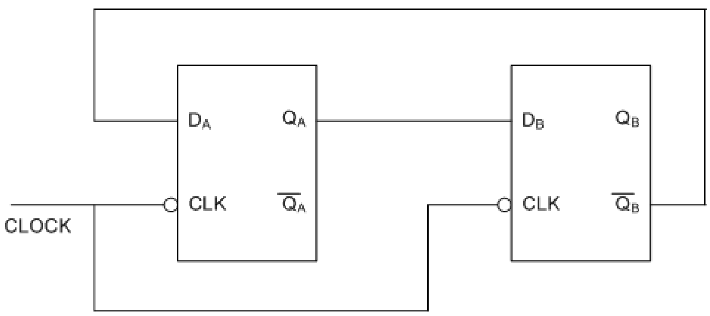


Truth Tables for f_A and f_B are given below

Q_B	Q_A	f_A	f_B
0	0	1	0
0	1	1	1
1	1	0	1
1	0	0	0

[2]

$f_A = \overline{Q}_B$ $f_B = Q_A$ **[1+1]**



[1]

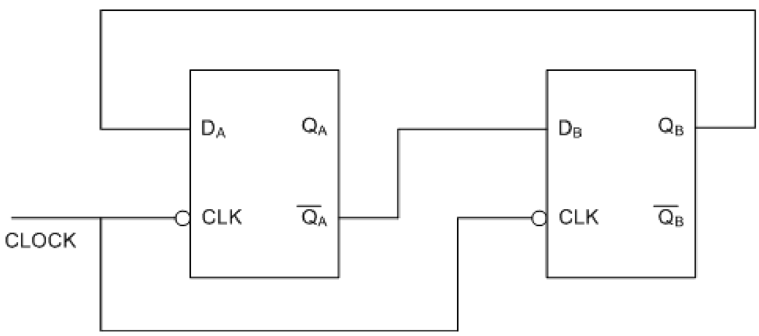
Alternate solution with B and A interchanged is also acceptable, Solution given below

Truth Tables for f_A and f_B in this case are –

Q_B	Q_A	f_A	f_B
0	0	0	1
1	0	1	1
1	1	1	0
0	1	0	0

[2]

$f_A = Q_B$ $f_B = \overline{Q}_A$ **[1+1]**



[1]

4. Consider the function –

$$Y=\overline{A}\,\overline{B}\,\overline{C}D+\overline{A}\,\overline{B}CD+\overline{A}B\overline{C}\,\overline{D}+A\overline{B}\,\overline{C}\,\overline{D}+A\overline{B}\,\overline{C}D+$$
$$\overline{A}BC\overline{D}+A\overline{B}C\,D+ABC\overline{D}$$

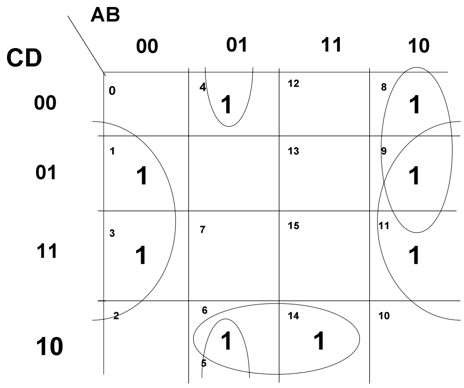
(a) Draw the Karnaugh Map for Y **[1]**

(b) Use the Karnaugh Map to simplify Y **[2]**

(c) Implement the reduced expression using only NAND gates. (The NAND gates can have any number of inputs that you may require. You can also assume that the complemented variables are available.) **[2]**

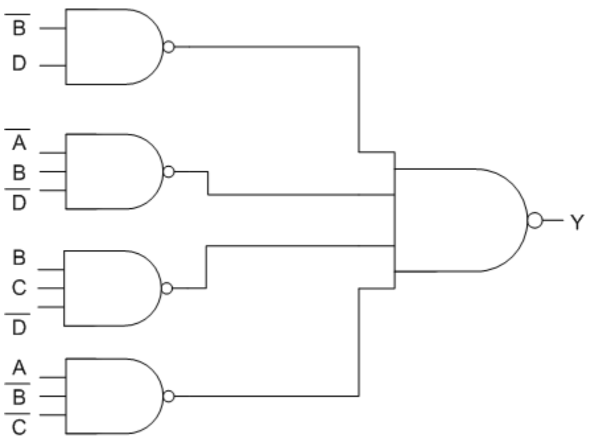
CD \ AB	00	01	11	10
00	^{0}	^{4} 1	^{12}	^{8} 1
01	^{1} 1	^{5}	^{13}	^{9} 1
11	^{3} 1	^{7}	^{15}	^{11} 1
10	^{2}	^{6} 1	^{14} 1	^{10}

[1]



[2]

$$Y=\overline{B}\,D+\overline{A}\,B\,\overline{D}+B\,C\,\overline{D}+A\,\overline{B}\,\overline{C}$$



[2]

5. Find the gain $A_V = \frac{V_O}{V_I}$ of the circuit shown in Fig. 3. **[5]**

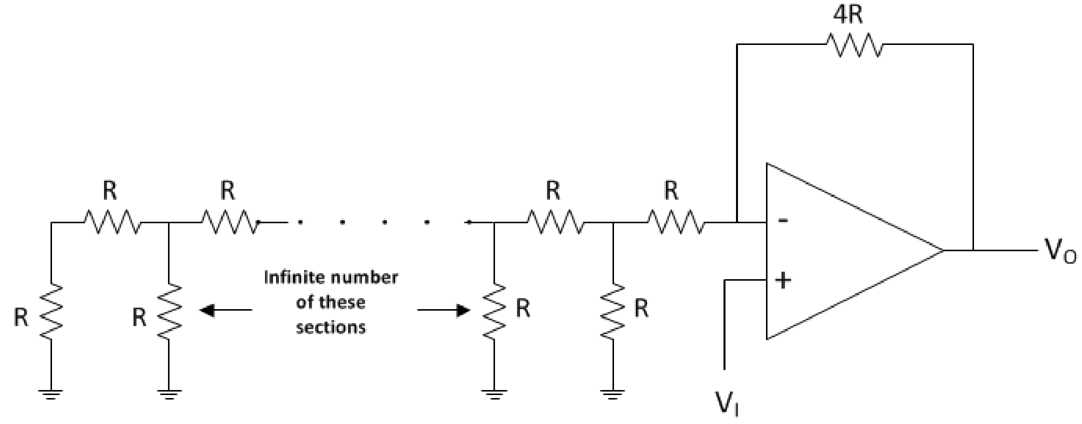
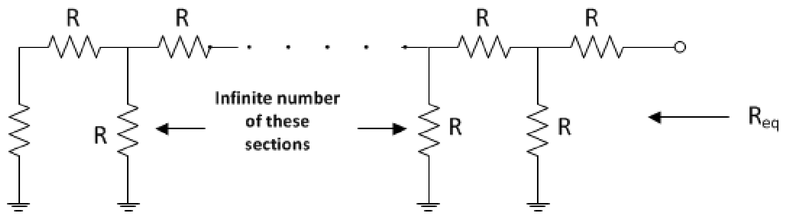
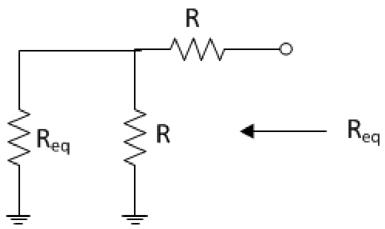


Fig. 3



or, equivalently



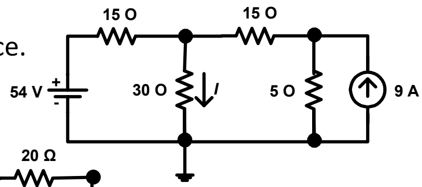
$$\left\{ \begin{array}{l} R_{eq} = R + \frac{RR_{eq}}{R+R_{eq}} \quad \text{or} \quad R_{eq}^2 + RR_{eq} = R^2 + RR_{eq} + RR_{eq} \\ R_{eq}^2 - RR_{eq} - R^2 = 0 \\ \text{Solving,} \quad R_{eq} = \frac{R+\sqrt{R^2+4R^2}}{2} = \left(\frac{1+\sqrt{5}}{2}\right) R = 1.618R \end{array} \right\} \quad \textbf{[2]}$$

$R_{eq} = (R_{eq} || R) + R$ **[1]**

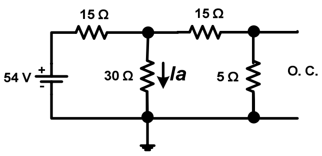
$$\frac{V_I}{R_{eq}} = \frac{V_O - V_I}{4R}$$ **[1]**

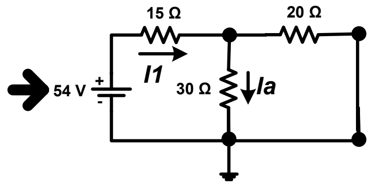
$$\frac{V_O}{V_I} = 1 + \frac{4R}{R_{eq}} = 1 + \frac{4}{1.618} = 3.472$$ **A_V=3.472** **[1]**

6.



<u>A.</u> Consider 54 V source only. Open circuit (O. C.) 9 A current source. Equivalent circuits are given below:

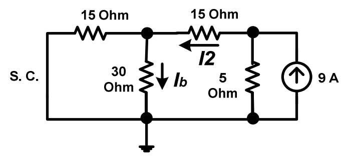




[**1.5 mark** for both circuits]

Thus, $I_1 = \dfrac{54}{15+\dfrac{30\times 20}{30+20}} = \dfrac{54}{27} = 2\,Amp$. And $I_a = 2\times\dfrac{20}{20+30} = \dfrac{4}{5} = 0.8\,Amp.$ [**1 mark**]

<u>B.</u> Now consider 9 A current source only. Short circuit (S.C.) 54 V voltage source. Equivalent circuit is shown.



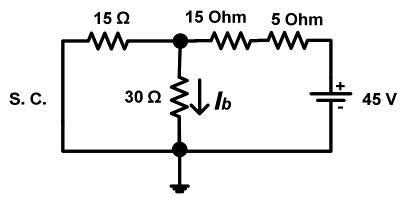
$$I_2 = 9\times\frac{5}{5+15+\dfrac{15\times 30}{15+30}} = \frac{9\times 5}{20+10} = 1.5\,Amp.$$

[**1 mark**]

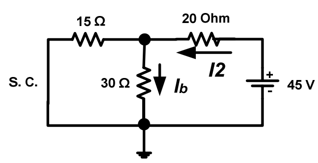
So, $I_b = I_2\times\dfrac{15}{15+30} = 9\times\dfrac{15}{45} = 0.5\,Amp.$ [**1 mark**]

Hence, total current $I = I_a + I_b = 0.8+0.5 = 1.3\,Amp.$ (Answer) [**0.5 mark for correct answer**]

Note: One may also transfer the current source into a voltage source and then solve for I_b. The equivalent circuit for this source transformation is shown (45 V in series with 5 Ohm resistance).



In this case, the current I_b due to 45 V voltage source only can be obtained as given below. Equivalent circuit is shown.



$$I_2 = \frac{45}{20+\dfrac{15\times 30}{15+30}} = \frac{45}{20+10} = 1.5\,Amp.$$

So, $I_b = 1.5\times\dfrac{15}{15+30} = 0.5\,Amp.$ [**1 mark**]

[**1 mark for both**]

7. The core shown in Figure 1 has the flux f shown in Figure 2. Sketch the voltage present at the terminals of the coil. (**5 marks**)

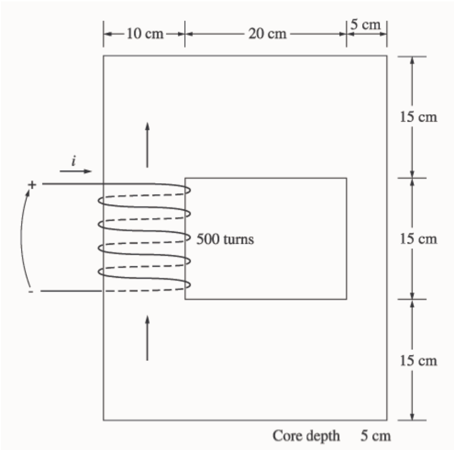


Figure 1

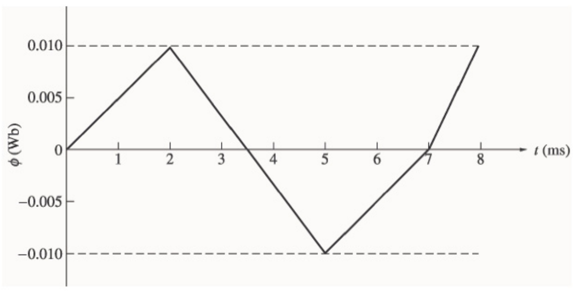


Figure 2

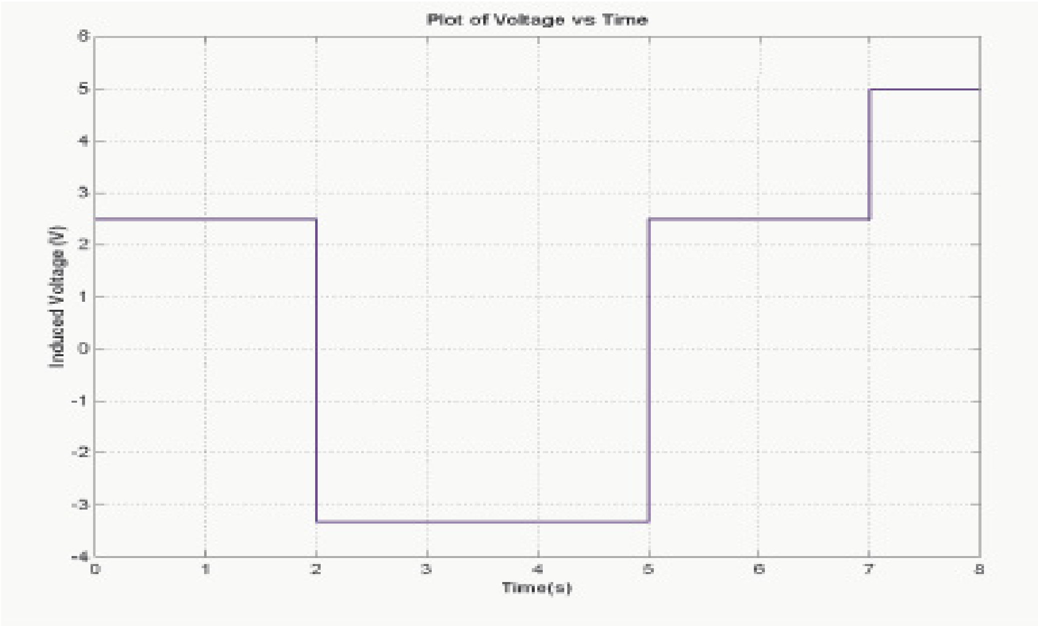
Sol: By Lenz' Law, an increasing flux in the direction shown on the core will produce a voltage that tends to oppose the increase. This voltage will be the same polarity as the direction shown on the core, so it will be positive. The induced voltage in the core is given by the equation

$e = N\dfrac{d\phi}{dt}$ ***(3 marks for the reasoning and proper use of formula)***

Hence, the voltage in the winding will be

Time [s]	$N\dfrac{d\phi}{dt}$ [V]	e [V]
$0 < t < 2$	$500 \times \dfrac{0.01}{2}$	2.50
$2 < t < 5$	$-500 \times \dfrac{0.02}{3}$	-3.33
$5 < t < 7$	$500 \times \dfrac{0.01}{2}$	2.50
$7 < t < 8$	$500 \times \dfrac{0.01}{1}$	5.00

The plot of the voltage is



(2 marks for the figure)

If the reasoning is not given and only figure is given then only 2 marks will be awarded.

If the units of the quantities are not given then 25% marks will be deducted.

8.

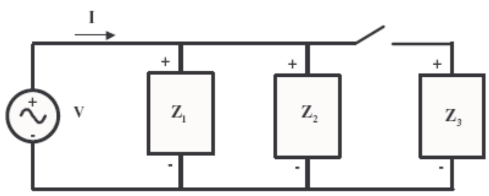


Figure 3

a. With the switch open, only loads 1 and 2 are connected to the source. The current I_1 in the load 1 is

$$I_1 = \frac{120\angle 0^o}{5\angle 30^o} = 24\angle -30^o\,A$$

The current I_2 in the load 2 is

$$I_2 = \frac{120\angle 0^o}{5\angle 45^o} = 24\angle -45^o\,A$$

Hence, the total current from the source is

$I = I_1 + I_2 = 24\angle -30^o + 24\angle -45^o = 47.59\angle -37.5^o\,A$ ***(0.5 marks, if units are not given and/or the phase angle with proper sign is not given then 50% marks will be deducted)***

The power factor is
$pf = \cos\theta = \cos(-37.5^o) = 0.793 \text{ lagging}$ ***(0.5 marks, if the word "lagging" is not mentioned then 50% marks will be deducted)***
The real, reactive and apparent powers supplied by the source are
$$P = VI\cos\theta = 120\times 47.59\times\cos\left(-37.5^o\right) = 4531W$$
$$Q = VI\sin\theta = 120\times 47.59\times\sin\left(-37.5^o\right) = -3477VAr$$
$$S = VI = 120\times 47.59 = 5711VA$$
(1 mark, if proper units are not mentioned then 50% marks will be deducted)

b. With the switch closed, all three loads are connected to the source. The current in the Load 1 and Load 2 is same as before. The current I_3 in the Load 3 is
$$I_3 = \frac{120\angle 0^o}{5\angle -90^o} = 24\angle 90^o\, A$$
Hence, the total load current is
$I = I_1 + I_2 + I_3 = 24\angle -30^o + 24\angle -45^o + 24\angle 90^o = 38.8\angle -7.5^o\, A$ ***(0.5 marks, if units are not given and/or the phase angle with proper sign is not given then 50% marks will be deducted)***
The power factor supplied by the source is
$pf = \cos\theta = \cos(-7.5^o) = 0.991 \text{ lagging}$ ***(0.5 marks, if the word "lagging" is not mentioned then 50% marks will be deducted)***
The real, reactive and apparent powers supplied by the source are
$$P = VI\cos\theta = 120\times 38.08\times\cos\left(-7.5^o\right) = 4531W$$
$$Q = VI\sin\theta = 120\times 38.08\times\sin\left(-7.5^o\right) = -596VAr$$
$$S = VI = 120\times 38.08 = 4570VA$$
(1 mark, if proper units are not mentioned then 50% marks will be deducted)

c. The current flowing *decreased* when the switch closed, because most of the reactive power being consumed by Loads 1 and 2 is being supplied by Load 3. Since less reactive power has to be supplied by the source, the total current flow decreases. ***(1 mark)***

9. a. The synchronous speed is
$n_s = \frac{120\times 50}{6} = 1000rpm$ ***(1 mark, if units are not mentioned 50% marks will be deducted)***
The rotor speed is
$n_r = (1-s)\times n_s = (1-0.06)\times 1000 = 940rpm$ ***(1 mark, if units are not mentioned 50% marks will be deducted)***

b. The mechanical load is of 50kW. Since, the mechanical load is connected to the shaft of the rotor, the shaft power is 50kW. Hence, the shaft torque is
$T_{sh} = \frac{50\times 1000}{940\times\frac{2\pi}{60}} = 508Nm$ ***(1 mark, if units are not mentioned 50% marks will be deducted)***

c. The air gap power is given by

$$P_{gap} = P_{shaft} + Rotor\ Ohmic\ Loss + Mechanical\ Losses$$

Since, the rotor Ohmic loss is not given, it is assumed to be zero. (***0.5 marks, if units are not***

$$P_{gap} = 50 \times 1000 + 300 = 50.3kW$$

mentioned 50% marks will be deducted)

The air gap torque is

$$T_{gap} = \frac{50.3 \times 1000}{940 \times \frac{2\pi}{50}} = 510.9Nm$$ (***0.5 marks, if units are not mentioned 50% marks will be deducted)***

d. The rotor frequency is

$f_r = sf = 0.06 \times 50 = 3Hz$ (electrical frequency)

$f_r = 1Hz$ (mechanical frequency)

$f_r = 60rpm$ (mechanical speed)

(1 mark for any of the three answers. However, 50% marks will be deducted if the proper units are not mentioned or words "electrical frequency/ mechanical speed/mechanical frequency" are not mentioned)

10. a. The slip before plugging is 0.03 or 3% ***(1 mark)***

b. The frequency of the rotor before plugging is $f_{rotor} = sf = 0.03 \times 50 = 1.5Hz$ (electrical frequency)

The frequency of the rotor before plugging is $45rpm$ (mechanical speed)

The frequency of the rotor before plugging is $0.75Hz$ (mechanical frequency)

(1 mark for any of the three answers. However, 50% marks will be deducted if the proper units are not mentioned or words "electrical frequency/ mechanical speed/mechanical frequency" are not mentioned)

c. After switching stator leads, the synchronous speed becomes -1500 rpm (clockwise), while the rotor speed at the instant of plugging remains 1455 rpm (anti clockwise). Hence, the slip becomes

$$s = \frac{-1500 - 1455}{-1500} = 1.962$$ ***(1 mark)***

d. The frequency of rotor after plugging is $f_{rotor} = sf = 1.962 \times 50 = 98.1Hz$ (electrical frequency)

The frequency of rotor after plugging is $f_{rotor} = 2955rpm$ (mechanical speed)

The frequency of rotor after plugging is $f_{rotor} = 49.5Hz$ (mechanical frequency)

(1 mark for any of the three answers. However, 50% marks will be deducted if the proper units are not mentioned or words "electrical frequency/ mechanical speed/mechanical frequency" are not mentioned)