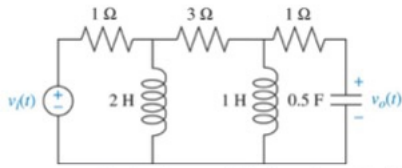


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### Question: Represent the electrical network shown in Figure P3.1 in state ...

1. Represent the electrical network shown in Figure P3.1 in state space, where  $v_o(t)$  is the output



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### Expert Answer

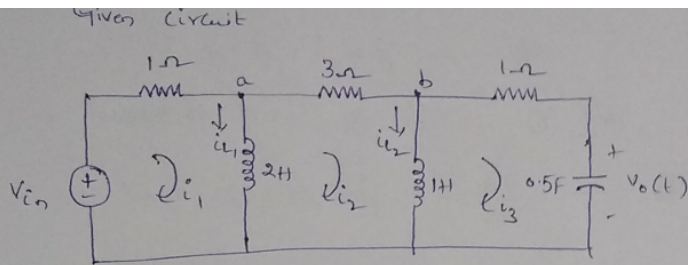
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let us assume the state variables of the system as  $i_1 = x_1$ ,  $i_2 = x_2$ ,  $v_c = x_3$

Applying KVL to 1<sup>st</sup> loop

$$V_{in} = i_1 + L \frac{di_1}{dt} \quad \text{--- (1)}$$

Applying KVL to 2<sup>nd</sup> loop

$$3i_2 - 2 \frac{di_1}{dt} + \frac{di_2}{dt} = 0 \quad \text{--- (2)} \quad \left[ \begin{array}{l} \because i_1 - i_3 = i_1 \\ i_2 - i_3 = i_2 \end{array} \right]$$

Applying KVL to 3<sup>rd</sup> loop

$$i_3 + v_c - \frac{di_2}{dt} = 0 \quad \text{--- (3)} \quad \left[ \because i_2 - i_3 = i_2 \right]$$

Applying KCL at node - a

$$i_1 = i_1 + i_2 \quad \text{--- (4)}$$

Applying KCL at node - b

$$i_2 = i_2 + i_3 \quad \text{--- (5)}$$

Substituting eq - (5) in eq - (4) gives (2)

$$i_1 = i_1 + i_2 + i_3 \quad \text{--- (6)}$$

Substituting eq - (6) in eq - (1) gives

$$V_{in} = i_1 + i_2 + i_3 + 2 \frac{di_1}{dt} \quad \text{--- (7)}$$

From equation - (2)

$$2 \frac{di_1}{dt} = 3i_2 + \frac{di_1}{dt}$$

$$\text{But from eq - (3)} \quad \frac{di_2}{dt} = i_3 + v_c$$

$$\therefore 2 \frac{di_1}{dt} = 3i_2 + i_3 + v_c$$

$$\text{But from eq - (5)} \quad i_3 = i_2 + i_3$$



$$\therefore 2 \frac{di_1}{dt} = 3(i_2 + i_3) + i_3 + V_c$$

$$2 \frac{di_1}{dt} = 3i_2 + 4i_3 + V_c$$

$$\frac{di_1}{dt} = \frac{3}{2}i_2 + \frac{4}{2}i_3 + \frac{1}{2}V_c \quad \text{--- (5)}$$

Substituting eq --- (5) in eq --- (1)

$$V_{in} = i_1 + i_2 + i_3 + 2 \left[ \frac{3}{2}i_2 + \frac{4}{2}i_3 + \frac{1}{2}V_c \right]$$

$$V_{in} = i_1 + i_2 + i_3 + 3i_2 + 4i_3 + V_c$$

$$V_{in} = i_1 + 4i_2 + 5i_3 + V_c \quad \text{(3)}$$

$$5i_3 = -i_1 - 4i_2 - V_c + V_{in}$$

But from the circuit  $i_3$  is given as the current flowing through capacitor

$$i_3 = C \frac{dV_c}{dt}$$

$$\therefore 5 \times 0.5 \frac{dV_c}{dt} = -i_1 - 4i_2 - V_c + V_{in}$$

$$\frac{5}{2} \frac{dV_c}{dt} = -i_1 - 4i_2 - V_c + V_{in}$$

Substituting the state variables.  $\Sigma$  1p variable

$$\frac{5}{2} \dot{x}_3 = -x_1 - 4x_2 - x_3 + u$$

$$\therefore \dot{x}_3 = -\frac{2}{5}x_1 - \frac{8}{5}x_2 - \frac{2}{5}x_3 + \frac{2}{5}u$$

From eq --- (3)

$$\frac{di_2}{dt} = i_3 + V_c$$

$$\text{But } i_3 = C \frac{dV_c}{dt} = 0.5 \frac{dV_c}{dt} = 0.5 \dot{x}_3$$

$$\therefore \frac{di_2}{dt} = 0.5 \dot{x}_3 + V_c$$

$$\dot{x}_2 = 0.5 \left[ -\frac{2}{5}x_1 - \frac{8}{5}x_2 - \frac{2}{5}x_3 + \frac{2}{5}u \right] + x_3$$

$$\dot{x}_2 = -\frac{1}{5}x_1 - \frac{4}{5}x_2 - \frac{1}{5}x_3 + \frac{1}{5}u + x_3$$



$$\frac{1}{5} \dot{x}_1 - \frac{4}{5} \dot{x}_2 + \frac{4}{5} \dot{x}_3 + \frac{1}{5} u \quad (4)$$

From eq - (3) we have

$$\frac{di_1}{dt} = \frac{3}{2} i_2 + \frac{4}{2} i_3 + \frac{1}{2} v_c$$

$$\text{But } i_3 = C \frac{dv_c}{dt} = 0.5 \frac{dv_c}{dt} = 0.5 \dot{x}_3$$

$$\therefore \frac{di_1}{dt} = \frac{3}{2} i_2 + \dot{x}_3 + \frac{1}{2} v_c \quad [\because i_3 = 0.5 \dot{x}_3]$$

$$\begin{aligned} \therefore \dot{x}_1 &= \frac{3}{2} x_2 + \dot{x}_3 + \frac{1}{2} x_3 \\ &= \frac{3}{2} x_2 + \left[ \frac{2}{5} x_1 - \frac{8}{5} x_2 - \frac{2}{5} x_3 + \frac{2}{5} u \right] + \frac{1}{2} x_3 \\ &= -\frac{2}{5} x_1 + \left[ \frac{3}{2} - \frac{8}{5} \right] x_2 + \left[ \frac{1}{2} - \frac{2}{5} \right] x_3 + \frac{2}{5} u \end{aligned}$$

$$\dot{x}_1 = -\frac{2}{5} x_1 - \frac{1}{5} x_2 + \frac{1}{5} x_3 + \frac{2}{5} u$$

The state equations are

$$\dot{x}_1 = -\frac{2}{5} x_1 - \frac{1}{5} x_2 + \frac{1}{5} x_3 + \frac{2}{5} u$$

$$\dot{x}_2 = -\frac{1}{5} x_1 - \frac{4}{5} x_2 + \frac{4}{5} x_3 + \frac{1}{5} u$$

$$\dot{x}_3 = -\frac{2}{5} x_1 - \frac{8}{5} x_2 - \frac{2}{5} x_3 + \frac{2}{5} u$$

The output equation is

$$y = v_o(t) = v_c = \dot{x}_3$$

$$y = x_3$$



The above State-Space representation can be represented in matrix form as

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -2/5 & -1/5 & 1/5 \\ -1/5 & -4/5 & 4/5 \\ -2/5 & -8/5 & -2/5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 2/5 \\ 1/5 \\ 2/5 \end{bmatrix} u$$

$$y = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

where  $A = \begin{bmatrix} -2/5 & -1/5 & 1/5 \\ -1/5 & -4/5 & 4/5 \\ -2/5 & -8/5 & -2/5 \end{bmatrix}$   $B = \begin{bmatrix} 2/5 \\ 1/5 \\ 2/5 \end{bmatrix}$

$$C = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

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A: [See answer](#)

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Q: Represent the electrical network shown in Figure P3.1 in state space, where  $v_o(t)$  is the output. [Section: 3.4]

A: [See answer](#)

Q: Represent the electrical network shown in Figure P3.1 in state space, where  $v_o(t)$  is the output. Represent the electrical network shown in Figure P3.2 in state space, where  $i_R(t)$  is the output. [Section: 3.4]

A: [See answer](#)

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