Department of Electronics and Electrical Engineering, IIT Guwahati

Electrical Sciences: EE101

Time: 2 hours Mid Semester Exam (24 Sep 2014) Max. Marks: 30

Instruction: *Attempt all problems.*

1. The terminal voltage of the balanced 3-phase delta connected load shown in Figure 1 is maintained constant at 100 V and the total power drawn by the load is 6 kW at 0.83 pf (lag).

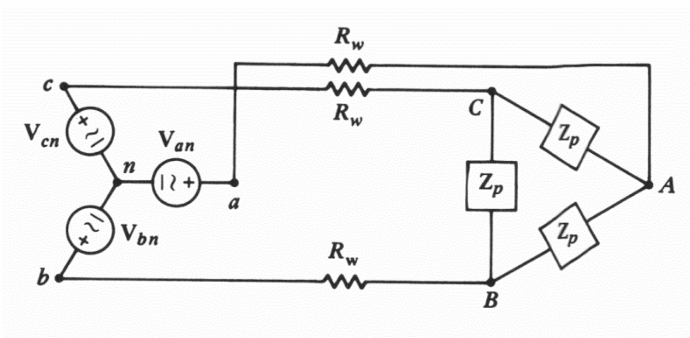


Figure 1

   a. Calculate the impedance Z_p and the current drawn by the load.
   b. If the resistance of the lines, R_w = 0.8 Ω/phase,
      i. draw the per-phase equivalent circuit of the system,and
      ii. calculate the terminal voltage of the source, total power loss in the lines, and the total complex power supplied by the source.

[3+5]

2. For the circuit shown in Figure 2,
   a. Determine the Thevenin's resistance between *a*, and *b*.
   b. Use nodal analysis to determine the open circuit voltage between *a*, and *b*.
   c. Use mesh analysis to determine the short circuit current from *a* to *b*.
   d. Draw the Thevenin's equivalent circuit between *a* and *b*.
   e. Draw the Norton's equivalent circuit between *a* and *b*.

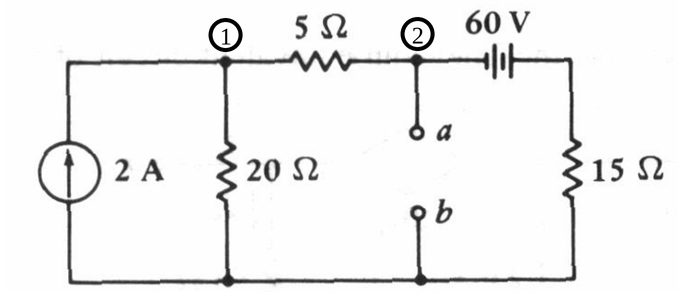


Figure 2

[1+2+2+1+1]

3. For circuit shown in Fig.3, the applied input is half-wave rectified sine wave with amplitude of 12 V. Assume that in breakdown region the Zener diode has the equivalent circuit as shown in figure. Neglect the reverse saturation current.

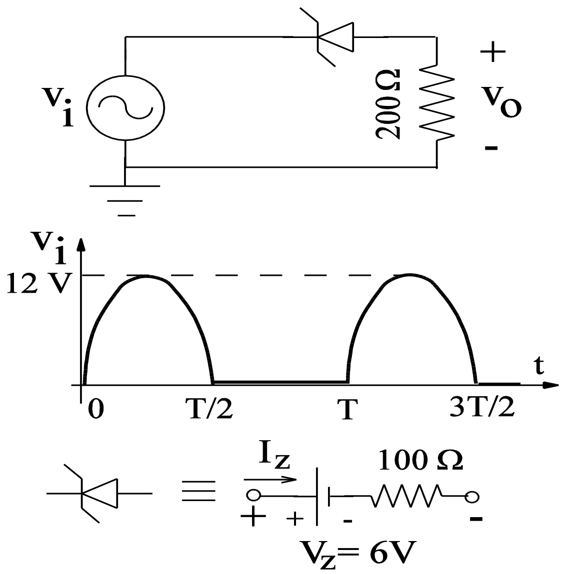


Figure 3

a. Sketch the output waveform v_O with labeling of the break points. [4]
b. Determine average (dc) voltage at the output. [3]

4. For circuit shown in Fig. 4, the transistor has $\beta = 150$, $V_{BE} = 0.7\,V$ and $V_T = 26\,mV$. The bias point is to be set such that $V_{CQ} = 5\,V$ and $I_{CQ} = 1.5\,mA$. Assume that capacitors are prefect short at signal frequency and r_0 is very large so that its effect can be neglected.
   a. Find R_C , R_B, and V_{CEQ}. [1+1+1]
   b. Find $A_v = \frac{v_o}{v_i}$, R_i and $A_{v_s} = \frac{v_o}{v_s}$. [2+2+1]

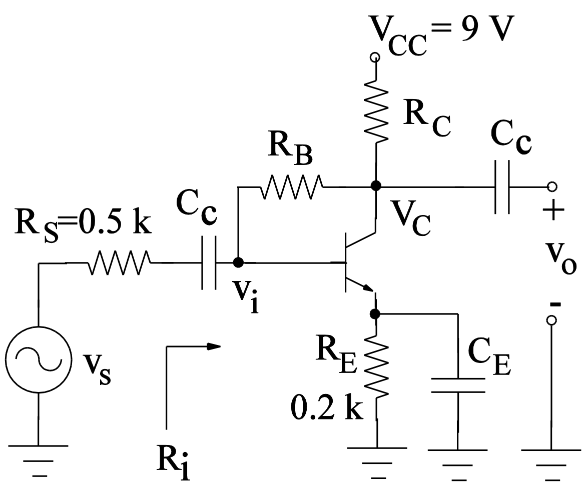


Figure 4

Solutions

Q1. *a*. Power drawn per phase = 2kW at 0.83 pf (lag) =$(2000/0.83)\angle\cos^{-1} 0.83$

= $2409.64\angle 33.9°$

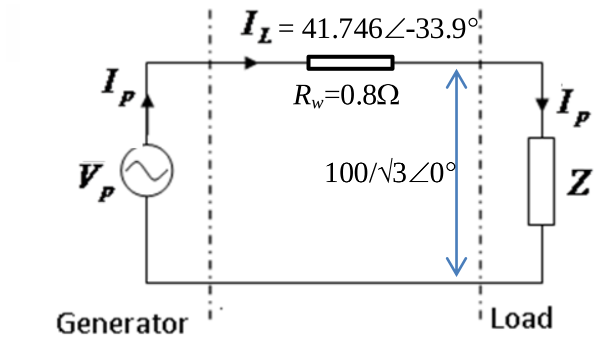
= $2000.03 + j\ 1343.96$ VA

Therefore, $Z_p = \dfrac{100^2}{(2409.64\angle 33.9°)^*} = 4.15\angle 33.9°\ \Omega$ [1.5]

Impedance / star phase $= Z_p / 3 = 1.383\angle 33.9°\ \Omega = 1.148 + j0.771$

Current drawn by the load = $I_L = I_{ph} = \dfrac{(100/\sqrt{3})\angle 0°}{1.383\angle 33.9°} = 41.746\angle -33.9°\ A$ [1.5]

b. The per phase equivalent circuit is as shown.



Then, the source voltage per phase may be calculated as:

$$V_{sp} = V_a\angle 0° + I_a \times R_w$$
$$= (100/\sqrt{3})\angle 0° + 41.746\angle -33.9° \times 0.8 = 85.45 - j18.62$$
$$= 87.455\angle -12.29°$$

Terminal voltage of the source V_t $= \sqrt{3} \times 87.455 = 151.5$ V [2]

Power lost in R_w $= 41.746^2 \times 0.8 = 1394.18$ W

Total power loss in the line $= 3 \times 1394.18 = 4182.54$ W [1]

Therefore, total power output

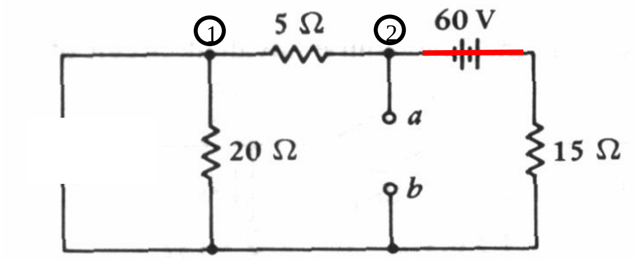
$$= 3 \times (2000.03 + j\ 1343.96 + 1394.18)\ \text{VA}$$
$$=10182.6 + j\ 4031.9$$
$$= 10951.8\angle 21.60°\ \text{VA}$$ [2]

The complex power may also be calculated as

$$= 3 \times 87.455\angle -12.29° \times (41.746\angle -33.9°)^*$$

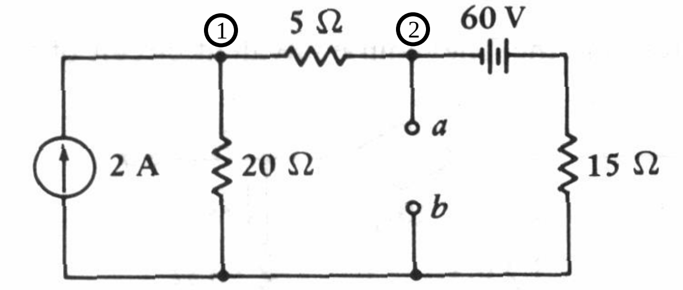
Q2.

a. The circuit find the Thevenin's resistance is:



$$R_{th}^{ab} = 15//(20+5) = \frac{15\times 25}{15+25} = 9.375 \;\; \Omega$$ [1]

a. The Thevenin's voltage is the node 2 voltage. The circuit for nodal analysis for V_{th} is:



Writing node equations at nodes 1, and 2,

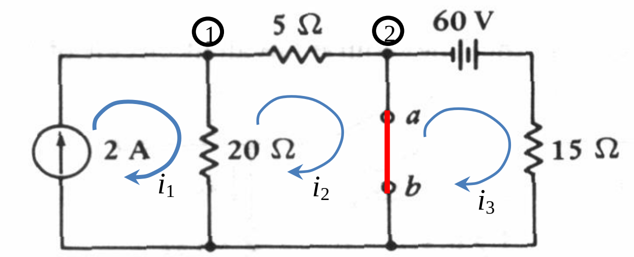
$$2 - \frac{v_1}{20} - \frac{v_1 - v_2}{5} = 0 \qquad \rightarrow \qquad -5v_1 + 4v_2 = -40$$

$$\frac{v_2 + 60}{15} + \frac{v_2 - v_1}{5} = 0 \qquad \rightarrow \qquad -3v_1 + 4v_2 = -60$$

$$v_1 = -10 \qquad \text{and} \qquad v_2 = -22.5$$

Thevenin's voltage = -22.5 V [2]

b. The circuit for mesh analysis for short circuit current is:



$$i_1 = 2 \;\; \text{A}$$

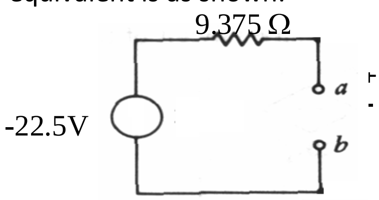
$$(i_2 - 2)\times 20 + i_2 \times 5 = 0 \qquad \rightarrow \qquad i_2 = 1.6 \;\; \text{A}$$

$$60 - 15i_3 = 0 \qquad \rightarrow \qquad i_3 = 4 \;\; \text{A}$$

$$i_{sc} = i_2 - i_3 = -2.4$$

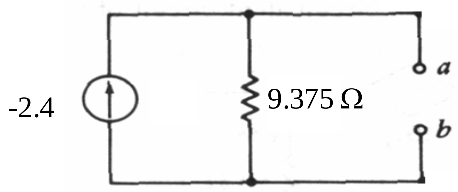
[2]

c. The Thevenin's equivalent is as shown:



[1]

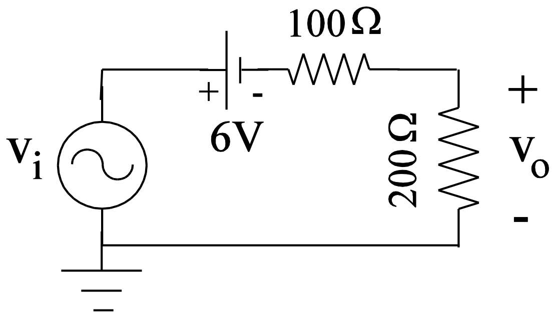
d. The Norton's equivalent is as shown:

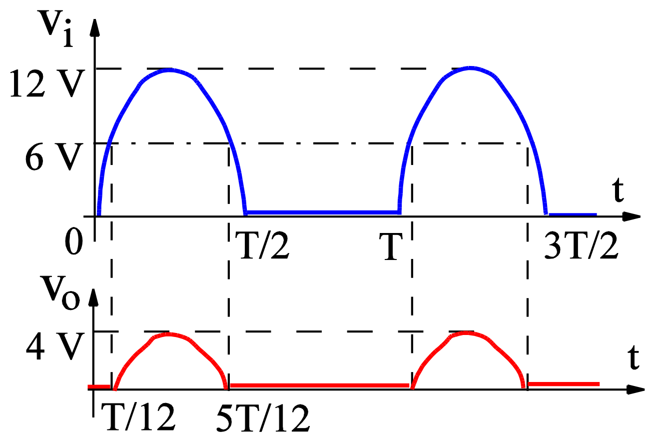


[1]

3 (a) For the input voltage $0 \le v_i < 6\,V$, the Zener diode does not breakdown and remains OFF, so the output voltage v_O be zero. (1/2 mark)

For $v_i \ge 6\,V$, the Zener diode breaks down and the given circuit reduces to





From the above circuit diagram the output voltage can found as

$$v_O = \frac{2}{3}(v_i - 6)\,V \qquad \text{for} \quad 6\,V \le v_i \le 12\,V \qquad \text{(1 mark)}$$

The time t at which v_i attains value of 6 V in first cycle can be found as

$$12\sin(\omega t)\,V = 6\,V \;\Rightarrow\; t = \frac{1}{\omega}\,sin^{-1}\left(\frac{6}{12}\right) = \frac{T}{2\pi}\,\frac{\pi}{6} = \qquad \text{(1/2 mark)}$$

Thus in each cycle, the non-zero portion of the output waveform is scaled and shifted sinusoid between $\frac{T}{12}$ and $\frac{5T}{12}$ with peak value of 4 V as shown above.

(2 marks)

(b) By definition $V_{O(avg)} = \frac{1}{T}\int_0^T v_O\,dt$

$$= \frac{2}{3T}\int_{T/12}^{5T/12} v_i\,dt - \frac{4}{T}\int_{T/12}^{5T/12} dt$$

$$= \frac{2}{3T}\int_{T/12}^{5T/12} 12\sin(\omega t)dt - \frac{4}{T}\int_{T/12}^{5T/12} dt$$

$$= -\frac{2\times 12}{3\omega T}[\cos\omega t]_{T/12}^{5T/12} - \frac{4}{T}[t]_{T/12}^{5T/12}$$

$$= -\frac{4}{\pi}\left[\cos\frac{5\pi}{6} - \cos\frac{\pi}{6}\right] - \frac{4}{T}\left[\frac{5T}{12} - \frac{T}{12}\right]$$

$$= \frac{8}{\pi}\cos\frac{\pi}{6} - \frac{4}{3} = 4\left(\frac{\sqrt{3}}{\pi} - \frac{1}{3}\right) \cong 0.8712\,V$$

(3 marks)

Q4. (a) For bias point of $V_{CQ} = 5\ V$ and $I_{CQ} = 1.5\ mA$, it is obvious that transistor is in active region of operation

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1.5\ mA}{150} = 0.01\ mA$$

From DC equivalent circuit of amplifier, we have

$$V_{CQ} = V_{CC} - R_C(I_{CQ} + I_{BQ}) \quad \Rightarrow R_C = \frac{V_{CC}-V_C}{I_{CQ}+I_{BQ}} = \frac{9\ V - 5\ V}{1.51\ mA} \cong 2.65\ k\Omega$$

(1 mark)

On writing KVL in the base-emitter loop, we have

$$V_C = R_B I_{BQ} + V_{BE} + (\beta+1) I_{BQ} R_E$$

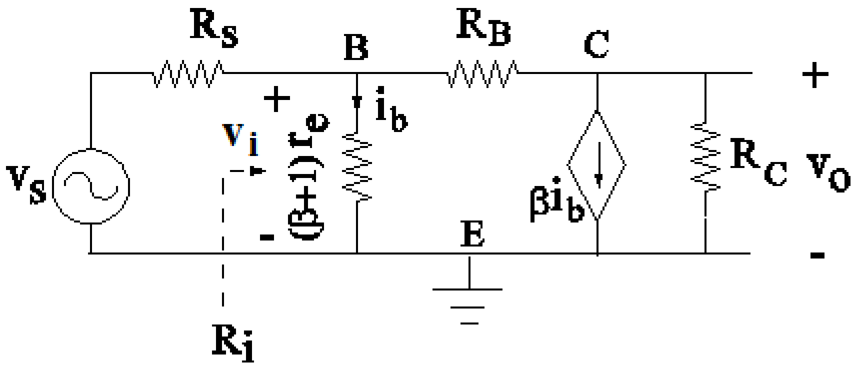
$$5\ V = R_B \times 0.01\ mA + 0.7\ V + 151 \times 0.01\ mA \times 0.2\ k\Omega$$

$$R_B = \frac{(5-0.7-0.302)V}{0.01\ mA} = 399.8$$ (1 mark)

$$V_{CEQ} = V_C - V_E = V_C - (\beta+1) I_{BQ} R_E = 5 - 0.302 = 4.698\ V$$

(1 mark)

(b) The AC equivalent circuit of the transistor amplifier is shown below



$$r_e = \frac{26\ mV}{I_E} = \frac{26\ mV}{1.51\ mA} \cong 17.22\ \Omega$$ (1 mark)

Note $i_b = \frac{v_i}{(\beta+1)r_e}$, now applying KCL at node 'C', we have

$$\frac{v_i - v_o}{R_B} - \frac{v_o}{R_C} = \beta i_b = \frac{\beta\ v_i}{(\beta+1)r_e}$$

On making due approximations, the voltage gain without R_s is

$$A_v = \frac{v_o}{v_i} \cong -\frac{R_C}{r_e} = -\frac{2.65\ k\Omega}{17.22\ \Omega} \cong -154$$ (1 mark)

Now,

$$i_i = \frac{v_i}{(\beta+1)r_e} + \frac{v_i - v_o}{R_B} \cong v_i\left[\frac{1}{\beta r_e} + \frac{1}{R_B} + \frac{R_C}{R_B r_e}\right]$$

$$R_i = \frac{v_i}{i_i} \cong \frac{r_e}{\frac{1}{\beta} + \frac{R_C}{R_B}} = \frac{17.22\ \Omega}{\frac{1}{150} + \frac{2.65\ k\Omega}{399.8\ k\Omega}} \cong 1.3\ k\Omega$$

(2 marks)

The overall voltage gain can be deduced as

$$A_{v_s} = \frac{v_o}{v_s} = \frac{R_i}{R_i + R_s} \times A_v = \frac{1.3\ k\Omega}{1.3\ k\Omega + 0.5\ k\Omega}(-154) \cong -111$$

(1 marks)

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