Experiment No.3 **Date:28/09/2021**

Verification of Kirchhoff's Voltage Law, Mesh Analysis and Equivalent Resistance

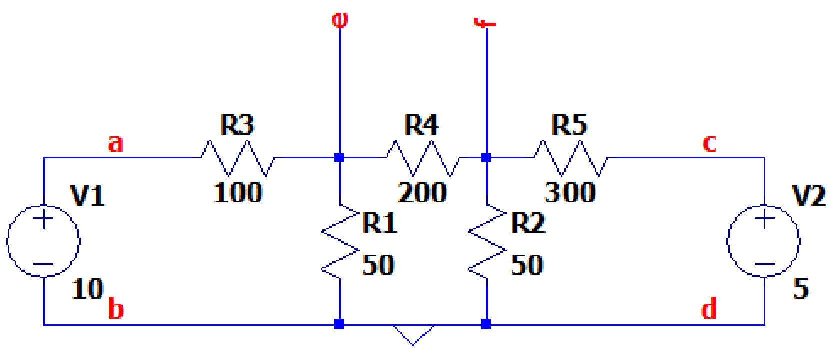
Objectives:

1. To verify KVL and find the mesh currents and nodal voltages.
2. To verify the equivalent resistance of the circuit from different terminals

Simulation Tool:

LTSpice – dc operating point analysis and transient analysis.

Circuit:



Observation:

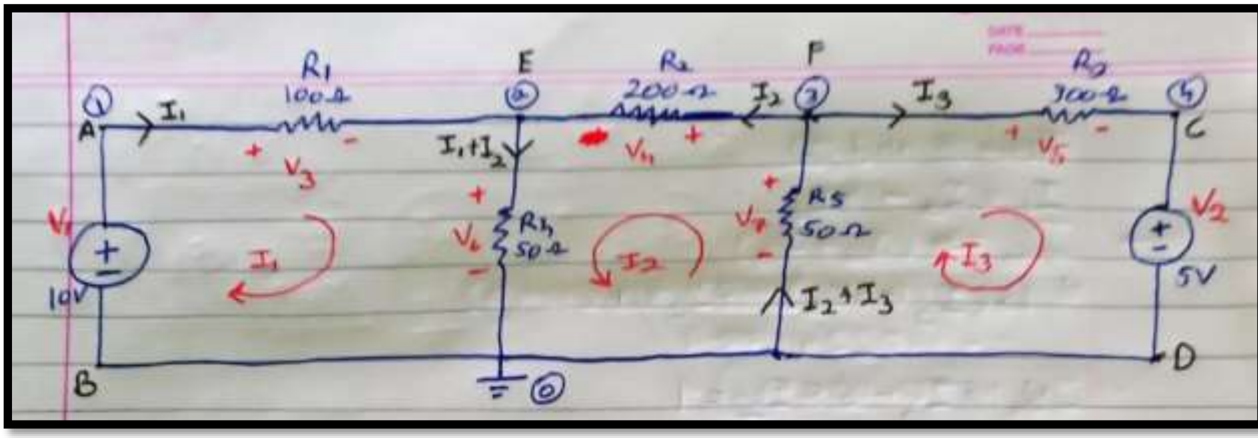
I1 = 0.06983A
I2 = -0.00948A
I3 = -0.01293A

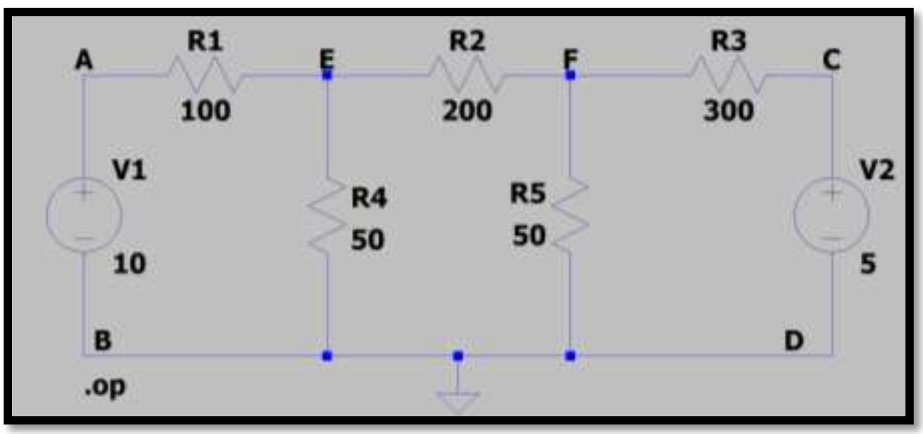
S. No	Element/Branch	Current (A)	Voltage (V)	Power (W) Dissipated
1	R1	0.06983A	6.9827 V	0.488W
2	R2	-0.00948A	-1.8965 V	0.018W
3	R3	-0.01293A	-3.8790 V	0.050W
4	R4	0.06034A	3.0172 V	0.182W
5	R5	-0.02241A	1.1205 V	0.025W
6	V1	-0.06983A	10 V	-0.698W
7	V2	-0.01293A	5 V	-0.064W

To Do:

1. Find the mesh currents **I1, I2 and I3** using the above measurements
2. Verify KVL in the independent loops
3. Compute the equivalent resistance of the circuit from terminals **a-b, c-d, e-f** and understand they are different.
4. Insert the picture of all the theoretical calculation done in your notebook

1. KVL and Mesh Analysis:



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--- Operating Point ---

V(a):      10            voltage
V(e):      3.01724       voltage
V(f):      1.12069       voltage
V(c):      5             voltage
I(R5):     -0.0224138    device_current
I(R4):     0.0603448     device_current
I(R3):     -0.012931     device_current
I(R2):     -0.00948276   device_current
I(R1):     0.0698276     device_current
I(V2):     -0.012931     device_current
I(V1):     -0.0698276    device_current
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- **Calculations**

KVL in loop ①: $\Sigma V_{Active} = \Sigma V_{passive}$

$V_3 = 100 I_1$

$V_6 = 50(I_1 + I_2)$

$$V_1 = V_3 + V_6$$
$$10 = 100I_1 + 50(I_1+I_2)$$
$$\Rightarrow 150I_1 + 50I_2 = 10$$
$$\Rightarrow \boxed{15I_1 + 5I_2 = 1} - ①$$

KVL in loop ②: $\Sigma V_{Active} = \Sigma V_{passive}$

$$V_7 = V_4 + V_6$$

$V_7 = -50(I_2 + I_3)$

$$-50(I_2+I_3) = 200I_2 + 50(I_1+I_2)$$

$V_4 = 200 I_2$

$$300I_2 + 50I_1 + 50I_3 = 0$$
$$\boxed{I_1 + 6I_2 + I_3 = 0} - ②$$

KVL in loop ③: $\Sigma V_{active} = \Sigma V_{passive}$

$$V_7 = V_5 + V_2$$

$V_5 = 300 I_3$

$$-50(I_2+I_3) = 300I_3 + 5$$

$$50I_2 + 350I_3 = -5$$
$$\Rightarrow \boxed{10I_2 + 70I_3 = -1} - ③$$

From ②

$I_1 = -I_3 - 6I_2$

Substituting I_1 in ①:

$-15I_3 - 90I_2 + 5I_2 = 1$

$\Rightarrow 85I_2 + 15I_3 = -1$ —④

From ③ and ④

$850I_2 + 150I_3 = -10$

$(-)850I_2 \overset{(-)}{+} 5950I_3 = (+)85$

$-5800I_3 = 75$

$\Rightarrow I_3 = \frac{-75}{5800} = -0.01293A$

$\boxed{I_3 = -12.93\text{ mA}}$

Now from ③,

$70\left(\frac{-75}{5800}\right) + 10I_2 = -1$

$\Rightarrow 10I_2 = -1 + \frac{525}{580}$

$\Rightarrow I_2 = \frac{-55}{5800} = -0.0094827\text{ A}$

$\Rightarrow \boxed{I_2 = -9.483\text{ mA}}$

Now from ①

$I_1 = -I_3 - 6I_2$

$= \frac{75}{5800} + \frac{55\times6}{5800}$

$\Rightarrow I_1 = \frac{405}{5800} = 0.069827A$

$\Rightarrow \boxed{I_1 = 69.8\text{ mA}}$

$\rightarrow V_1 = 10V = V_a$

$\rightarrow V_2 = 5V = V_c$

$\rightarrow V_3 = 100 I_1$

$= 100(0.069827)$

$\boxed{V_3 = 6.98V}$

$\rightarrow V_4 = 200 I_2$

$= 200(-0.0094827)$

$\boxed{V_4 = -1.896V}$

$\rightarrow V_5 = 300 I_3$

$= 300(-0.01293)$

$\boxed{V_5 = -3.879V}$

$\rightarrow V_6 = 50(I_1 + I_2)$

$= 50(0.069827 - 0.0094827)$

$= 50(0.0603443)$

$\boxed{V_6 = 3.0172V} = V_e$

$\rightarrow V_7 = -50(I_2 + I_3)$

$= -50(-0.0094827 - 0.01293)$

$\boxed{V_7 = 1.12V} = V_f$

$\rightarrow I_{R_1} = I_1 = 0.0698A$

$\rightarrow I_{R_2} = I_2 = -0.009483A$

$\rightarrow I_{R_3} = I_3 = -0.01293A$

$\rightarrow I_{R_4} = I_1 + I_2 = 0.069827 - 0.0094827$

$\boxed{I_{R_4} = 0.06034A}$

$\rightarrow \; I_{R_5} = (I_2 + I_3)$

$= -(0.0094827 + 0.01293)$

$= -0.02241 \, A$

$\Rightarrow \boxed{I_{R_5} = -0.02241 A}$

$\rightarrow \; I_{V_1} = -I_1 = -0.06983 A$

$\rightarrow \; I_{V_2} = I_3 = -0.01293 A$

<u>Power dissipated:</u>

$P_{R_1} = I_1 \times V_3$

$= 0.487589 \, W$

$\Rightarrow \boxed{P_{R_1} = 0.488 W}$

$P_{R_2} = I_2 \times V_4$

$= 0.017984 \, W$

$\Rightarrow \boxed{P_{R_2} = 0.018 W}$

$P_{R_3} = I_3 \times V_5$

$= 0.050163 \, W$

$\Rightarrow \boxed{P_{R_3} = 0.05 W}$

$P_{R_4} = I_{R_4} V_6$

$= 0.182074$

$\Rightarrow \boxed{P_{R_4} = 0.182 W}$

$P_{R_5} = -I_{R_5} V_7$

$= 0.0251189 \, W$

$\Rightarrow \boxed{P_{R_5} = 0.025 W}$

$P_{V_1} = -I_1 V_1$

$= -0.698276 \, W$

$\Rightarrow \boxed{P_{V_1} = -0.698 W}$

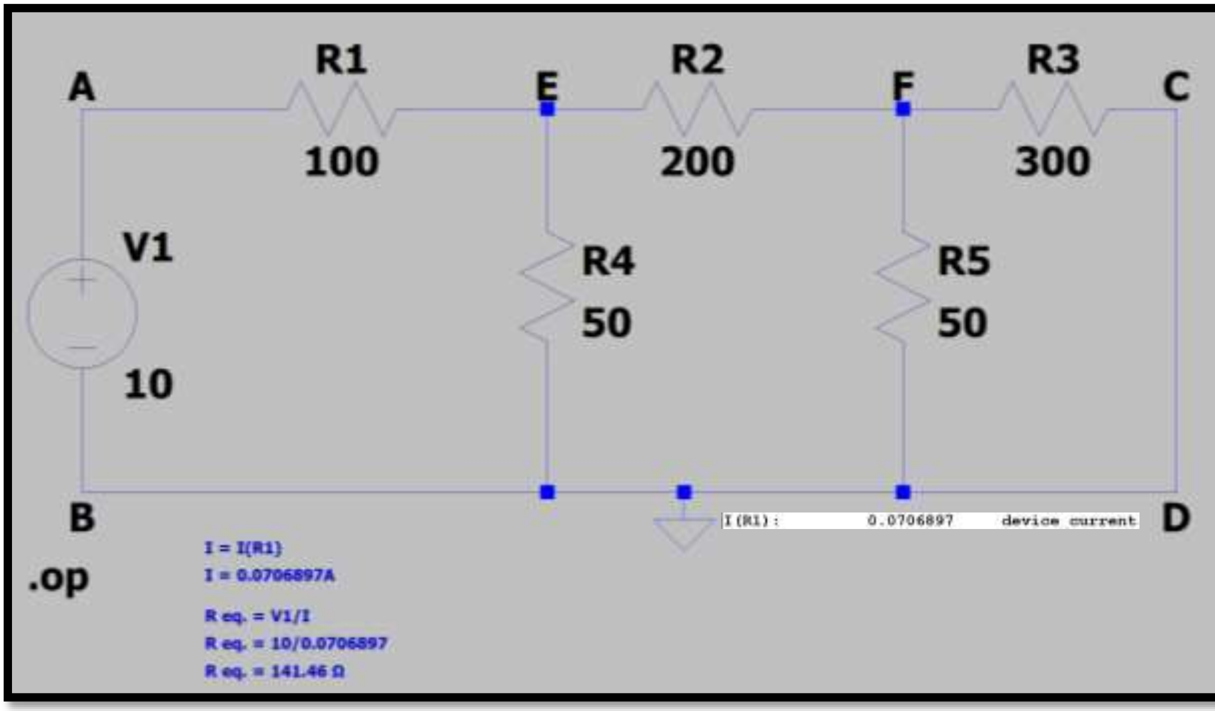
$P_{V_2} = I_3 V_2$

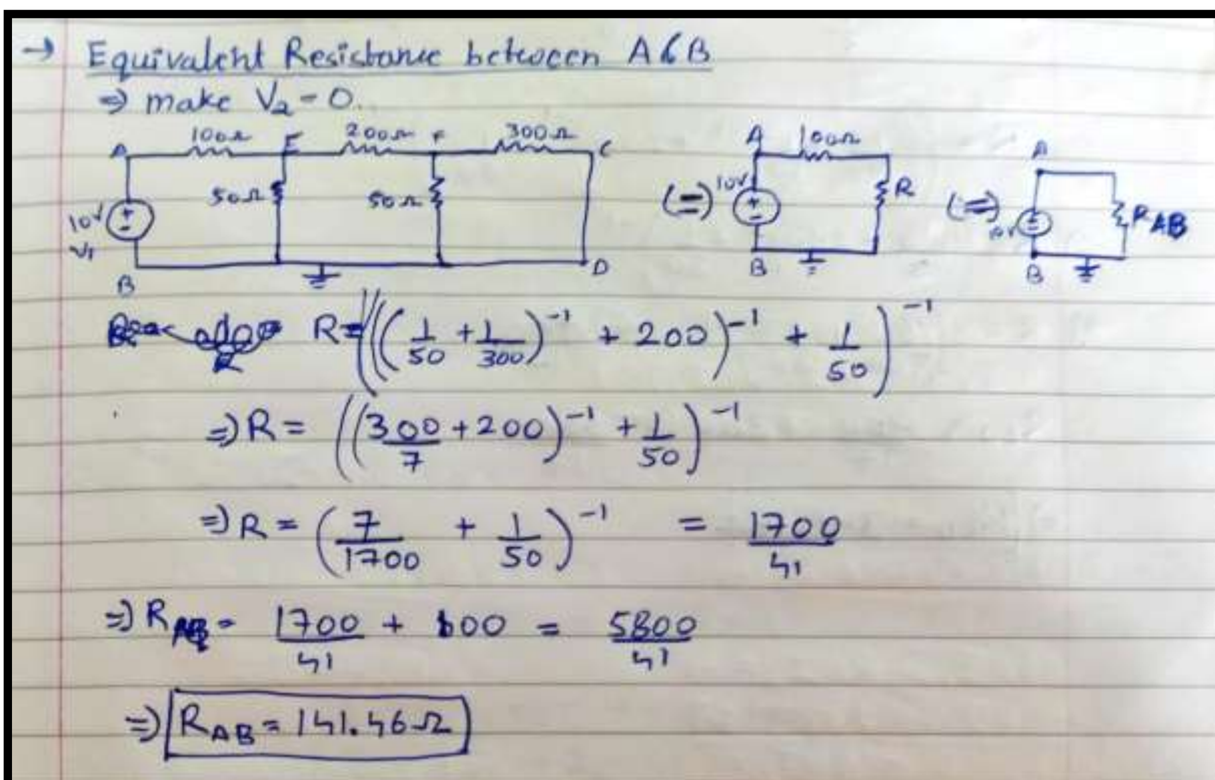
$= -0.064655 \, W$

$\Rightarrow \boxed{P_{V_2} = -0.064 W}$

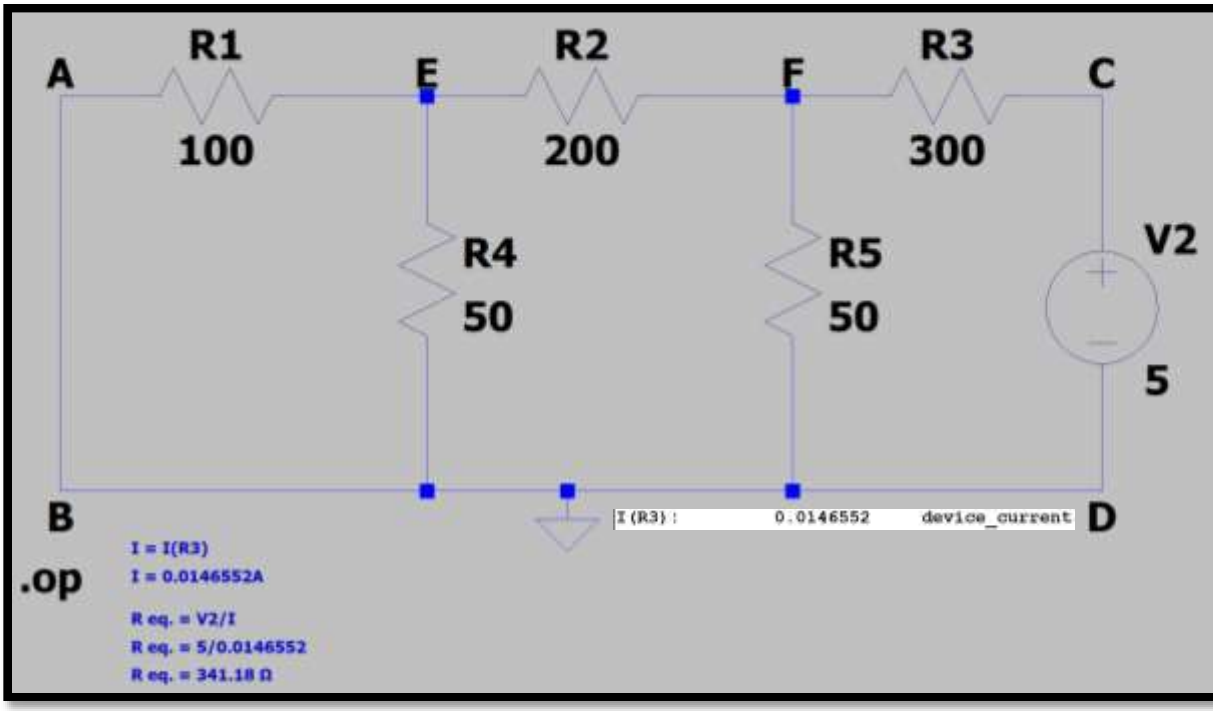
2. Compute Equivalent Resistance between different nodes

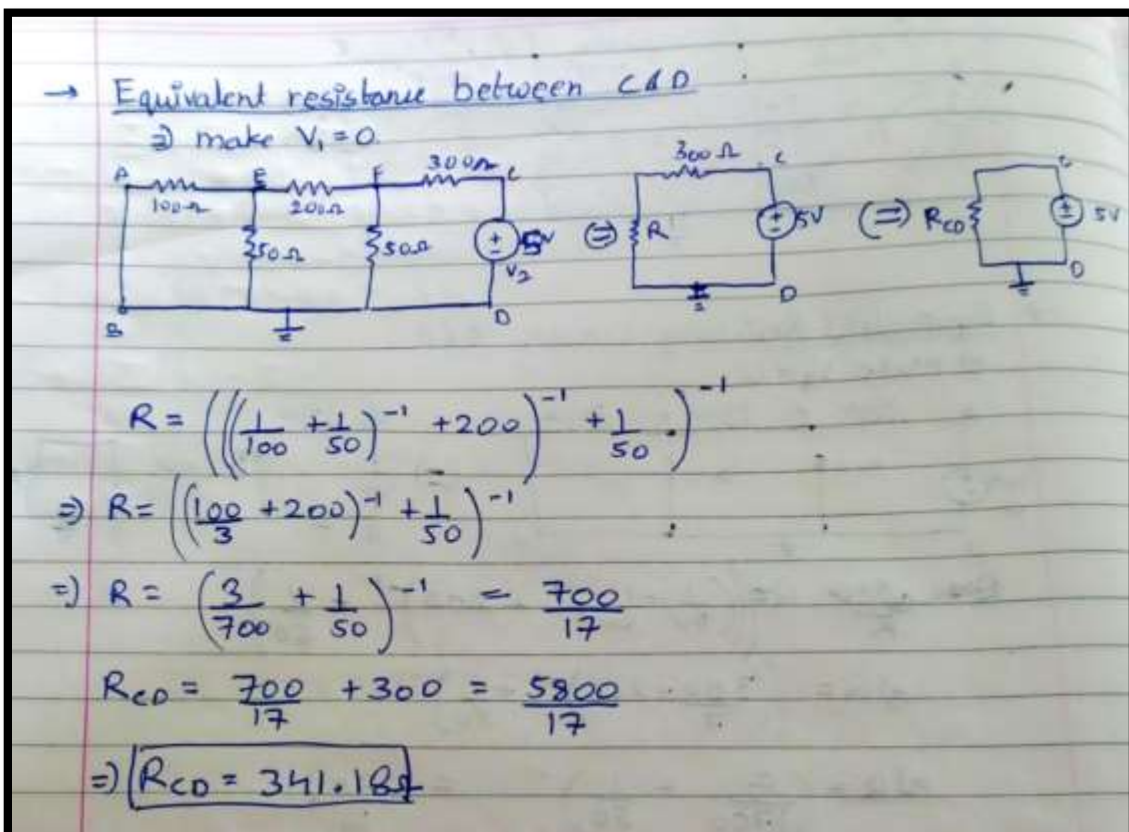
a-b





c-d





→ Equivalent resistance between C & D

⇒ make $V_1 = 0$.

$$R = \left(\left(\left(\frac{1}{100} + \frac{1}{50}\right)^{-1} + 200\right)^{-1} + \frac{1}{50}\right)^{-1}$$

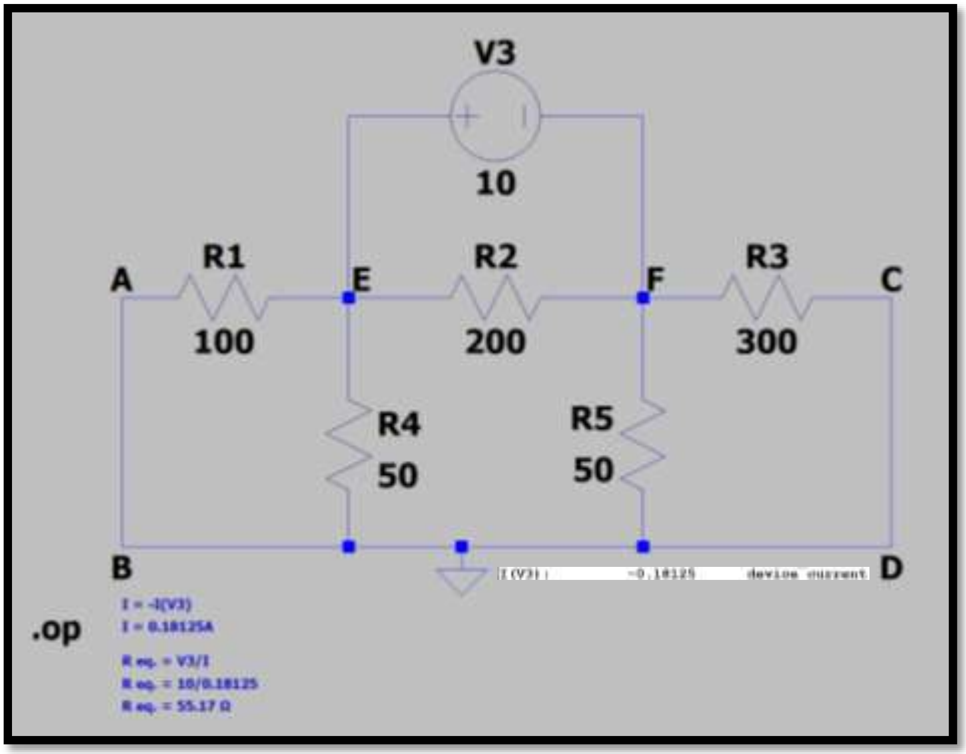
$$\Rightarrow R = \left(\left(\frac{100}{3} + 200\right)^{-1} + \frac{1}{50}\right)^{-1}$$

$$\Rightarrow R = \left(\frac{3}{700} + \frac{1}{50}\right)^{-1} = \frac{700}{17}$$

$$R_{CD} = \frac{700}{17} + 300 = \frac{5800}{17}$$

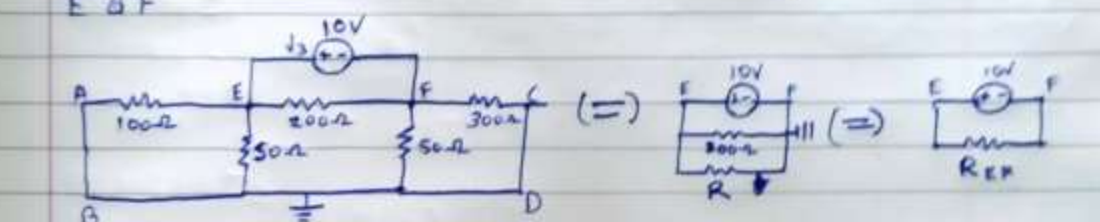
$$\Rightarrow \boxed{R_{CD} = 341.18\,\Omega}$$

e-f



→ Equivalent resistance between E & F

⇒ make $V_1 = 0$, $V_2 = 0$ and put independent voltage source V_3 between E & F



$$R = \left(\left(\frac{1}{100} + \frac{1}{50} \right)^{-1} + \left(\frac{1}{300} + \frac{1}{50} \right)^{-1} \right)^{-1}$$

$$\Rightarrow R = \frac{100}{3} + \frac{300}{7} = \frac{1600}{21}$$

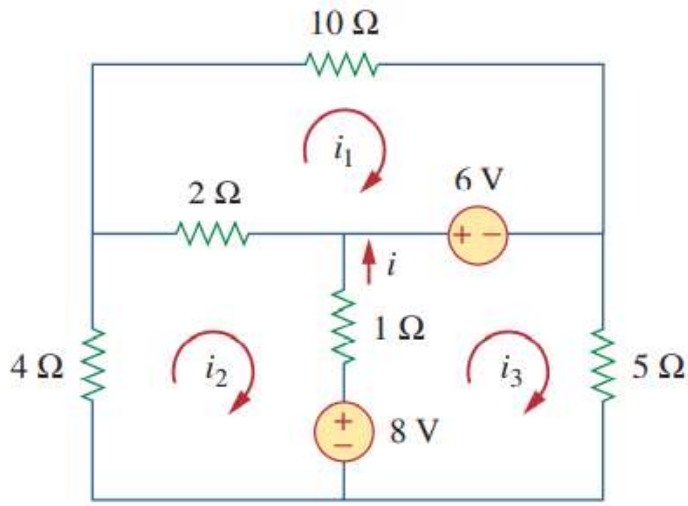
$$R_{EF} = \frac{21}{1600} + \frac{1}{200}$$

$$\Rightarrow R_{EF} = \frac{1600}{29}$$

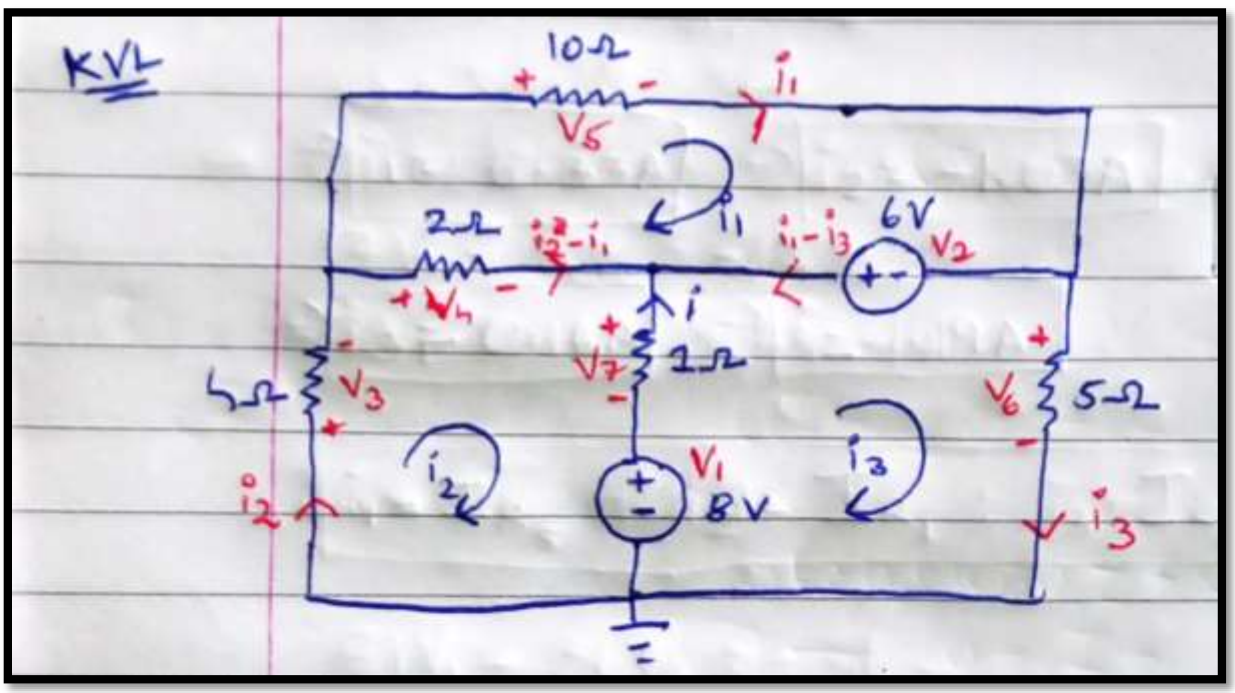
$$\Rightarrow \boxed{R_{EF} = 55.17\,\Omega}$$

Do it yourself:

For the circuit given below, Verify KVL, KCL, Nodal Analysis and Mesh Analysis using LTSpice and TinkerCAD



1) **KVL – Mesh Analysis**



KVL in loop 1: $V_{active} = V_{passive}$

$$V_4 + V_2 = V_5$$

$$2(i_2 - i_1) + 6 = 10 i_1$$

$$\Rightarrow 12 i_1 - 2 i_2 = 6$$

$$\Rightarrow \boxed{6 i_1 - i_2 = 3} - (1)$$

$V_4 = 2(i_2 - i_1)$

$V_5 = 10(i_1)$

KVL in loop 2 :- $V_{active} = V_{passive}$

$$0 = V_3 + V_4 + V_7 + V_1$$

$$0 = 4 i_2 + 2(i_2 - i_1) - (i_3 - i_2) + 8$$

$$\Rightarrow \boxed{2 i_1 - 7 i_2 + i_3 = 8} - (2)$$

$V_7 = -i(1)$

$i = (i_3 - i_2)$

KVL in loop 3: $V_{active} = V_{passive}$

$$V_1 + V_7 = V_2 + V_6$$

$$8 - (i_3 - i_2) = 6 + 5 i_3$$

$$\Rightarrow \boxed{6 i_3 - i_2 = 2} - (3)$$

$V_6 = 5(i_3)$

→ From (2).

$$i_3 = 8 - 2 i_1 + 7 i_2$$

→ Substituting i_3 in (3)

$$\boxed{-12 i_1 + 41 i_2 = -46 - (4)}$$

From (1) and (4)

$$246 i_1 - 41 i_2 = 123$$

$$-12 i_1 + 41 i_2 = -46$$

$$234 i_1 = 77$$

$$\Rightarrow i_1 = \frac{77}{234}$$

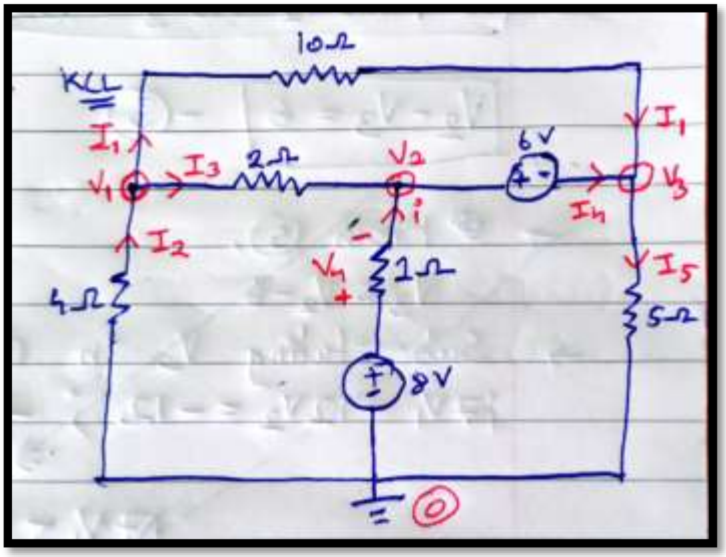
$$\Rightarrow \boxed{i_1 = 0.32906A}$$

$\Rightarrow \boxed{i_1 = 0.33A}$ $\Rightarrow \boxed{i_2 = -1.03A}$

$\Rightarrow \boxed{i_3 = 0.16A}$ $\Rightarrow \boxed{i = 1.19A}$

$$\boxed{i_1 = I_{R_5} \ ; \ i_2 = I_{R_1} \ ; \ i_3 = I_{R_3}}$$

2) KCL – Nodal Analysis



KCL at node ①: $\Sigma I_{entering} = \Sigma I_{leaving}$

$$I_2 = I_1 + I_3$$

$$\frac{-V_1}{4} = \frac{V_1 - V_3}{10} + \frac{V_1 - V_2}{2}$$

$$\Rightarrow -5V_1 = 2V_1 - 2V_3 + 10V_1 - 10V_2$$

$$\Rightarrow \boxed{17V_1 - 10V_2 - 2V_3 = 0 \quad -①}$$

KCL at node ②: $\Sigma I_{entering} = \Sigma I_{leaving}$

$$I_3 + i = I_4 \quad -②$$

KCL at node ③: $\Sigma I_{entering} = \Sigma I_{leaving}$

$$I_4 + I_1 = I_5$$

$$\Rightarrow I_4 = I_5 - I_1 \quad -③$$

From ② and ③

$$I_3 + i = I_5 - I_1 \qquad V_4 = 8 - V_2$$

$$\frac{V_1 - V_2}{2} + \frac{V_4}{1} = \frac{V_3}{5} - \left(\frac{V_1 - V_3}{10}\right)$$

$$\Rightarrow \frac{V_1 - V_2}{2} + \frac{8 - V_2}{1} = \frac{V_3}{5} - \left(\frac{V_1 - V_3}{10}\right)$$

$$\Rightarrow 5V_1 - 5V_2 + 80 - 10V_2 = 2V_3 - V_1 + V_3$$

$$\Rightarrow \boxed{-6V_1 + 15V_2 + 3V_3 = 80} \quad - (5)$$

$$\boxed{V_2 - V_3 = 6} \quad - (5)$$

From (5), $V_3 = V_2 = 6$

$\rightarrow$ Substituting V_3 in (1) and (4)

$$17V_1 - 12V_2 = -12 \quad - (6)$$

$$-3V_1 + 9V_2 = 49 \quad - (7)$$

From (6) and (7),

$$51V_1 - 36V_2 = -36$$

$$-51V_1 + 153V_2 = 797$$

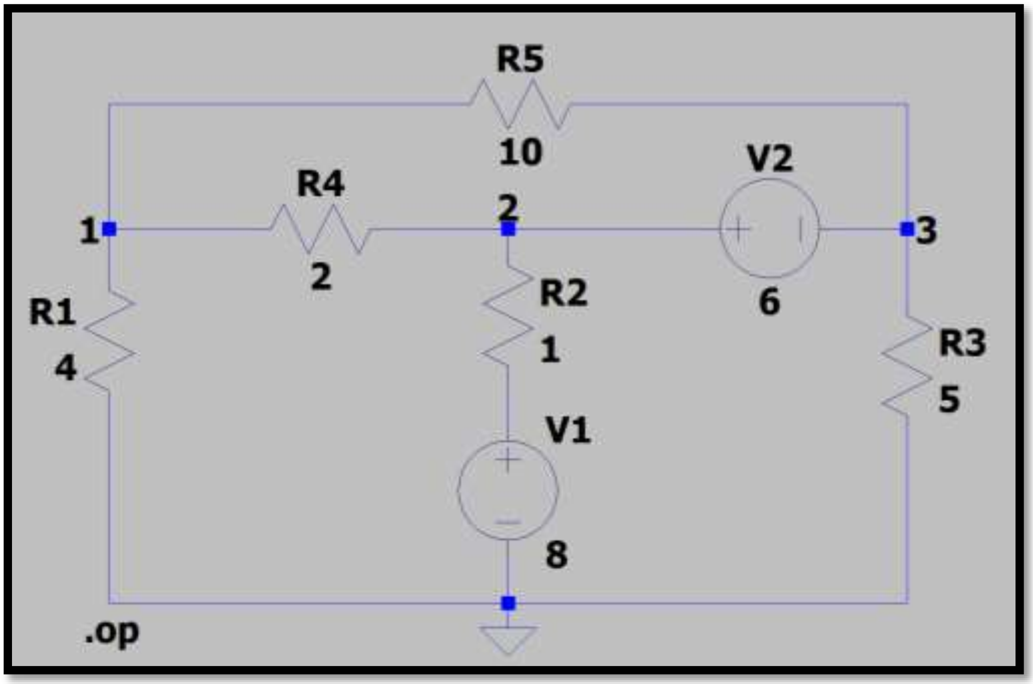
$$117V_2 = 797$$

$$\Rightarrow V_2 = \frac{797}{117}$$

$$\Rightarrow \boxed{V_2 = 6.81V} \quad \Rightarrow \boxed{V_3 = 0.81V}$$

$$\Rightarrow \boxed{V_1 = 4.10V} \quad \Rightarrow \boxed{i = 8 - V_2 = 1.19A}$$

3) **LTSpice**

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        --- Operating Point ---

V(1):              4.10256         voltage
V(2):              6.81197         voltage
V(4):              8               voltage
V(3):              0.811966        voltage
I(R5):             0.32906         device_current
I(R4):             1.3547          device_current
I(R3):             0.162393        device_current
I(R2):             -1.18803        device_current
I(R1):             -1.02564        device_current
I(V2):             -0.166667       device_current
I(V1):             -1.18803        device_current
```

4) TinkerCAD