EEEE1028 Power and Energy

Coursework 1

Investigating Kirchhoff's Voltage Law and Resistor Combinations

Academic year: 2020 / 2021

Prepared by:

DEREK CHEEN XIN HEE

(20317350)

Circuit 1: Simple Resistor Circuit

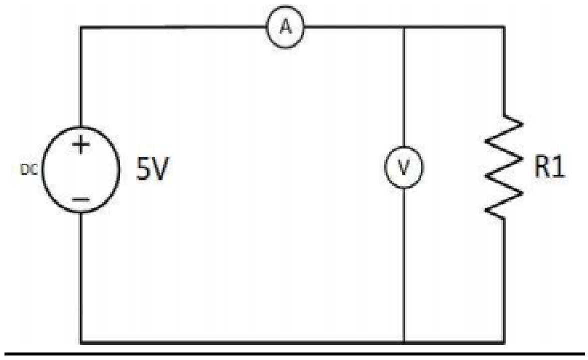

Figure 1 Circuit 1

Question 1

a) The effective resistance of the ammeter is very near to zero. Ideally, the resistance of an ammeter should be zero. Ammeter measures the amount of current flow in an electronic circuit, and it should always be connected in series with the circuit. According to Ohm's law, if the resistance of an ammeter is high, the current flowing through the circuit will be low. As such, the resistance of the ammeter must be very low or near to zero so that it would not affect the amount of current flowing in the circuit.

b) The effective resistance of the voltmeter is very high. Ideally, the resistance of a voltmeter should be an infinite value. Voltmeter measures the potential difference between two points in an electronic circuit, and it should always be connected in parallel with the circuit. The resistance must be very high so that it only very little amount of current can pass through it.

Question 2

Value of resistance require for circuit 1 to have a supply current of 23mA:

By applying Ohm's law,

$$\boldsymbol{R} = \frac{V}{I}$$

$$= \frac{5}{(23 * 10^{-3})}$$

$$= \mathbf{217.39}\ \Omega$$

Using PLECs simulation to check the calculated value:

When the resistance in Circuit 1, R1=217.39Ω, the current measured, I1=23mA, as shown in Figure 2.1 and Figure 2.2. The calculated value is the same as the simulated value.

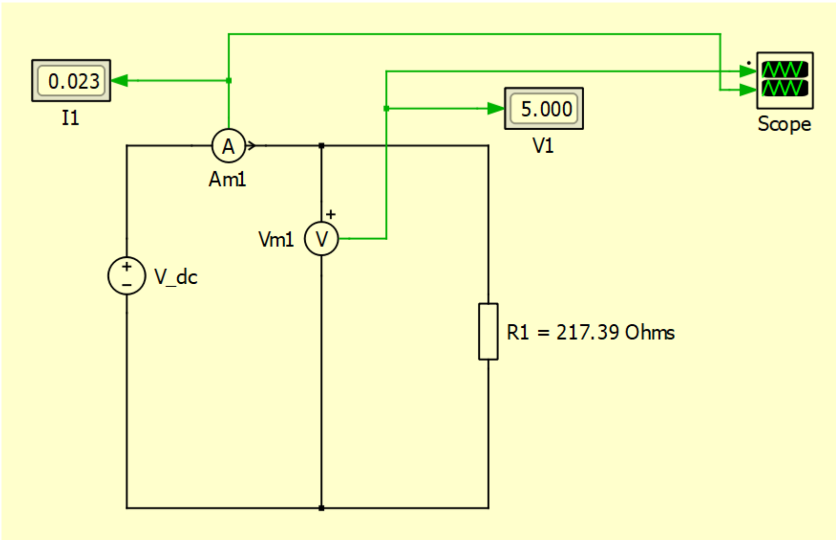

Figure 2.1 Circuit 1

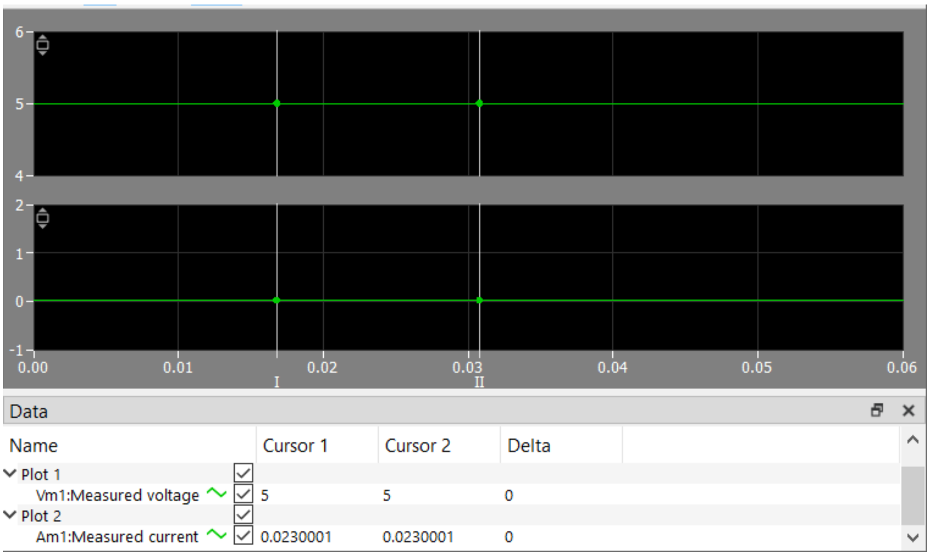

Figure 2.2 Reading of Vm1 and Am1

Question 3

From PLECs simulation, Vm1 measured is 5V and Im1 measured is 0.5A as shown in Figure 3.1 and Figure 3.2.

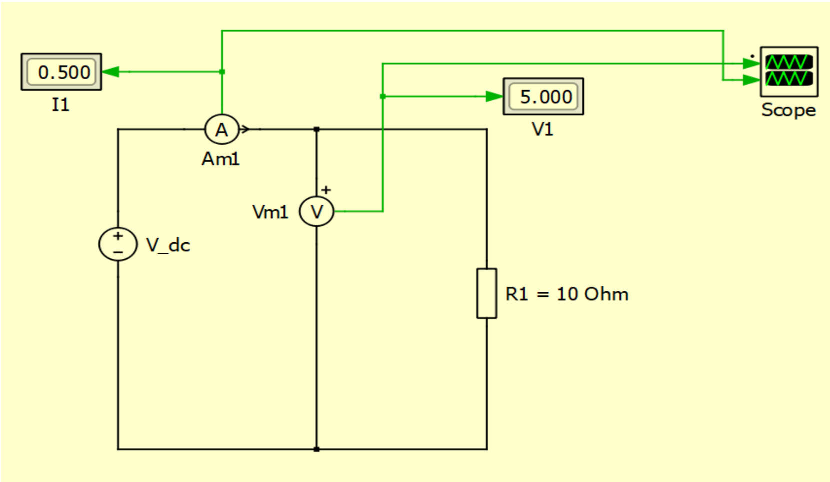

Figure 3.1 Circuit 1

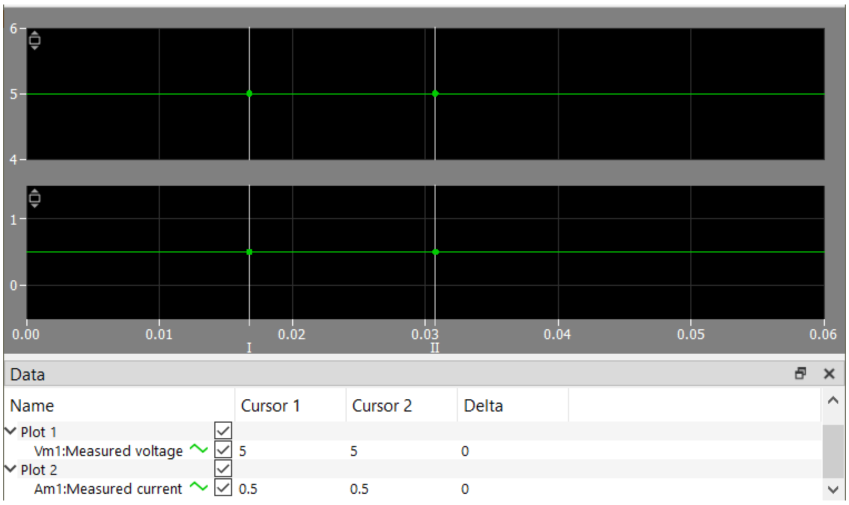

Figure 3.2 Readings of Vm1 and Am1

<u>Checking whether the values obtained follow Ohm's law:</u>

$$I = \frac{V}{R}$$

$$= \frac{5}{10}$$

$$= 0.5A$$

<u>Conclusion:</u>

The value of current calculated using Ohm's law is the same as the value of current obtained from the PLECs simulation. Thus, these **measurements follow Ohm's law**.

Question 4

$$\boldsymbol{P_{min}} = I^2R$$

$$= (23 * 10^{-3})^2\ (217.39)$$

$$= \mathbf{0.115}\boldsymbol{W}$$

The minimum required power rating of the resistor is 0.115Watt.

Circuit 2: Series-parallel Circuit

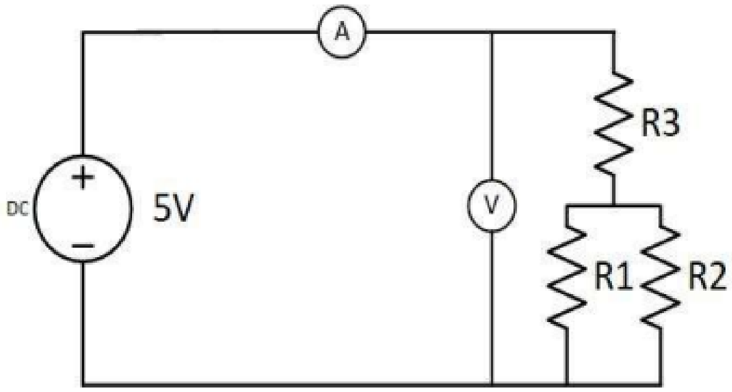

Figure 4 Circuit 2

Question 5

Total resistance of R_1 and R_2 :

$$R_1//R_2 = \left(\frac{1}{40} + \frac{1}{20}\right)^{-1}$$

$$= 13.33\Omega$$

Total resistance in the circuit:

$$R_{total} = R_1//R_2 \ + \ R_3$$

$$= 13.333 + 30$$

$$= 43.333\Omega$$

Current I_3 passing through R_3 :

$$\mathbf{I_3} = \frac{v}{R_{total}}$$

$$= \frac{5}{43.333}$$

$$= \mathbf{0.1154}\ \boldsymbol{A}$$

Using current divider rule to calculate I_1 and I_2:

$$\mathbf{I_2} = \left(\frac{R_1}{R_1 + R_2}\right)(I_3)$$

$$= \left(\frac{40}{40 + 20}\right)(0.1154)$$

$$= \mathbf{76.93}\boldsymbol{mA}$$

$$\mathbf{I_1} = \left(\frac{R_2}{R_1 + R_2}\right)(I_3)$$

$$= \left(\frac{20}{40 + 20}\right)(0.1154)$$

$$= \mathbf{38.47}\boldsymbol{mA}$$

Calculating voltage across R_1 , R_2 and R_3 :

$$\mathbf{V_{R1}} = (I_1)(R_1)$$

$$= (0.03847)(40)$$

$$= \mathbf{1.539}\ \boldsymbol{V}$$

$$\mathbf{V_{R2}} = (I_2)(R_2)$$

$$= (0.07693)(20)$$

$$= \mathbf{1.539}\ \boldsymbol{V}$$

$\mathbf{V_{R1}}$ and V_{R2} is the same because R_1 and R_2 are connected in parallel:

$$\mathbf{V_{R3}} = (I_3)(R_3)$$

$$= (0.1154)(30)$$

$$= \mathbf{3.462}\ \boldsymbol{V}$$

Question 6

The values of currents and voltages obtained from the simulation are shown in Figure 5.1, Figure 5.2, Figure 5.3, Table 1.1 and Table 1.2.

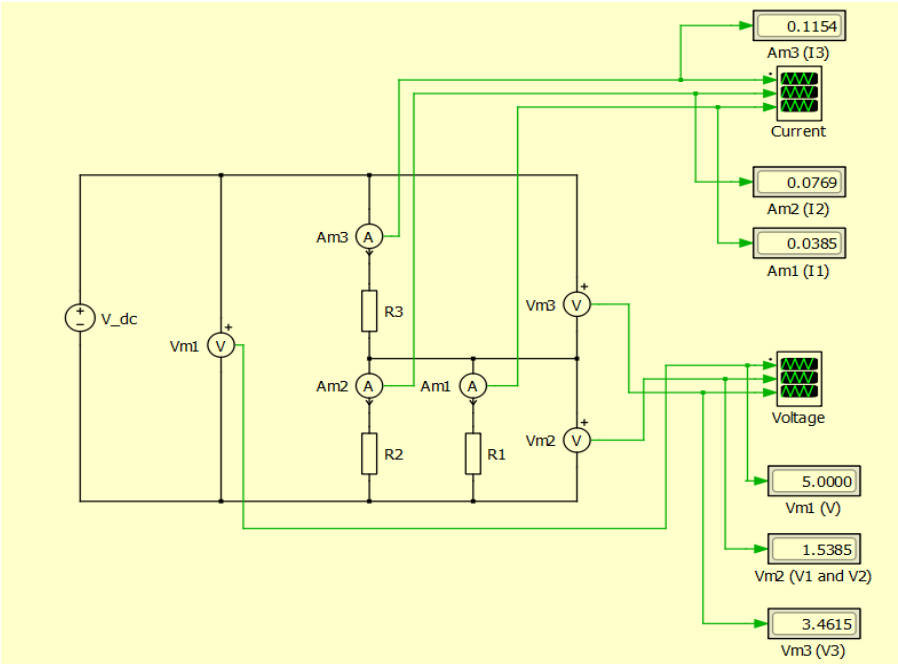

Figure 5.1 Circuit 2

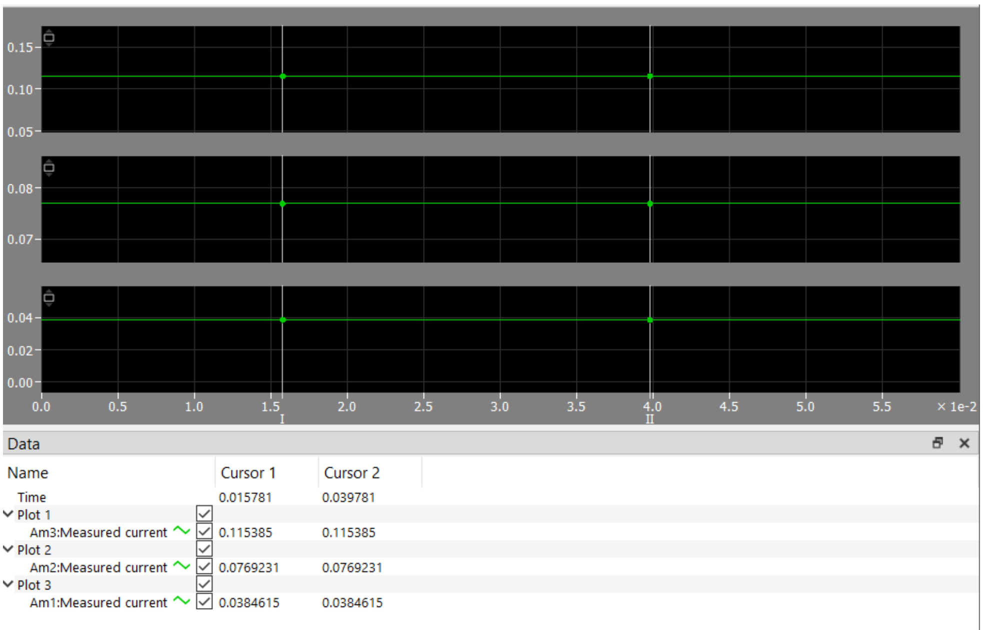

Figure 5.2 Currents, I_1, I_2 and I_3

measured by Vm1, Vm2 and Vm3 respectively

Figure 5.3 Voltages, V, V_{R1}, V_{R2} and V_{R3}

measured by Vm1, Vm2 and Vm3

Data collected in table form:

Ammeter	Current	Readings (A)
Am1	I_1	0.0385
Am2	I_2	0.0769
Am3	I_3	0.1154

Table 1.1 Currents measured

Voltmeter	Voltage	Readings (V)
Vm1	V	5.0000
Vm2	V_1 & V_2	1.5385
Am3	V_3	3.4615

Table 1.2 Voltages measured

Conclusion:

After comparing the results, it can be concluded that the results obtained from the simulation **matches** my calculated predictions.

A slight difference is that the values obtained from my calculations were rounded up to 3 decimal places whereas the values obtained from the simulation include more decimal places.

Circuit 3: Series – Parallel – Series Circuit

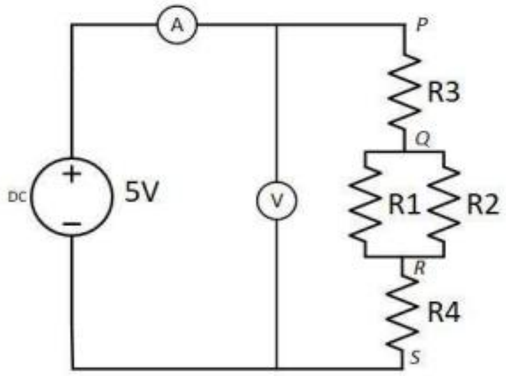

Figure 6 Circuit 3

Question 7

Total resistance of R_1 , R_2 and R_3 is calculated above:

$R_{1,2,3} = 43.333\Omega$

Value of R4 required to reduce the supply current to 50mA:

$$R_{total} = \frac{V}{I}$$

$$R_{1,2,3} + R_4 = \frac{V}{I}$$

$$43.333 + R_4 = \frac{5}{50*10^{-3}}$$

$$\boldsymbol{R_4} = \frac{5}{50*10^{-3}} - 43.333$$

$$= \mathbf{56.667}\Omega$$

Supply current (I_s), is equal to current in R3 and R4:

$I_s = \boldsymbol{I_3} = \boldsymbol{I_4} = \mathbf{50}\boldsymbol{mA}$

Using current divider rule to calculate I_1 and I_2:

$$\boldsymbol{I_1} = \frac{R_2}{R_1 + R_2}(I_s)$$

$$= \frac{20}{40 + 20}(50 * 10^{-3})$$

$$= \mathbf{0.01667}\boldsymbol{A}$$

$$\boldsymbol{I_2} = \frac{R_1}{R_1 + R_2}(I_s)$$

$$= \frac{40}{40 + 20}(50 * 10^{-3})$$

$$= \mathbf{0.03333}\boldsymbol{A}$$

<u>Calculating voltages across each resistor:</u>

Voltage across R_1 and R_2 is the same since they are connected in parallel:

$$\boldsymbol{V_{QR}} = \boldsymbol{V_1} = \boldsymbol{V_2} = I_2 R_2$$

$$= (0.03333)(20)$$

$$= \mathbf{0.6666}\boldsymbol{V}$$

Voltage across R_3:

$$\boldsymbol{V_{PQ}} = \boldsymbol{V_3} = I_3 R_3$$

$$= (50 * 10^{-3})(30)$$

$$= \mathbf{1.5}\boldsymbol{V}$$

Voltage across R_4:

$$\boldsymbol{V_{RS}} = \boldsymbol{V_4} = I_4 R_4$$

$$= (50 * 10^{-3})(56.667)$$

$$= \mathbf{2.8334}\boldsymbol{V}$$

Measurements obtained from simulation are shown in Figure7.1, Figure7.2 and Figure7.3

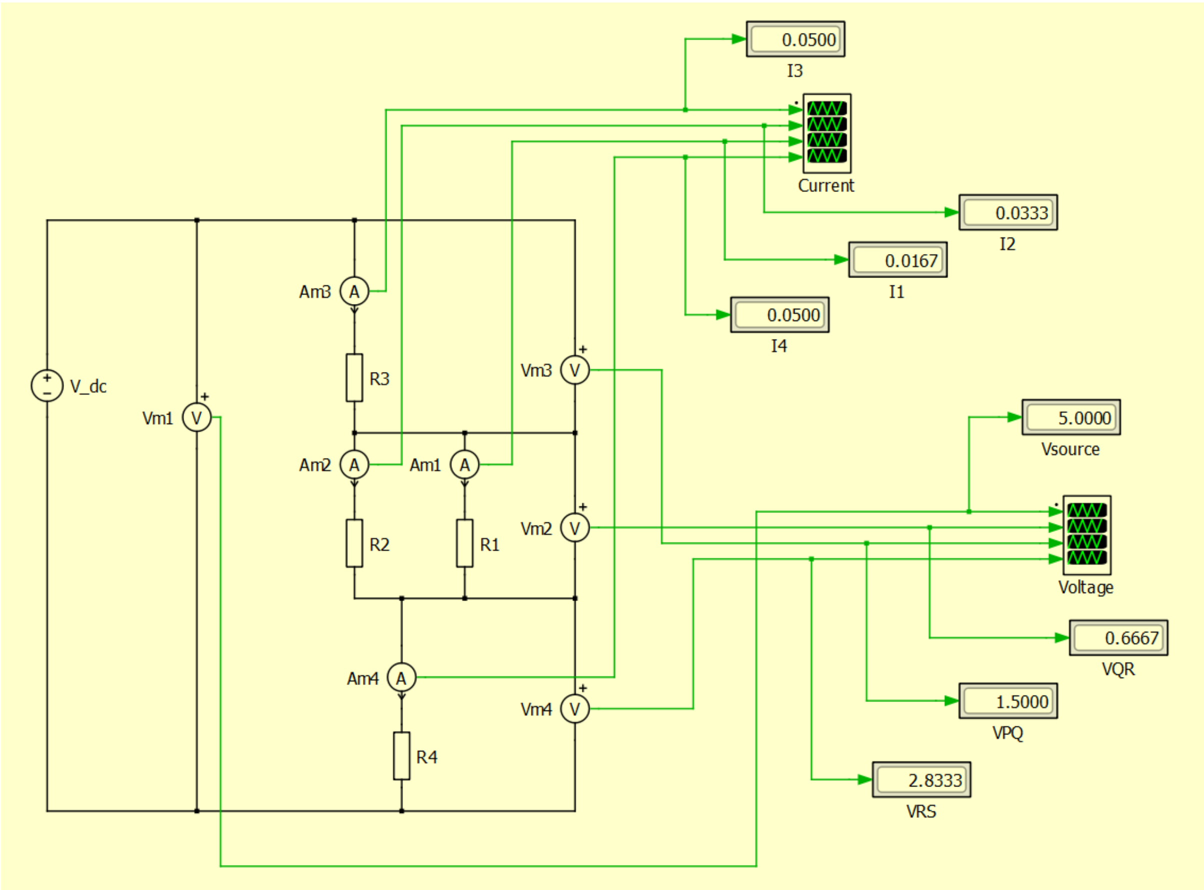

Figure7.1 Circuit 3

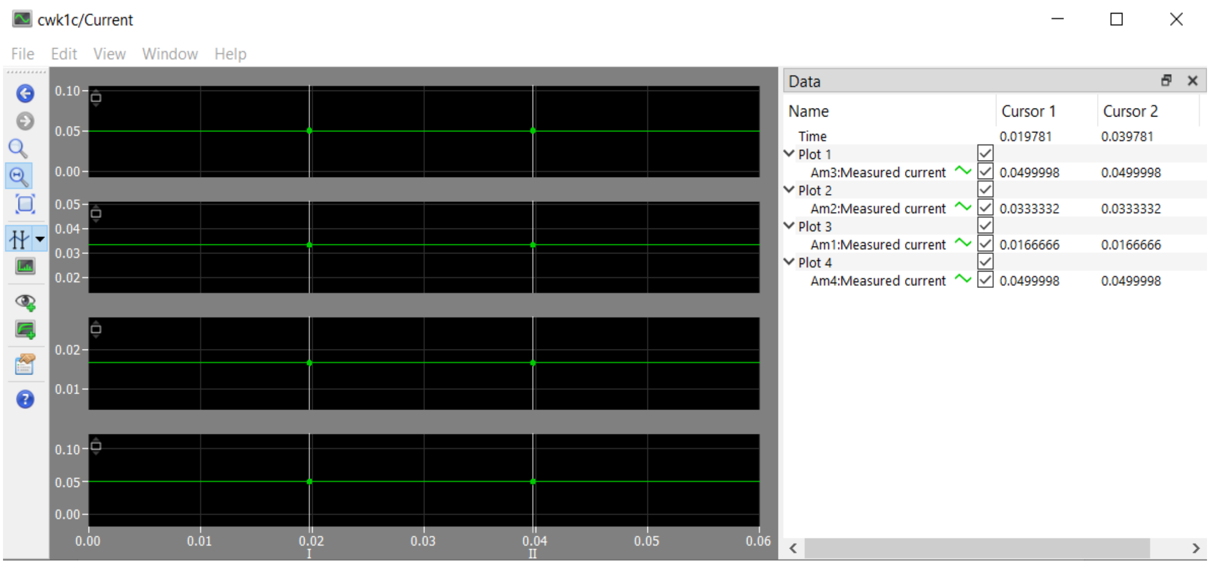

Figure7.2 Currents I_1, I_2, I_3 and I_4

measured by Am1, Am2, Am3 and Am4 respectively

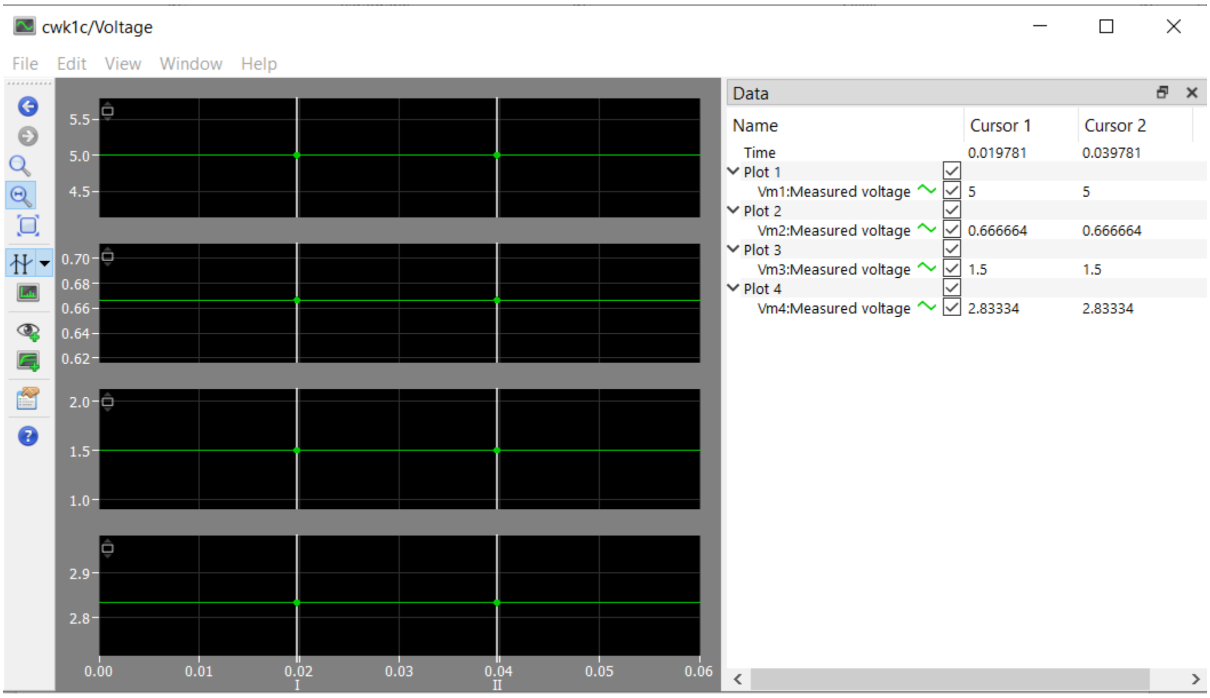

Figure7.3 Voltages V_{source}, V_{QR}, V_{PQ} and V_{RS}

measured by Vm1, Vm2, Vm3 and Vm4 respectively

Question 8

By Kirchhoff's Voltage Law:

$$V_{source} = V_{PQ} + V_{QR} + V_{RS}$$

$$V_{source} = 5V$$

$$V_{PQ} + V_{QR} + V_{RS}$$

$$= 1.5 + 0.667 + 2.833$$

$$= 5V$$

The measurements obtained follows Kirchhoff's Voltage Law.

By voltage divider rule:

$$\boldsymbol{V_{PQ}} = \frac{R_3}{R_{total}}(V_{source})$$

$$= \frac{30}{100}(5)$$

$$= \mathbf{1.5}\boldsymbol{V}$$

$$\boldsymbol{V_{QR}} = \frac{R_{1,2}}{R_{total}}(V_{source})$$

$$= \frac{13.333}{100}(5)$$

$$= \mathbf{0.667}\boldsymbol{V}$$

$$\boldsymbol{V_{RS}} = \frac{R_4}{R_{total}}(V_{source})$$

$$= \frac{56.667}{100}(5)$$

$$= \mathbf{2.833}\boldsymbol{V}$$

Question 9

1) The potential of nodes P, Q, R and S.

$$\boldsymbol{V_P} = V_{source} = \mathbf{5.00}\boldsymbol{V}$$

$$\boldsymbol{V_Q} = V_P - V_{PQ}$$

$$= 5 - 1.5$$

$$= \mathbf{3.5}\boldsymbol{V}$$

$$\boldsymbol{V_R} = V_P - V_{PQ} - V_{QR}$$

$$= 5 - 1.5 - 0.667$$

$$= \mathbf{2.833}\boldsymbol{V}$$

$V_S = 0$ since it is the ground point. To prove it mathematically:

$$\boldsymbol{V_S} = V_P - V_{PQ} - V_{QR} - V_{Rs}$$

$$= 5 - 1.5 - 0.667 - 2.833 - 2.833$$

$$= \mathbf{0}\boldsymbol{V}$$

2) Voltage between nodes P and R:

$$\boldsymbol{V_{PR}} = V_P - V_R$$

$$= 5 - 2.833$$

$$= \mathbf{2.167}\boldsymbol{V}$$

3) Potential difference between nodes S and Q:

$$\boldsymbol{V_{SQ}} = V_S - V_Q$$

$$= 0 - 3.5$$

$$= \mathbf{-3.5}\boldsymbol{V}$$

The magnitude of potential difference between nodes S and Q is $3.5V$.

Question 10

$$\boldsymbol{V_{QR}} = V_Q - V_R$$

$$= 3.5 - 2.833$$

$$= \mathbf{0.667}\boldsymbol{V}$$

Circuit 5: Dual Supply Circuit

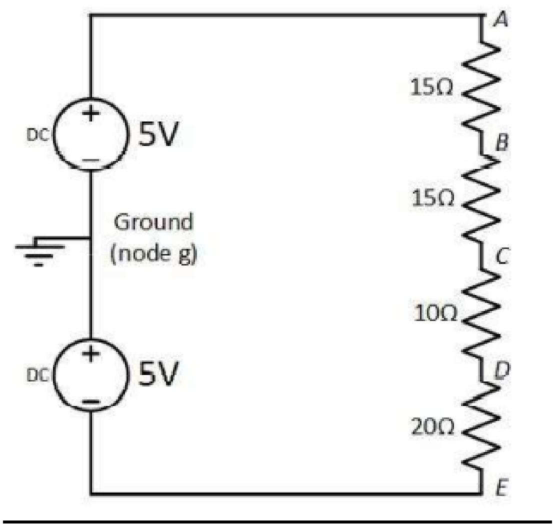

Figure 8 Circuit 5

Question 11

Calculating V_{AB}, V_{Bc}, V_{CD} and V_{DE} :

$V_{total} = 10V$

$$R_{total} = R_{AB} + R_{Bc} + R_{CD} + R_{DE}$$
$$= 15 + 15 + 10 + 20$$
$$= 60\Omega$$

By voltage divider rule:

$$\boldsymbol{V_{AB}} = \frac{R_{AB}}{R_{total}}(V_{total})$$
$$= \frac{15}{60}(10)$$
$$= \mathbf{2.5}\boldsymbol{V}$$

$$\boldsymbol{V_{BC}} = \frac{R_{BC}}{R_{total}}(V_{total})$$
$$= \frac{15}{60}(10)$$
$$= \mathbf{2.5}\boldsymbol{V}$$

$$\boldsymbol{V_{CD}} = \frac{R_{CD}}{R_{total}}(V_{total})$$

$$= \frac{10}{60}(10)$$

$$= \mathbf{1.6667}\boldsymbol{V}$$

$$\boldsymbol{V_{DE}} = \frac{R_{DE}}{R_{total}}(V_{total})$$

$$= \frac{20}{60}(10)$$

$$= \mathbf{3.3333}\boldsymbol{V}$$

Calculating V_{EC} :

$$V_{CE} = V_{CD} + V_{DE}$$

$$= 1.6667 + 3.3333$$

$$= 5V$$

$$\boldsymbol{V_{EC}} = -V_{CE}$$

$$= -\mathbf{5}\boldsymbol{V}$$

Measurements obtained from the simulation is shown in Figure 9.

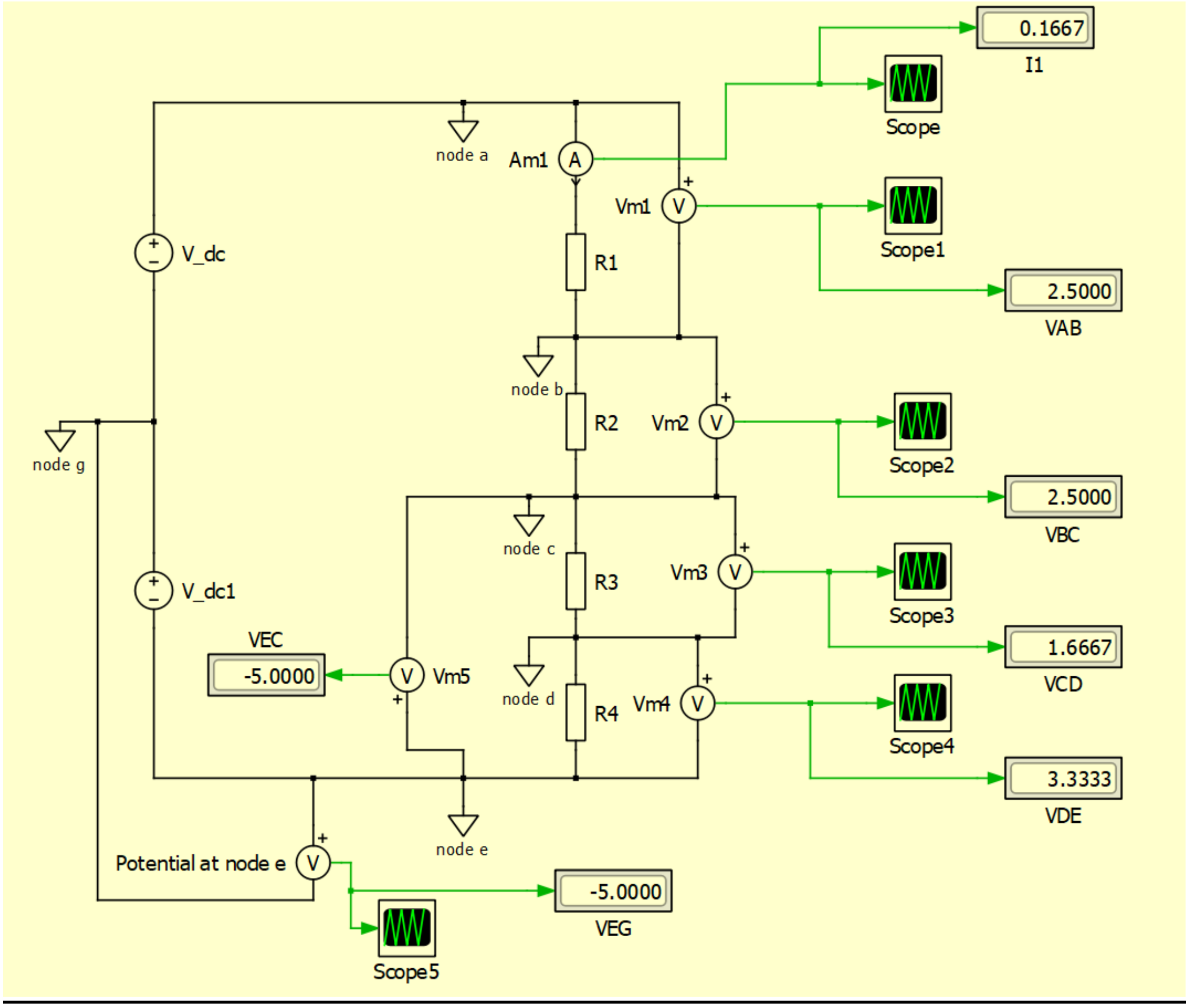

Figure 9 Potential difference across each node including V_{EC}

Question 12

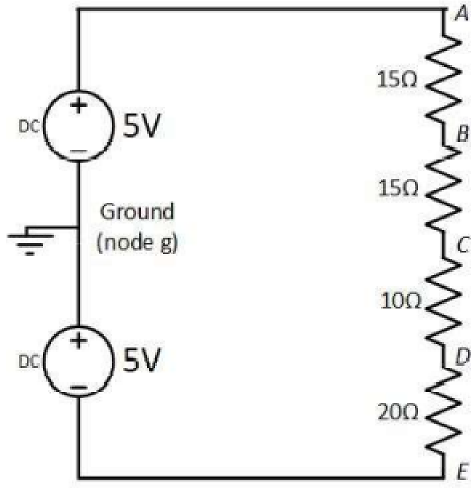

Figure 10 Circuit 5

Potentials at node A, B, C, D and E:

$$\boldsymbol{V_A = 5V}$$

$$\boldsymbol{V_B} = V_A - V_{AB}$$
$$= 5 - 2.5$$
$$= \mathbf{2.5}\boldsymbol{V}$$

$$\boldsymbol{V_C} = V_B - V_{BC}$$
$$= 2.5 - 2.5$$
$$= \mathbf{0}\boldsymbol{V}$$

$$\boldsymbol{V_D} = V_C - V_{CD}$$
$$= 0 - 1.6667$$
$$= \mathbf{-1.6667}\boldsymbol{V}$$

$$\boldsymbol{V_E} = V_D - V_{DE}$$
$$= -1.6667 - 3.3333$$
$$= \mathbf{-5}\boldsymbol{V}$$

Calculating V_{AB} and V_{Bc} :

$$\boldsymbol{V_{AB}} = V_A - V_B$$
$$= 5 - 2.5$$
$$= \mathbf{2.5}\boldsymbol{V}$$

$$\boldsymbol{V_{CD}} = V_C - V_D$$
$$= 0 - (-1.6667)$$
$$= \mathbf{1.6667}\boldsymbol{V}$$

Question 13

Circuit modified to measure potential at nodes A to D is shown in Figure 11.

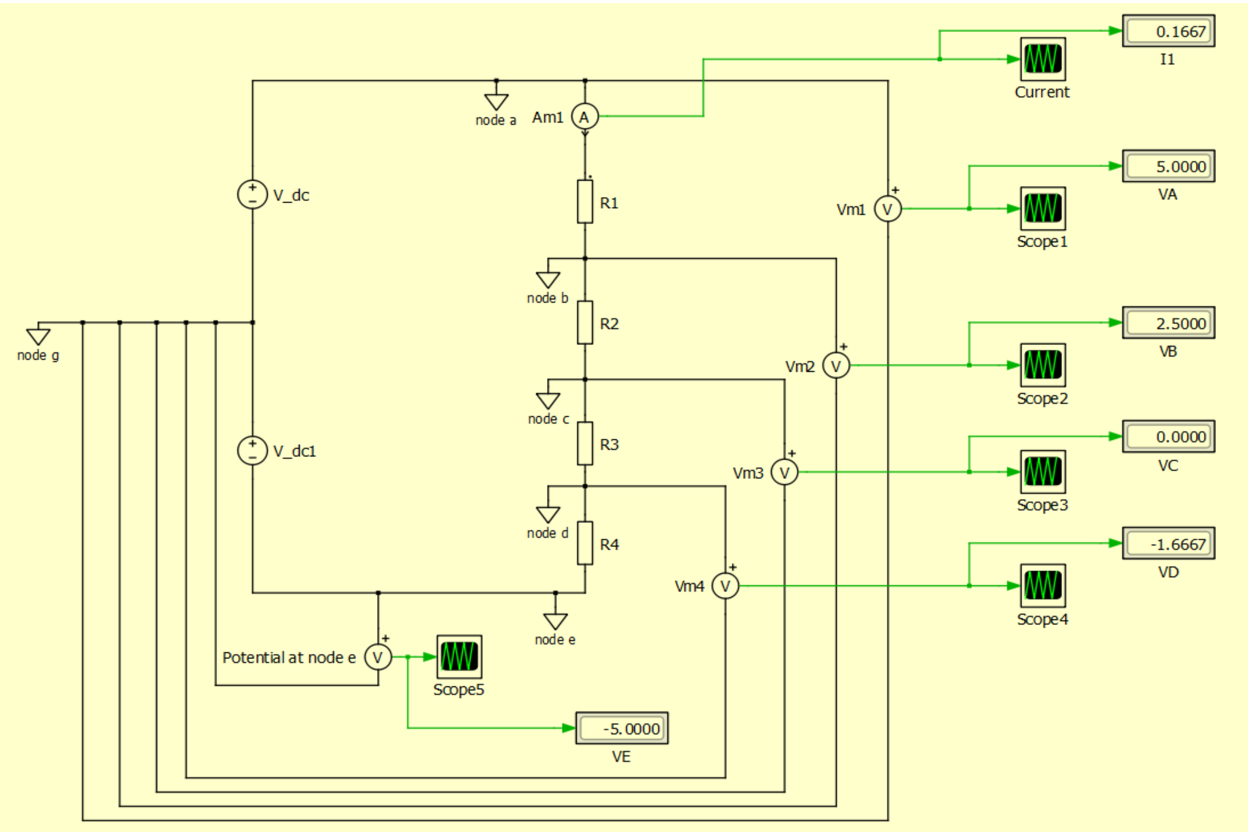

Figure 11 Measuring potential at nodes A to D

Conclusion:

Yes. The potentials measured from the simulation match the values calculated in Q12.

Circuit 6: The Limits of a Potential Divider

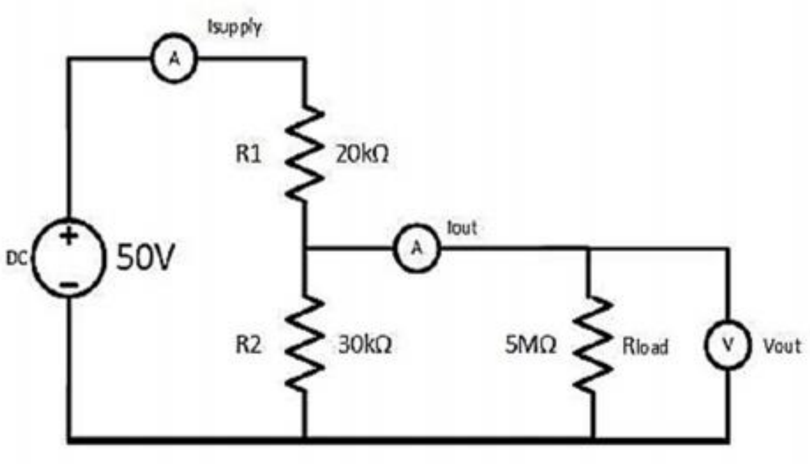

Figure 12 Circuit 6

Question 14

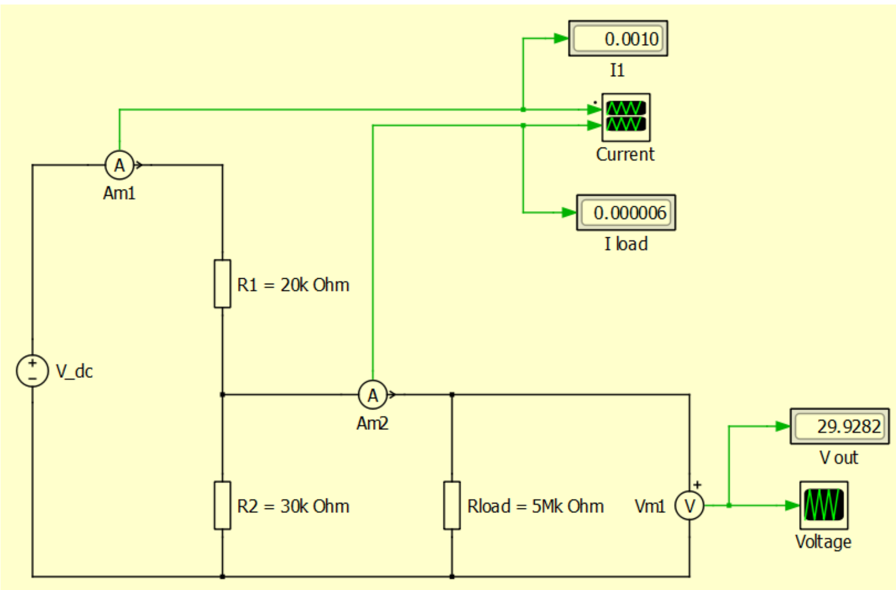

Figure 13 Circuit simulation of Circuit 6

No. Voltage divider rule does not apply in such connection.

To use the voltage divider rule to measure potential difference across a load, the load itself should not be connected parallel to the circuit.

Question 15

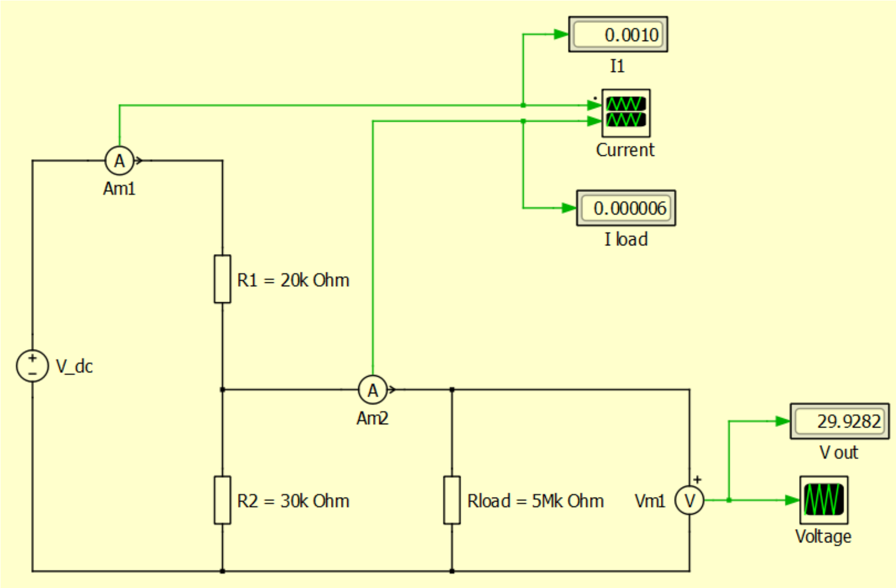

Figure 14.1 Rload=5MΩ

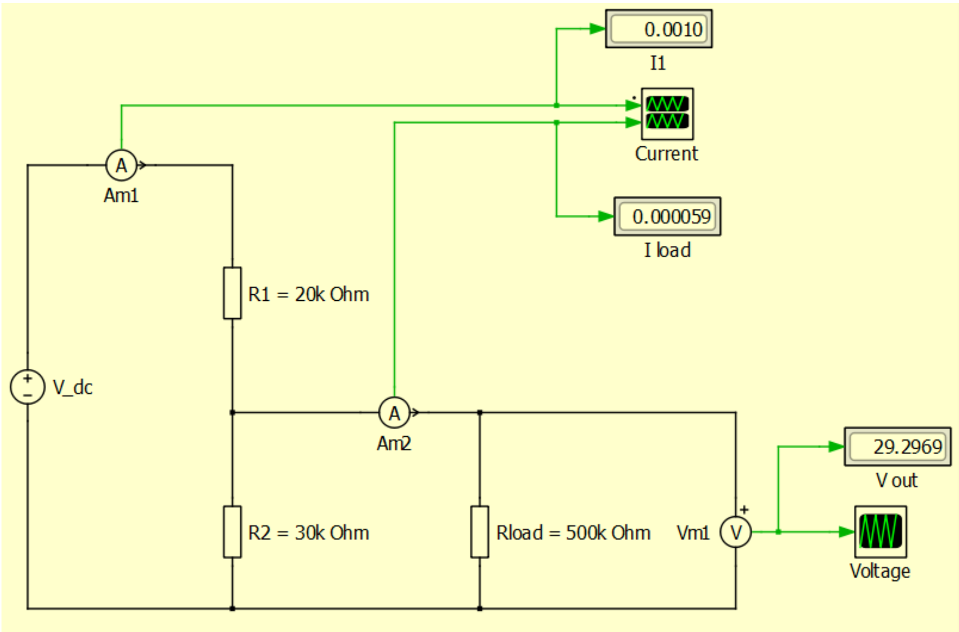

Figure 14.2 Rload=500kΩ

The potential difference across the load **(V_{out}) decreases**. It has decreased by 0.6313V. From 29.9282V to 29.2969V when R_{load} changed from 5MΩ to 500kΩ.

Question 16

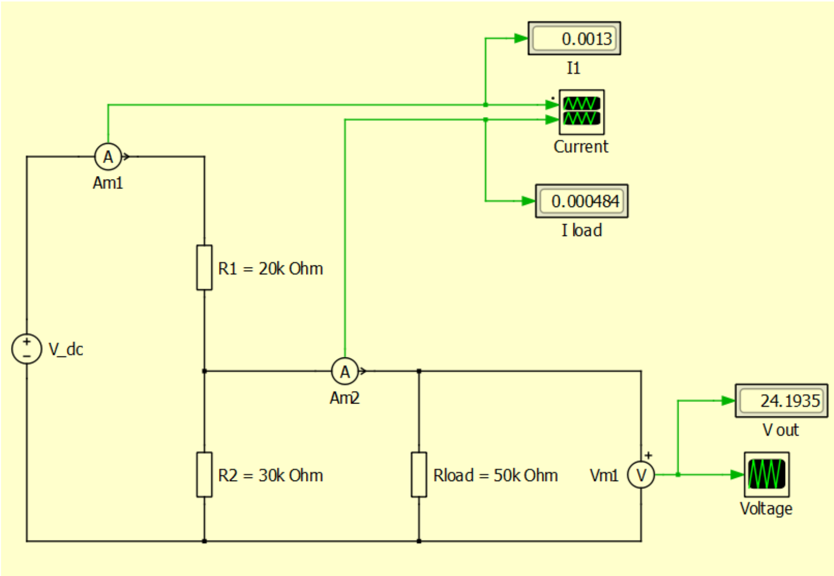

Figure 15.1 Rload=50kΩ

The potential difference across the load **(V_{out}) decreases**. It has decreased by 5.1034V. From 29.2969V to 24.1935V when R_{load} changed from 500kΩ to 50kΩ.

Conclusion:

It was observed that **V_{out} decreases as R_{load} decreases.**

Question 17

Potential divider rule is only applicable when the load is placed in series with the circuit, not parallel to it.

In Circuit 6, R_{load} is placed in parallel with another resistor which is in series with the main circuit. That is why the potential divider rule cannot be directly applied here to calculate potential difference across the resistor.

Technically, we can still use potential divider rule to calculate V_{out} which in this case, is the potential difference across the resistor. It can be calculated by first finding the total resistance of R_2 and R_{load}, which are connected in parallel. However, note that this is not the best way to connect the resistor as per the connection in Figure 12, because we cannot directly use the potential divider rule to calculate the potential across the resistor.

V_{out} measured in the simulation can also be calculated using the Ohm's law or the current divider rule. Here is how to calculate V_{out} simply by using Ohm's law.

Calculating V_{out} when R_{load} is 50kΩ:

Total resistance of R_2 and R_{load} :

$$R_{2,load} = \left(\frac{1}{30000} + \frac{1}{50000}\right)^{-1}$$

$$= 18750\Omega$$

Total resistance in the circuit:

$$R_{total} = R_{2,load} \; + \; R_1$$

$$= 18750 + 20000$$

$$= 38750\Omega$$

Current I_1 passing through R_1 :

$$\mathrm{I}_1 = \mathrm{I}_{\mathrm{source}} = \frac{v}{R_{total}}$$

$$= \frac{50}{38750}$$

$$= 0.00129\ A$$

$$V_{out} = (I_{source}) * \left(R_{2,load}\right)$$

$$= (0.00129) * (18750)$$

$$= 24.19V$$