

Using MUTISIM software to reinforce use and application of Norton's theory in electrical circuits

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Abstract

MULTISIM is a computer simulation software that among other things simulates the performance of electric circuits. This article demonstrates using MULTISIM as an educational tool to enhance student learning process. The specific example subject demonstrated in this article is Norton's circuit analysis theory.

This article demonstrates using the software as an aid to check the intermediate steps of the hand calculation techniques that must be used if no computer software were being used. An example which was a part of a lecture is presented where every step of finding the Norton's equivalent circuit using a hand calculation technique was verified by simulating the step in MULTISIM.

By using the mixed approach of using a hand calculation technique and MULTISIM, the students have the opportunity to verify the accuracy of every step of the process which will improve the students' learning and will allow the students to find and correct their own errors.

Keywords

MULTISIM, Norton theory, Hardware Descriptive Languages

Introduction

The introductory electrical Circuits course for non-electrical engineering technology majors at author's institution contains a weekly lab component. However, due to Covid-19 pandemic the whole class and the lab were converted to an online format. Consequently, the lab could not be held in a traditional laboratory setting.

It was decided to use MULTISIM simulation software in place of the physical lab. It was quickly discovered that not only MULTISIM can replace the traditional labs, but it can also be a valuable teaching aid in enhancing student understanding of circuit analysis techniques.

This article discusses and demonstrates the use of MULTISIM software to enhance student understanding and provide a verification technique for Norton's theory technique when multiple power sources are present. This article presents segments of selected lectures and labs using the combination of classical calculation techniques and MULTISIM

Description of the teaching approach

The unique approach demonstrated in this article illustrates a hybrid use of MULTISIM where the software can be used to verify all the steps of a hand calculation technique that will enable the students to become more self-reliant in their studies.

Example of hybrid use of MULTISIM

Norton theorem enables a complex circuit to be replaced with an equivalent circuit consisting of an equivalent Norton resistor and an equivalent Norton current. Consider the circuit of figure 1. Let us assume that it is desired to find the current through R_6 using Norton theorem. The circuit can then be replaced by the circuit shown in figure 2 using Norton theorem. In order to calculate I_N (Norton current), R_6 should be shorted and 2 terminals added where R_6 was. The current through where R_6 was is the Norton current. In figure 3, the current through nodes A & B is Norton current. The current through A & B can be calculated and/or determined by using MULTISIM. Figure 4 is a MULTISIM simulation that shows the current through A & B is $4/3$ Amperes.

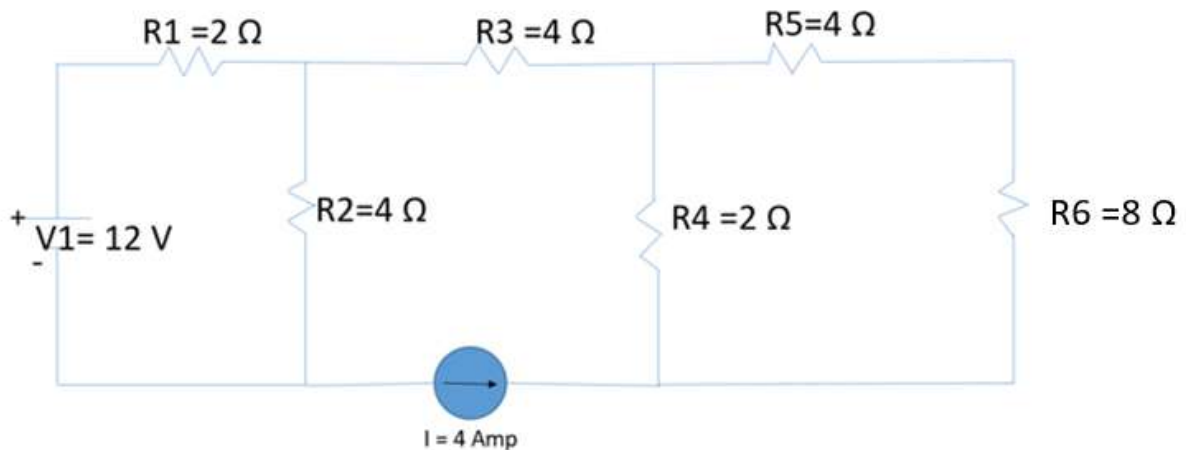


Figure 1: Circuit to be analyzed by Norton theorem

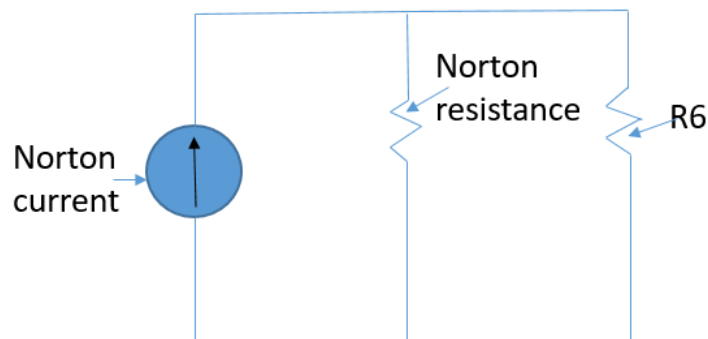


Figure 2: Equivalent Norton circuit of figure 1

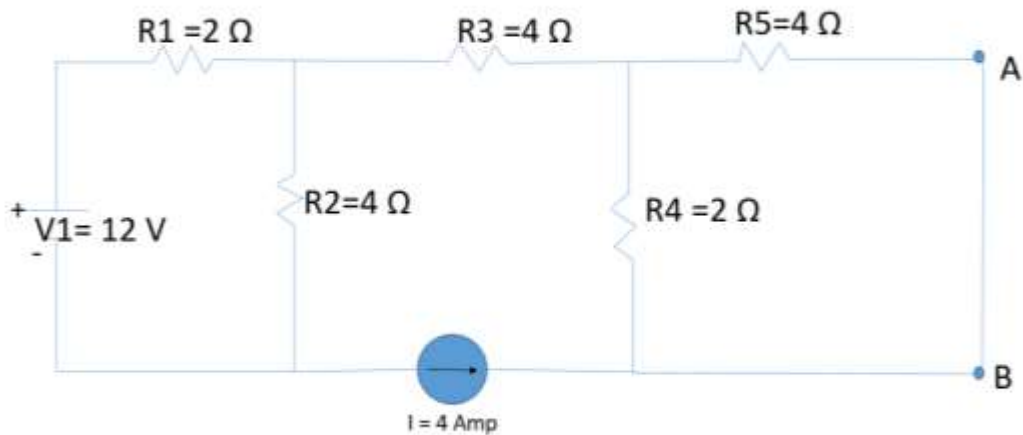


Figure 3: Current through A & B is I_N (Norton current)

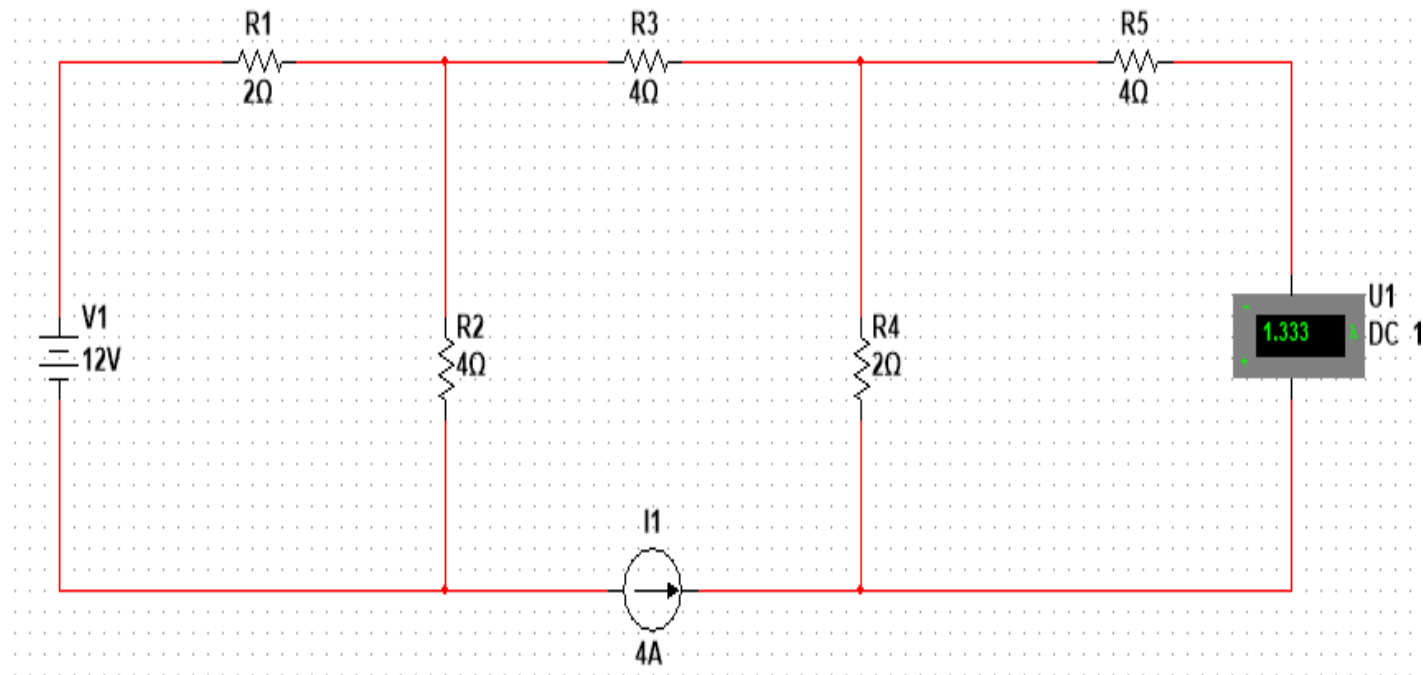


Figure 4: MULTISIM simulation of the voltage measurement across terminals A & B of figure 3

R_N is the resistance from the point of view of A & B when all the voltage sources are shorted out and the current source is opened. Figure 5 shows the circuit for calculating the resistance across A & B. Figure 6 is the MULTISIM simulation of the circuit of figure 5. As it is shown on figure 6, $R_N = 6 \Omega$. Then the Norton's equivalent circuit is as shown in figure 7.

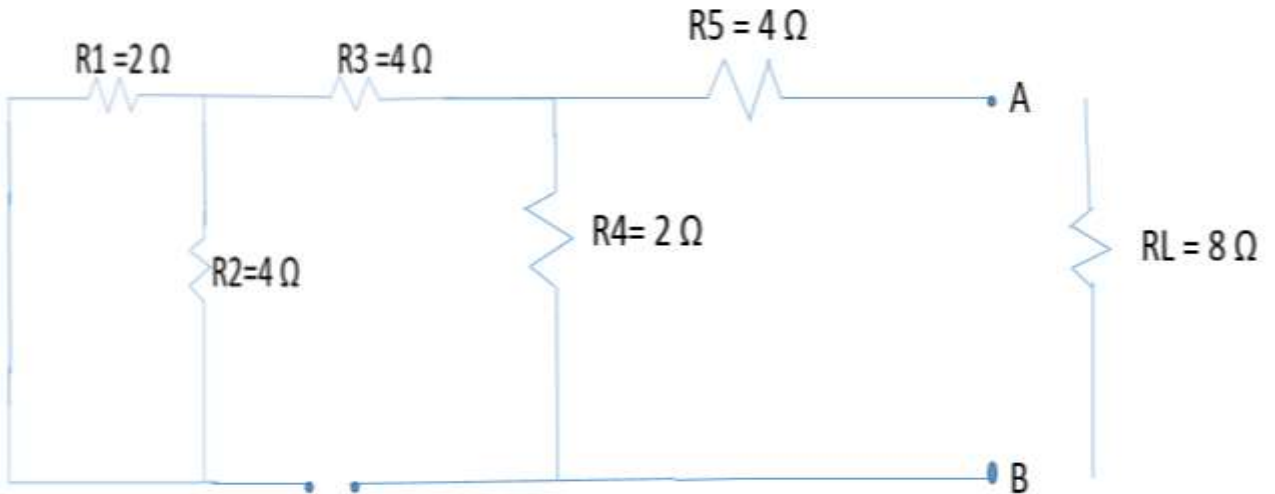


Figure 5: The total resistance across A & B is R_N (Norton resistance)

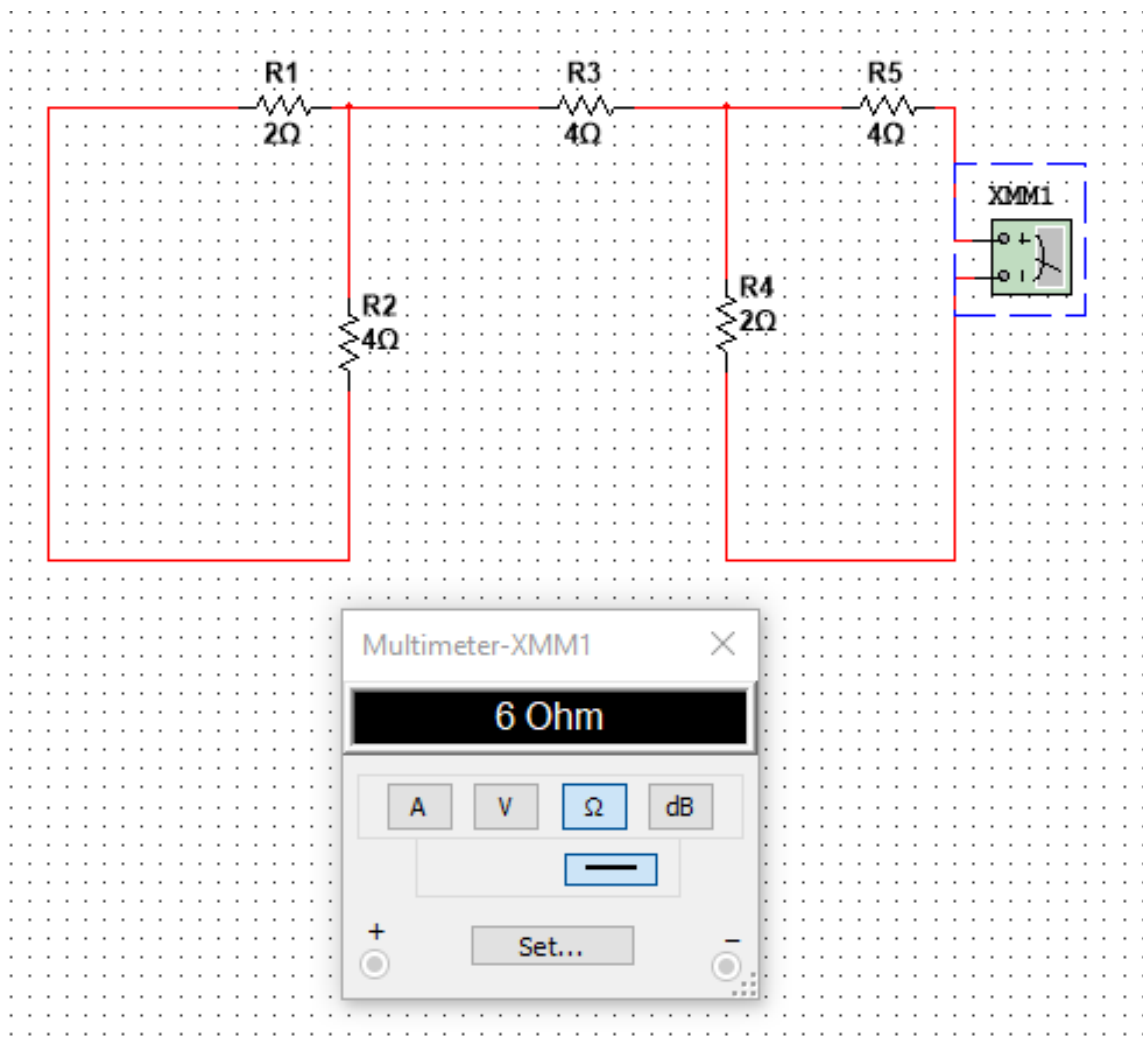


Figure 6: MUTISIM simulation of figure 5

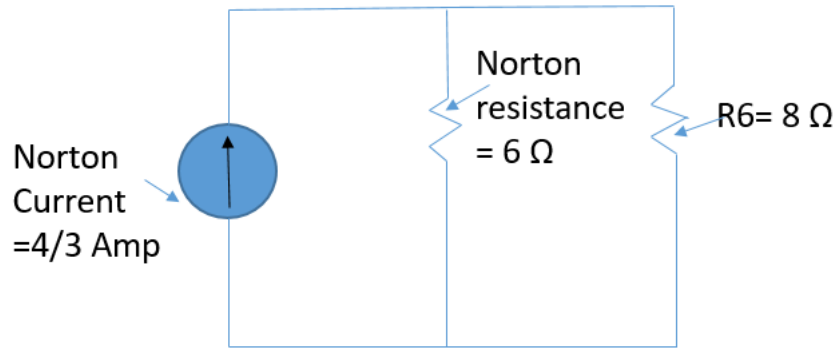


Figure 7: Norton's equivalent circuit of circuit of figure 1 for R6

Using Norton's circuit, the current through R6 can be calculated by Ohm's law as shown below.

$$I_{R6} = (I_N * R_N) / (R_N + R6) = (4/3 \text{ Amp})(6 \Omega) / (6\Omega + 8\Omega) = 4/7 \text{ Amp}$$

Figure 8 is the MULTISIM simulation of circuit of figure 1 with an ammeter measuring the current through R6. The MULTISIM simulation of figure 8, confirms the results obtained from Norton circuit of figure 7.

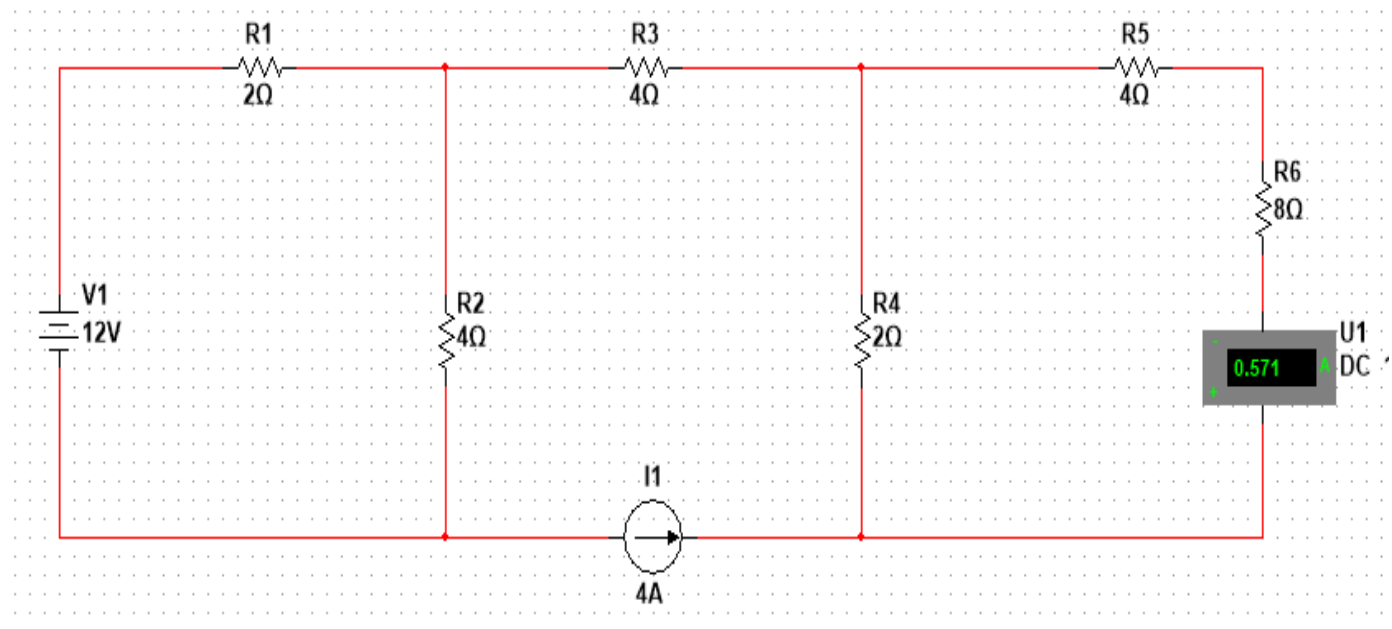


Figure 8: MULTISIM simulation showing current through R6 of circuit of figure 1

Taking the approach shown so far has significant educational value. But this approach can be extended to enhance the students' abilities. Norton current & Norton resistance can be calculated and in fact from an educational point of view should be calculated by manual techniques. These manual techniques can be enhanced and verified by using MULTISIM. The material presented in the remainder of this article demonstrate the mixed use of hand calculation (manual) techniques

and MULTISIM simulation for determining and checking the accuracy of physical interpretation of the circuits and their associated mathematical implementation used for calculating I_N & R_N .

Figure 9 further explains the concept of Norton's current. There is a difference between how a current source and how a voltage source are treated when superposition technique is being used. When taking out the voltage sources, the voltage source is replaced by a short. When a current source is taken out, the location of the current source is treated as an open. Figure 10 is the circuit that must be used to calculate the currents due to V_1 only.

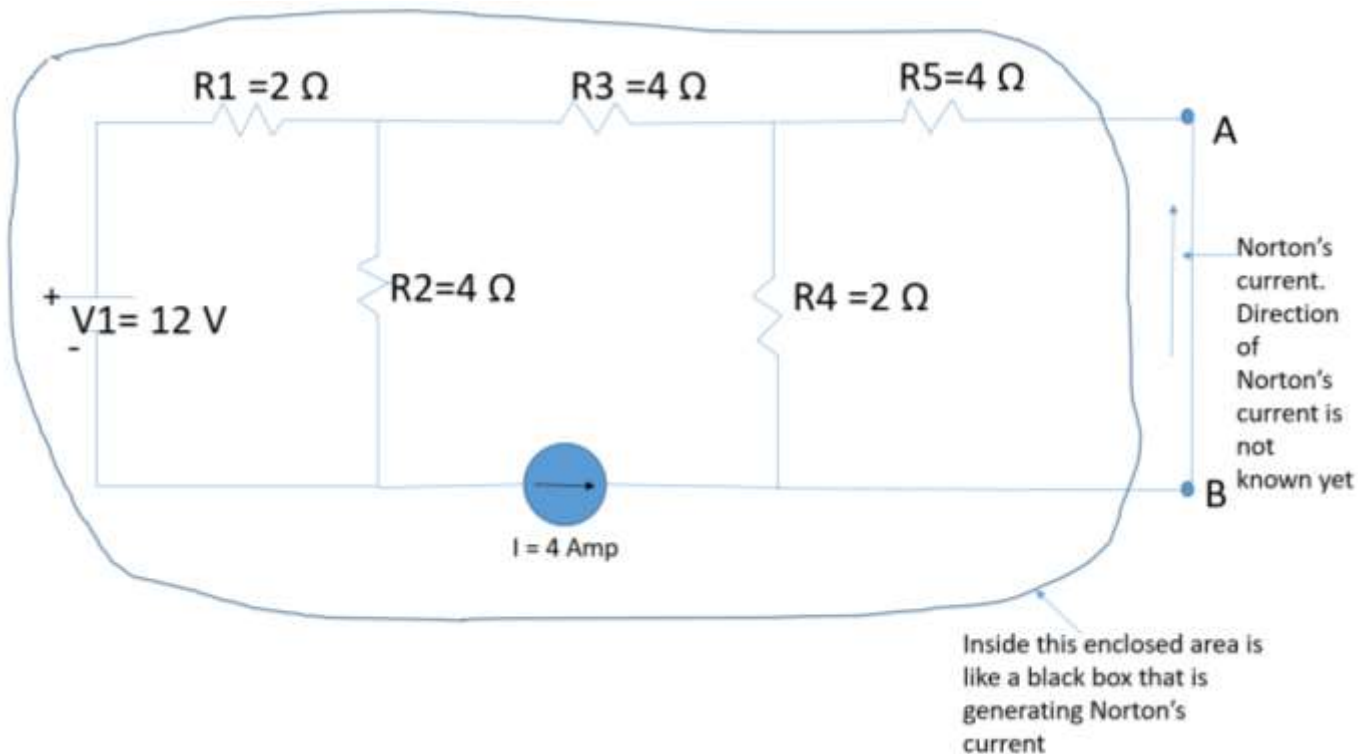


Figure 9: Current generated by the components inside the black box is I_N (Norton's current)

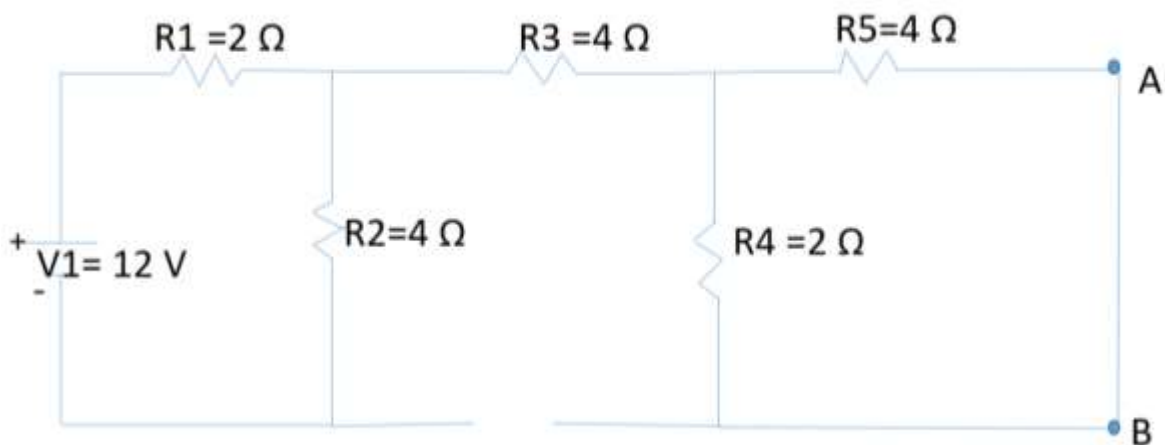


Figure 10: circuit for calculating the currents from voltage source V_1 only

Because of the open, the effective circuit is the left portion of the circuit of figure 10. The effective circuit and the direction of current from V1 is shown in figure 11. Note that in MULTISIM the current goes from the positive pole to the negative pole. In figure 11, the direction of IT1 is chosen as shown to keep the chosen direction consistent with MULTISIM.

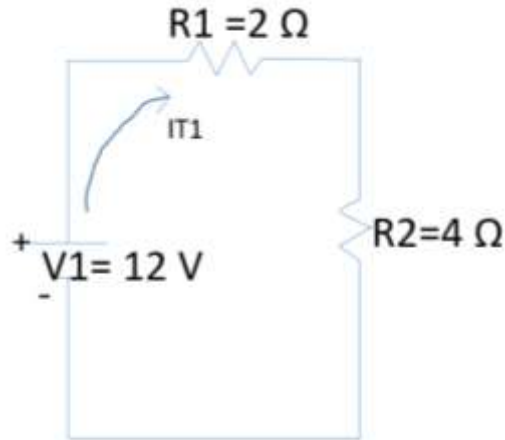


Figure 11: Effective circuit for the circuit shown in figure 10

$$I_{T1} = V1 / (R1 + R2)$$

$$I_{T1} = (12 \text{ V}) / (2 + 4) = 2 \text{ Amp}$$

Figure 12 shows the currents for the Norton circuit from voltage source V1. Figure 13 shows the circuit of figure 12 simulated in MULTISIM. In the simulation of figure 13, the value of the current in the current source is set to zero (0) which has the same effect as shorting the location of the current source. The simulation of figure 13 confirms the results shown in figure 12. The presence of a “u” indicates a zero (0) reading for the ammeters measuring the currents for R3, R4 & R5.

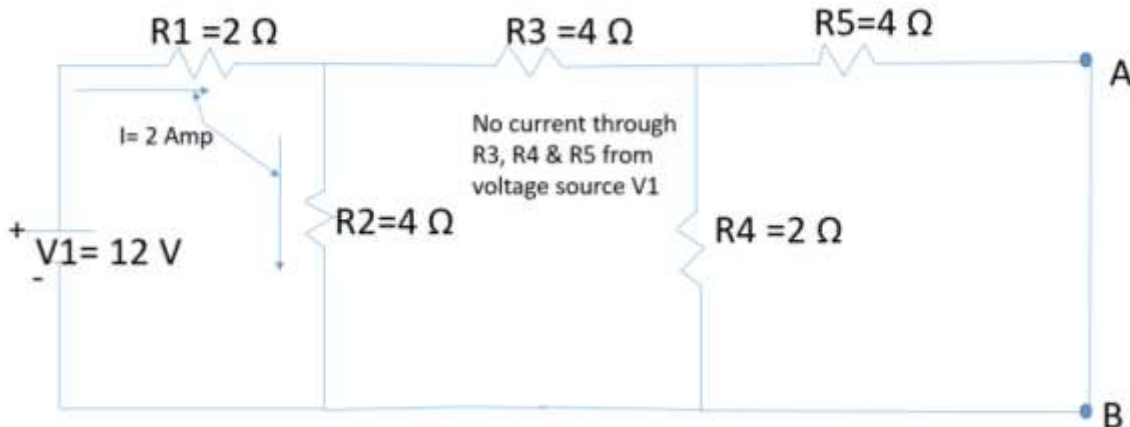


Figure 12: Currents for Norton's circuit from voltage source V1 calculated manually

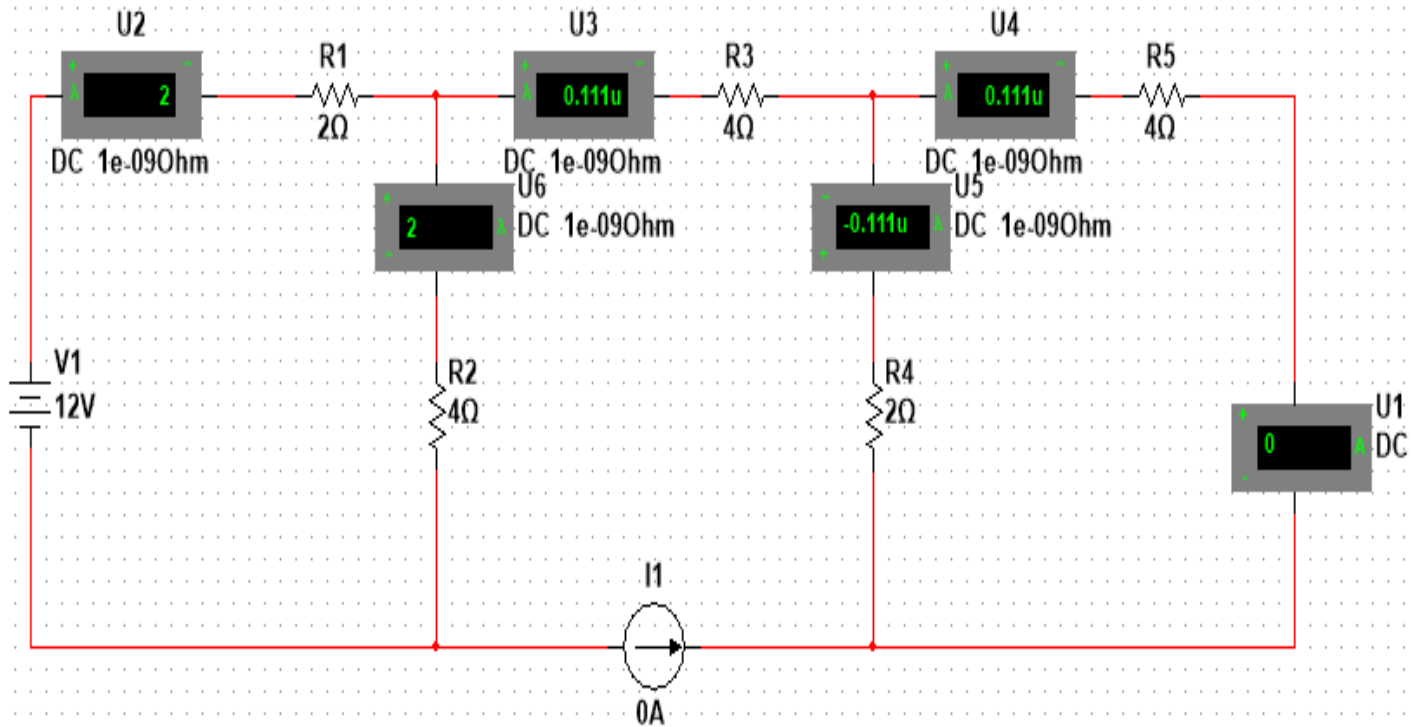


Figure 13: MULTISIM simulation of circuit of figure 1

Figure 14 is the circuit for calculating the currents from constant current source I for the Norton circuit. The circuit can be redrawn as shown in figure 15 in order to make relationships among resistors more clear and to define notation for further manual calculations.

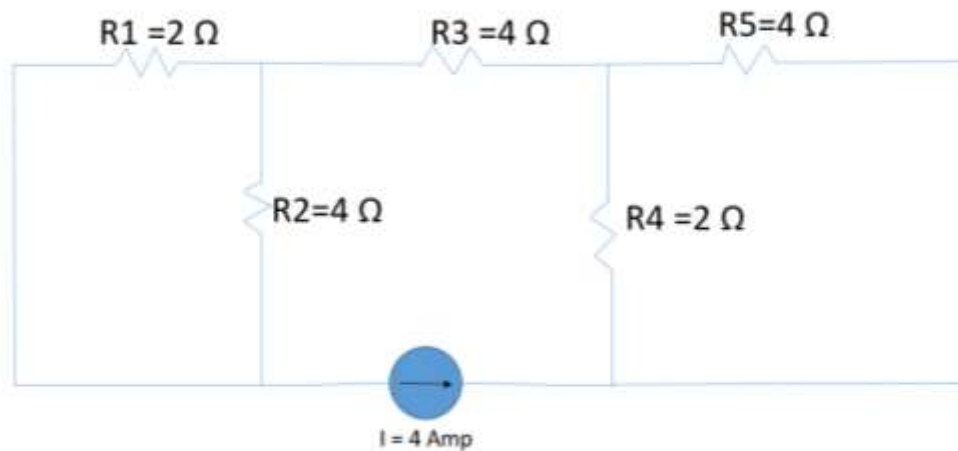


Figure 14: Circuit for calculating current from I only

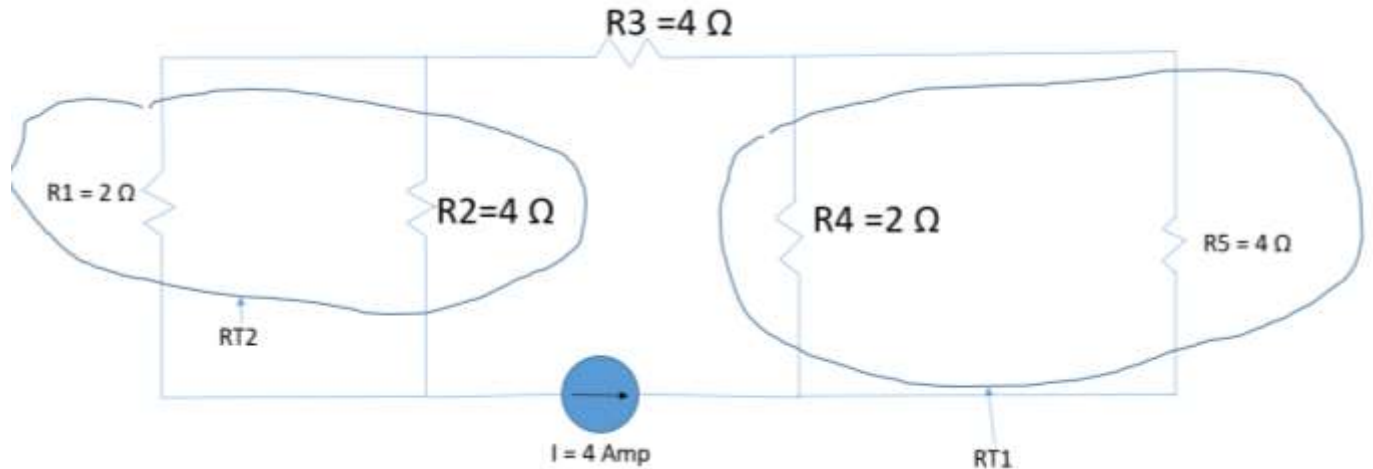


Figure 15: First step in manually solving the circuit of figure 14

The following shows the manual calculations.

$$1/RT1 = (1 / R4) + (1 / R5)$$

$$1/RT1 = (1/2) + (1/4)$$

$$RT1 = 4/3 \Omega$$

$$1/RT2 = (1/R1) + (1/R2)$$

$$1/RT2 = (1/2) + (1/4)$$

$$RT2 = 4/3 \Omega$$

Figure 16 shows the circuit of figure 15 in a more simplified format. Figure 16 illustrates that the current through RT1, R3 & RT2 is 4 Amp. Figure 17 shows the components for calculating the currents through R4 & R5.

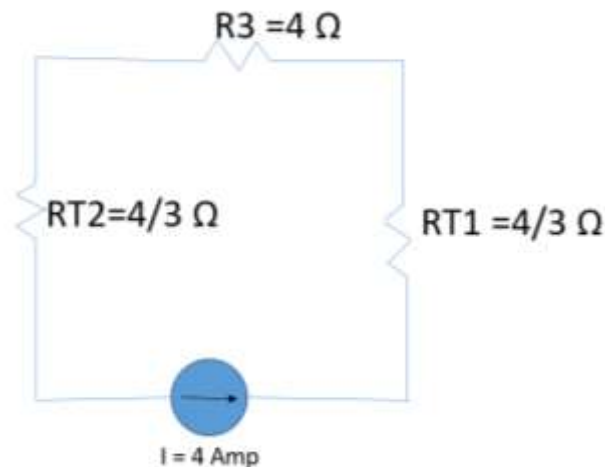


Figure 16: Simplified version of circuit of figure 15

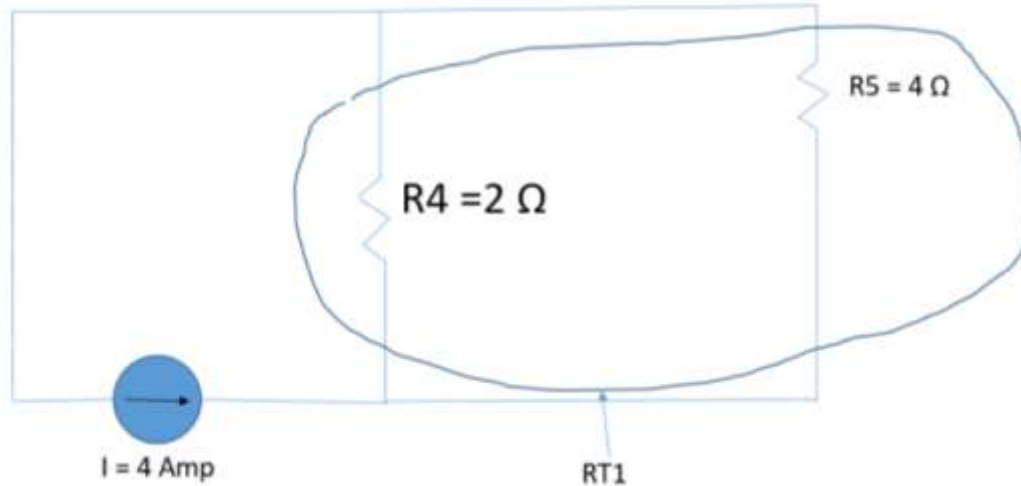


Figure 17: components necessary for calculation of currents through R4 & R5

$$I_{R4} = (I)(RT1)/R4 = (4 \text{ Amp})(4/3 \text{ } \Omega)/(2 \text{ } \Omega) = 8/3 \text{ Amp}$$

$$I_{R5} = (I)(RT1)/R5 = (4 \text{ Amp})(4/3 \text{ } \Omega)/(4 \text{ } \Omega) = 4/3 \text{ Amp}$$

Figure 18 is a MULTISIM simulation of figure 17. By similar techniques, the currents through all resistors due to current I1 can be calculated, and then simulated in MULTISIM to verify the results. Figure 19 shows the manually calculated currents through the resistors from current source I. Figure 20 is the circuit of figure 19 simulated using MULTISIM.

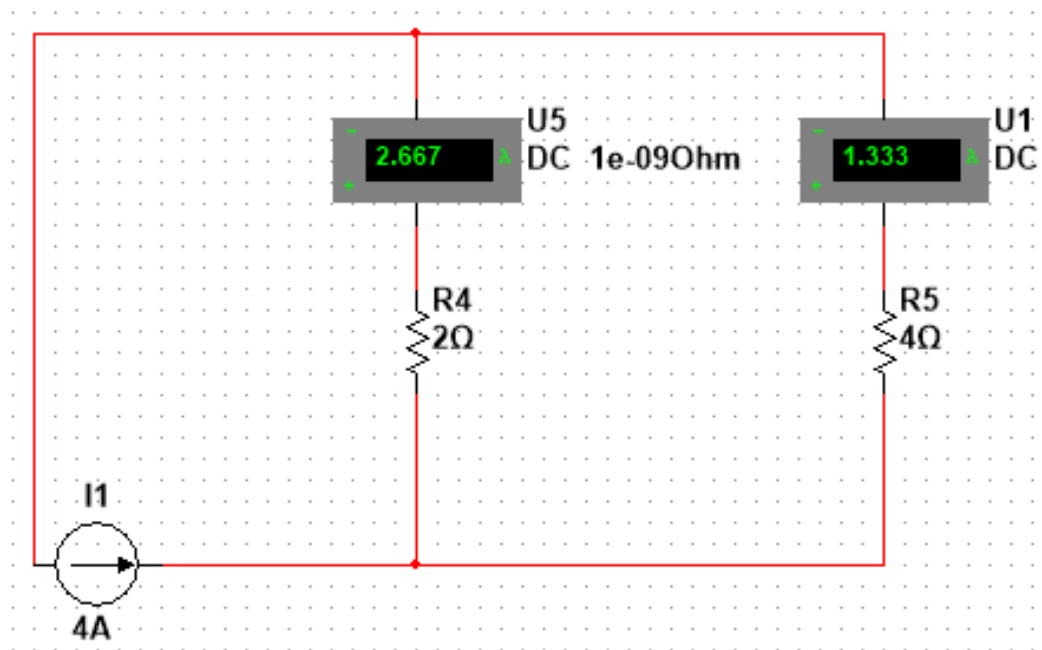


Figure 18: Multisim simulation of circuit of figure 17

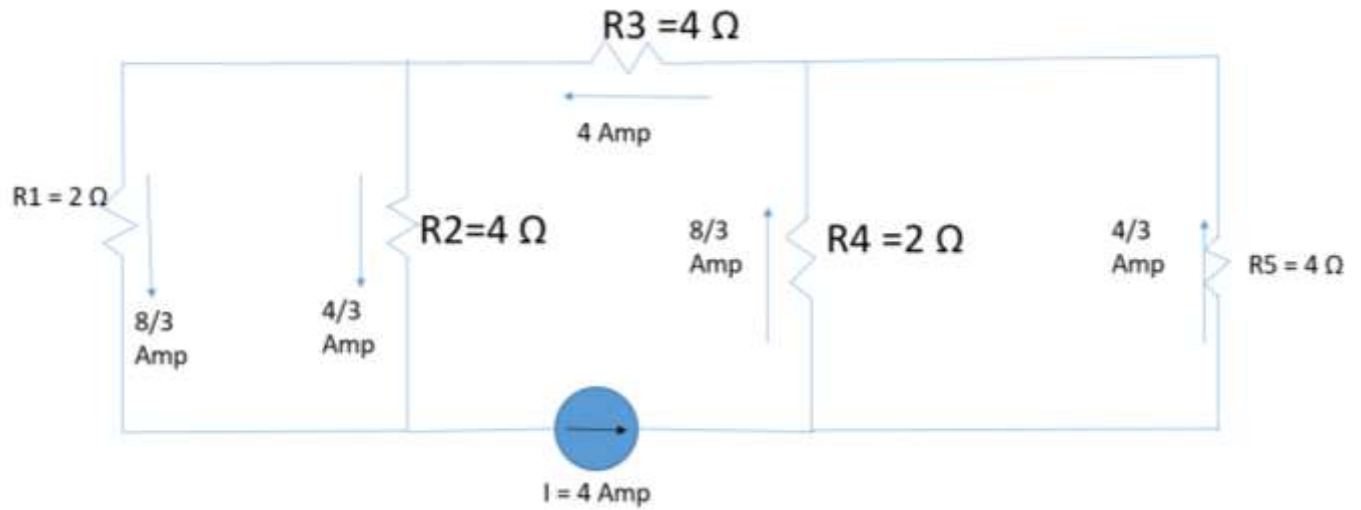
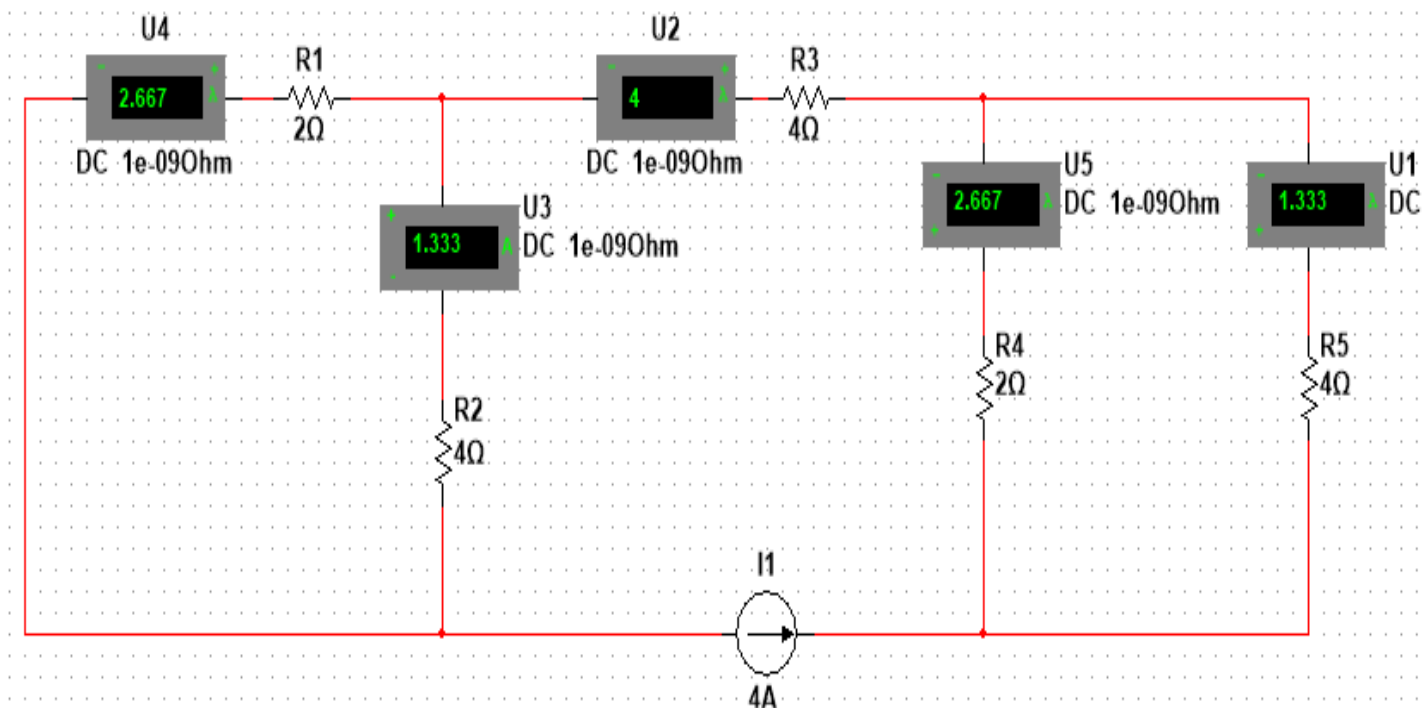
Figure 19: Currents due to current $I=4$ Amp only

Figure 20: Simulation of circuit of figure 19

If the currents from figures 12 and 19 are added algebraically (algebraically means accounting for their direction), then the currents shown in figure 21 are obtained for the Norton circuit when both V and I are present. Figure 22 is a MULTISIM simulation showing the currents of circuit of figure 21. From figures 21 & 22, it is determined the current through $R5$ of the Norton circuit is $4/3$ Amp. Current through $R5$ is the current through nodes A & B of figure 9. Therefore, the direction and magnitude of the Norton current is as shown on figure 23.

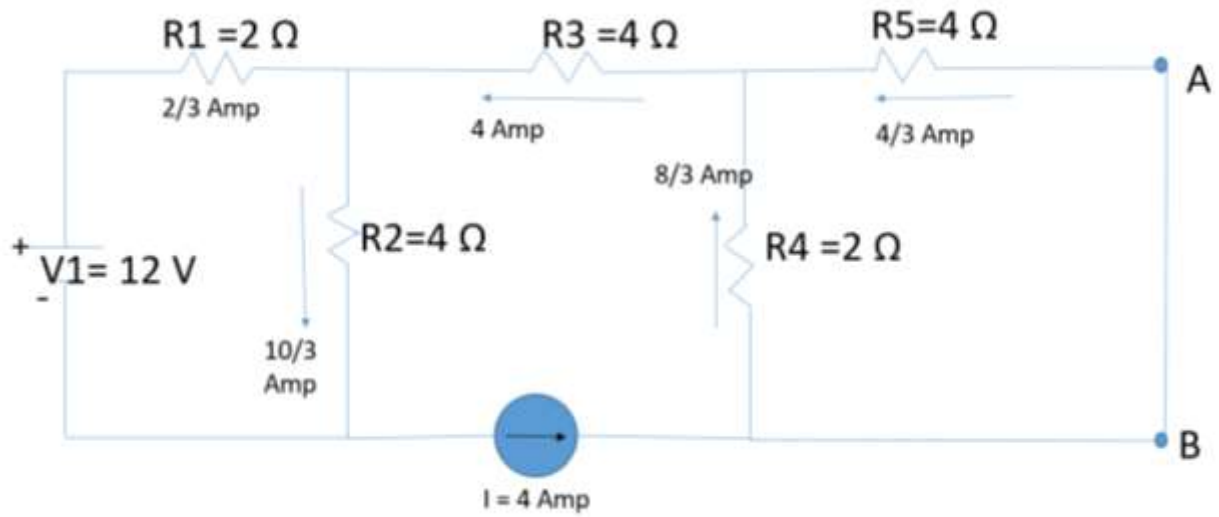


Figure 21: Currents in Norton circuit when both V & I are present

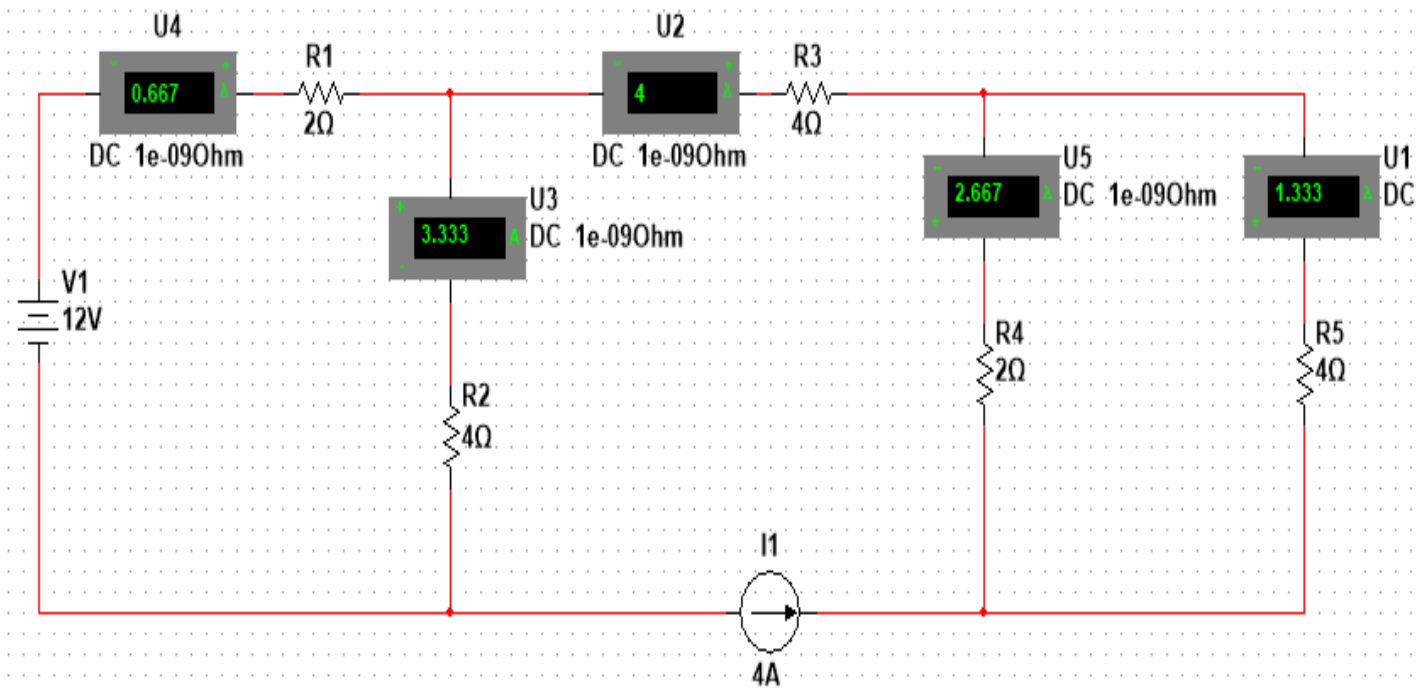
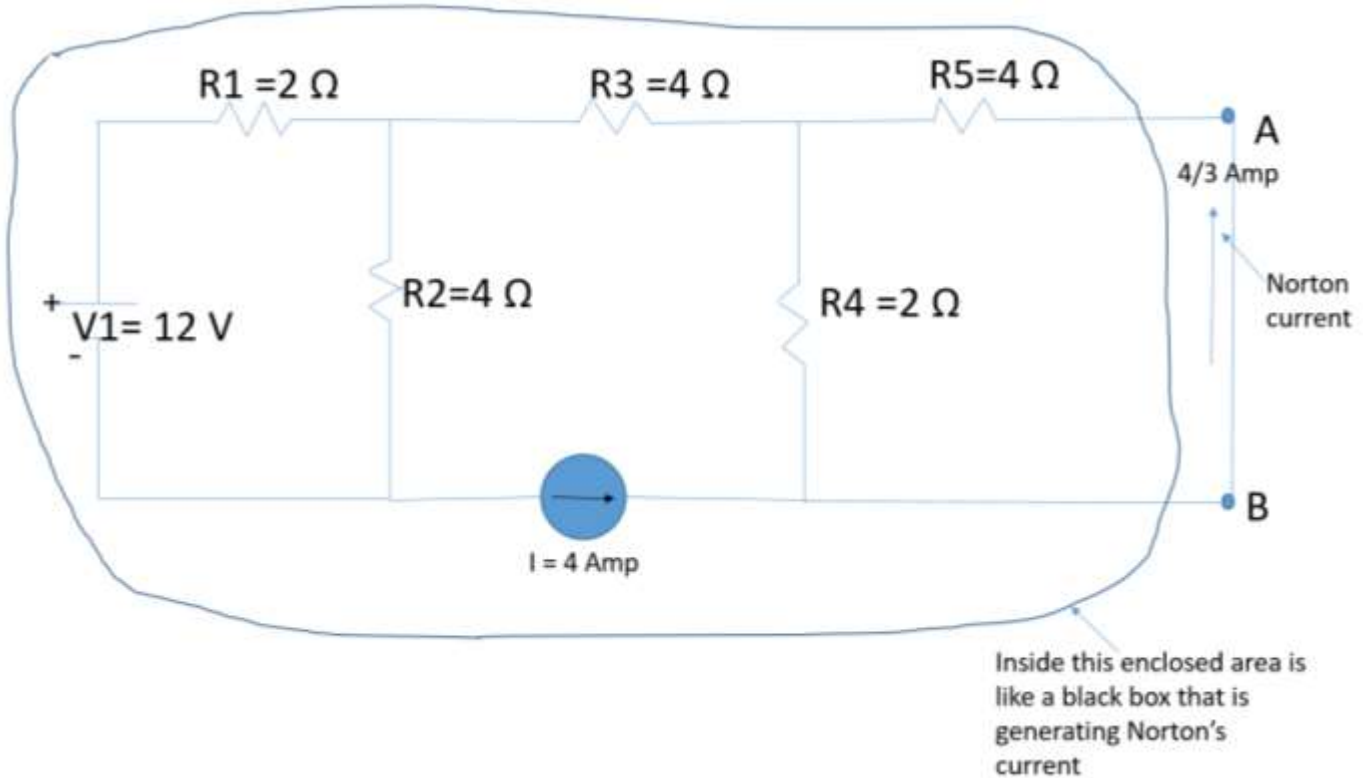
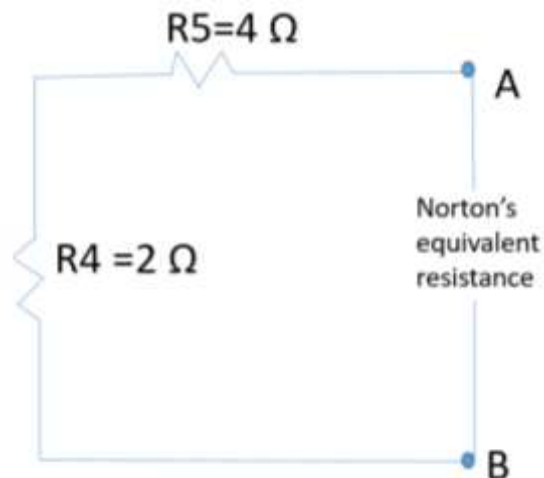


Figure 22: MULTISIM simulation of circuit of figure 21



From figure 5, it was determined that the equivalent circuit for determining Norton's resistance is the circuit shown in figure 24. From figure 24, it is determined that Norton's resistance is $6\ \Omega$. This result is verified in the MULTISIM simulation of figure 6. This result can further be verified by the MULTISIM simulation of figure 25 where "I" is set to zero (0) which is equivalent to shorting the circuit at the location of current "I".



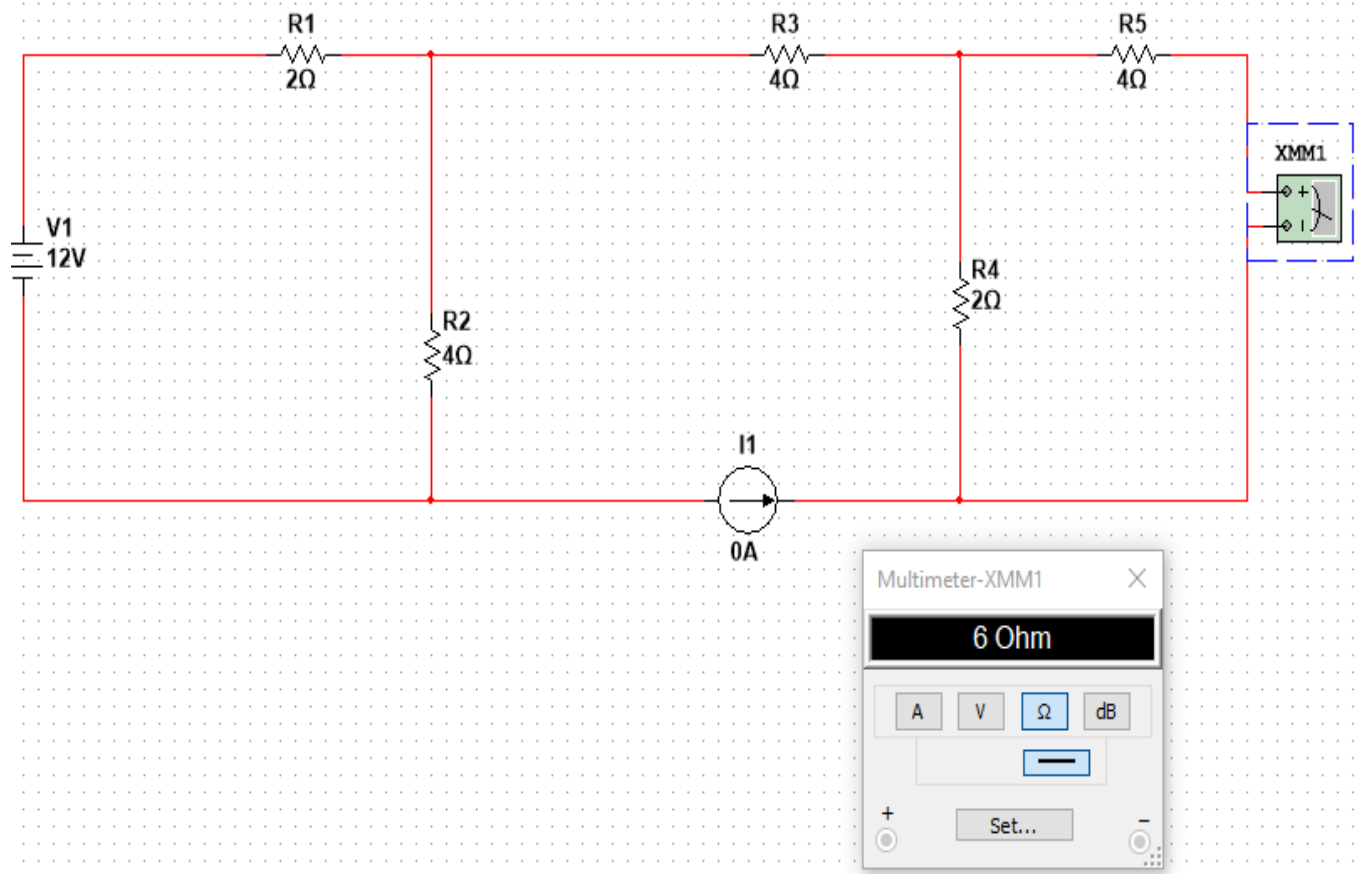


Figure 25: Simulation of Norton's resistance by setting the current to zero (0) which is equivalent to shorting the current source

The equivalent Norton circuit is then confirmed to be numerically as shown in figure 7. However, the Norton current direction shown in figure 23 dictates that the Norton current direction must be changed and figure 7 must be adjusted as shown in figure 26.

From the current divider rule, the following current for R6 can be calculated.

$$I_{R6} = (\text{Norton current})(\text{Norton resistor}) / (\text{Norton resistor} + \text{load resistor})$$

Load resistor is R6. Therefore, I_{R6} which is I of load = $(4/3 \text{ Amp})(6 \Omega) / (6 \Omega + 8 \Omega) = 4/7 \text{ Amp}$

The current through R6 and its direction can be verified by simulating the entire circuit of figure 1. This simulation has already been done and the results are shown in figure 8. The current shown in figure 8 confirms the manual calculations and the previous simulation techniques presented in this article.

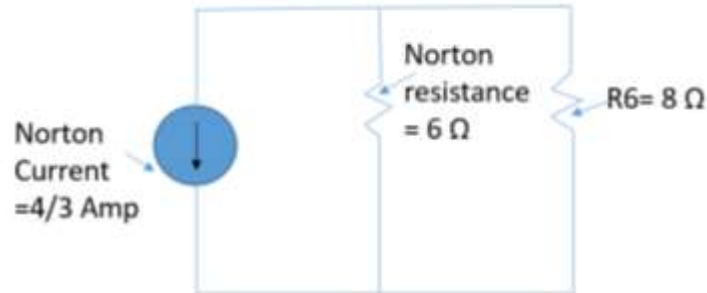


Figure 26: Norton circuit with corrected Norton current direction

Conclusion & summary

In this article the use of MULTISIM simulation software as a physical lab substitute and as a supplement for enhancing student understanding of the Norton's theorem when circuit contains multiple power sources are presented. The techniques are not technically complicated. However, that is precisely the point of this article. The techniques are suitable as teaching aids for students that are just beginning to learn electrical engineering concepts.

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Biographical Information

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