Experimental Verification of Kirchhoff's Voltage Law and Kirchhoff's Current Law.

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Abstract

By measuring the sum of the voltage drops around several closed paths, and the sum of the currents at several nodes, in two resistive circuits, We have experimentally tested Kirchhoff's Voltage Law and Kirchhoff's Current Law. A low resistance circuit was constructed using resistors in the range of 1[k], and a high resistance circuit was constructed using resistors in the range of 10[M].

Kirchhoff's Current Law, that states that the algebraical total of the currents at a node is zero, was found to be accurate to within 1% error.

Kirchhoff's Voltage Law, that states that the algebraical total of the voltage drops around a control system is zero, was found to be accurate to within 1% error when applied to the low resistance circuit, but when applied to the high resistance circuit gave errors of 10 to 20%.

The reason for this discrepancy isn't understood, however is believed to be associated with the operation of the meter once wont to live voltages across giant resistances.

With the exception of the voltage law applied to high resistance circuits, we conclude that Kirchhoff's Laws accurately predict the behaviour of resistive circuits.

KEYWORDS: Circuits, Current, Measurement, Resistors, Voltage

Introduction

The vary of quality exhibited by fashionable electronic systems is kind of broad. One encounters electrical systems as easy as a switch that closes to ring a push button, or as complicated because the central process unit of a high speed pc. In several areas of engineering, elementary ideas that guide the understanding and style of electrical systems square measure astonishingly few. A notable example is that of circuit theory which, it may be argued, is founded on three simples laws: Ohm's Law, Kirchhoff's Voltage Law (KVL), and Kirchhoff's Current Law (KCL).

Ohm's Law and Kirchhoff's Laws place constraints on voltages and current within a circuit, thus providing important information about these variables. In specific, Ohm's Law provides a relationship between the voltage and current associated with a resistor, while KVL and KCL provide constraints on the sum of the voltages around a closed-loop system and therefore the add of currents at a circuit node. Ohm's Law and Kirchhoff's Laws square measure applied ofttimes within the analysis and style of electrical circuits. In complex circuits they may be cast into more sophisticated forms that disguise their simplicity, but they nevertheless provide a basis for the understanding of virtually all electrical systems. Since an excellent several operating electronic circuits in gift use were designed and analysed victimisation these laws, their validity is tough to question.

Methodology

As a part of the verification of Kirchhoff's laws, 2 resistive circuits were created on a board victimization ¼ [W], five-hitter tolerance resistors. Where a voltage supply was needed, a Heath model 2918 tri-power offer was connected to the circuit. For voltage and current measurements, a Fluke model 8050A digital multimeter was used with standard multimeter probes.

Figure 1 illustrates the first of two circuits constructed for this experiment. Shown within the figure area unit current nodes labelled A through D, X, and Y, also in concert of many potential closed methods. Current nodes A and B were accustomed valuate Kirchhoff's Current Law, while the closed paths shown was one of several used to calculate Kirchhoff's Voltage Law. The values of the resistors and of the voltage source indicated in Figure 1 are nominal, that is, no measurements were taken of the actual values. As given within the Discussion section, correct information of voltage and resistance values wasn't necessary to get correct results.

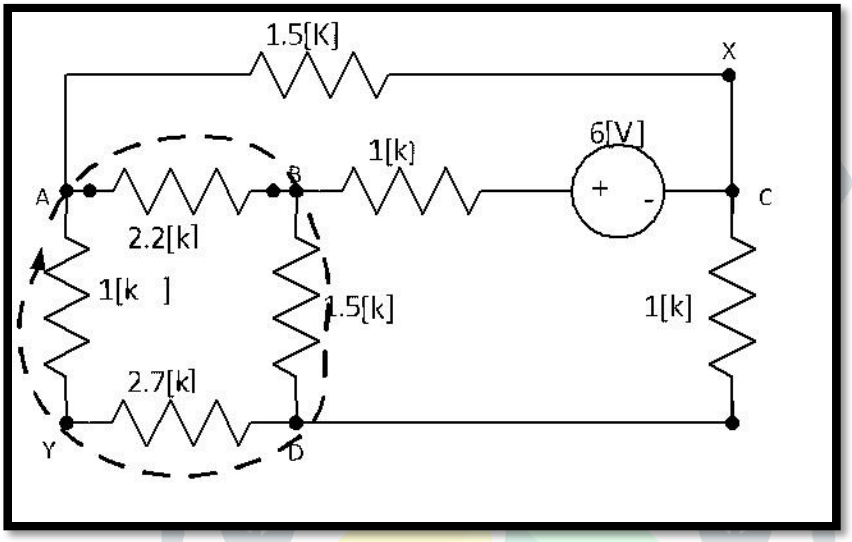

Figure 1. The first of two resistive circuits constructed for this work .

The second of the two circuits is shown in Figure . Four current nodes labelled A through D are shown, as is one of several possible closed paths. Again the indicated electrical device and voltage values square measure nominal. The principle difference between the circuits of Figures1 and 2 is in the value of the resistors; the circuit of Figure 1 contains resistors in the [k] range, and that of Figure 2 contains resistors in the [M] range.

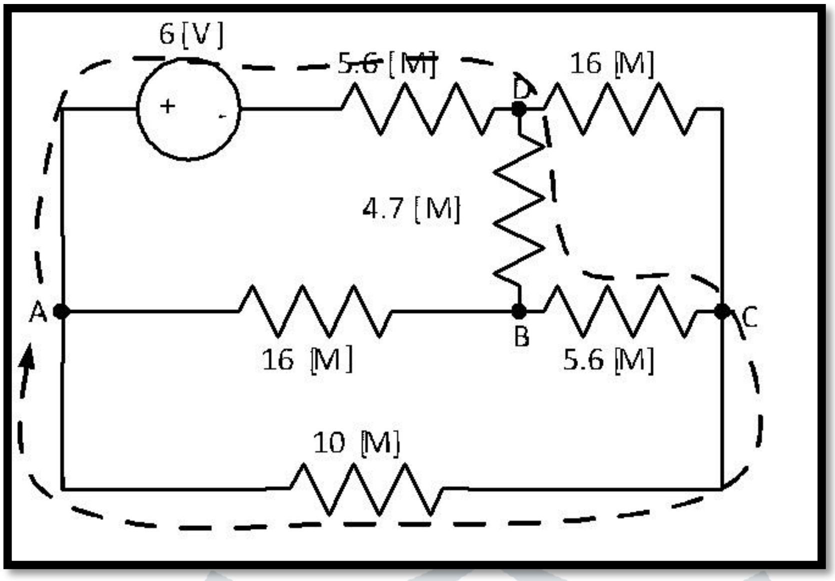

Figure 2. The second of two resistive circuits constructed for this work. The circuit contains larger resistors than those of Figure 1.

Kirchhoff's Voltage Law and Kirchhoff's Current Law were tested on the circuits shown in Figures 1 and 2. The take a look at of KVL was performed by measure voltage drops on closed ways indicated by pairs of nodes. For example, the voltage drop around the closed path shown in Figure 1 was taken as the sum of the voltage drops between nodes A and B, nodes B and D, and nodes D and A.

A take a look at of KCL was created by disconnecting, one at a time, the end of each circuit element arriving at a particular node and measuring the current leaving that node through the element.

This was done, however, solely at "essential nodes", i.e., those at that a minimum of 3 circuit components were connected. The current leaving the node was measured by connecting the positive terminal of the ammeter to the node and the common terminal to the disconnected end of the appropriate circuit element. As an example, the current leaving node A of Figure 1 though the [k] resistor was labelled iAB.

Voltage measurements were created with the Fluke multimeter within the dc voltage mode, and generally at 20[V] full scale. Voltage readings were found to be stable to zero.1[mV], that was the resolution of the multimeter. Current measurements were made with the Fluke multimeter in the dc current mode, and typically at 200[mA] full scale, except that currents less than 0.2[mA] were measured at 2[mA] full scale. Current readings were found to be stable to the utmost exactitude of the multimeter, that was zero.001[mA] at the 2[mA] full scale vary, and 0.01[mA] at the 200[mA] full scale range.

For this experiment, the % error couldn't be reported as a three-quarter distinction between a measured worth and a reference worth, as a result of during this case the reference is zero (it is that the add of the voltages around a closed path!). Therefore, the % error E indicated in Table one was calculated by comparison the measured add of voltage drops to the typical of absolutely the values of the voltage drops along the closed path, that is,

$$E = \frac{\sum v - 0}{\sum |v| / N} x 100\%.$$

Results

Table one reports the results of individual voltage drops, the add of the voltage drops, and therefore the p.c error for every of many closed ways within the circuit of Figure one. As delineate within the ways Section, the closed ways were made of smaller ways denoted by pairs of nodes; these smaller ways area unit enclosed within the table entries. The first row in Table 1, for example, corresponds to the closed path drawn in Figure 1. Measurements on other closed paths are similarly indicated.

Table 1. Tabulation of voltage drops around several closed paths for the circuit of Figure 1.

Path: voltage drop [V]				*v* [V]	% error
AB: 2.211	BD: -2.175	DA: -0.037	---	-0.001	-0.07
AC: -1.418	CD: 1.456	DA: -0.037	---	0.001	0.10
CB: 3.642	BD: -2.185	DA: -0.037	AC: -1.418	0.002	0.11
AX: -1.418	XY: 1.429	YA: -0.010	---	0.001	0.01

As an example, consider the first row of data in Table 1. The sum of the voltage drops is -0.001[V] and the average of the absolute values of the voltage drops AB, BD, and DA is 1.47[V]; therefore, the error is (-0.001 – 0)/1.47 x 100% = -0.07%.

Note that the last row in Table one corresponds to a closed path that doesn't go directly through circuit components. This path was chosen specifically to demonstrate that the closed path around that Kirchhoff's Voltage Law is evaluated needn't follow circuit components directly.

Kirchhoff's Current Law was evaluated at nodes A and B of the circuit shown in Figure 1. The results of the individual current measurements, as well as the sum of the currents and the percent error, are shown in Table 2. The notation preceding every current activity follows the convention delineate within the ways Section. Thus, the first row in Table 2 gives the measurement of currents leaving node A through each of the three branches; the second row gives the currents leaving node B.

As in Table 1, percent errors in Table 2 were evaluated by comparing the sum of the currents with the average of the absolute values of the currents at a node.

Table 2. Tabulation of currents leaving several nodes for the circuit of Figure 2.

Branch: current [mA]			*i* [mA]	% error
AB: 0.944	AD: 0.0085	AC: -0.953	0.00	0.00
BA: -0.943	BD: -1.406	BC: 2.388	0.039	2.5

Table 3. Tabulation of voltage drops around several closed paths for the circuit of Figure 2.

Path: voltage drop [V]				v [V]	% error
AC: -1.400	CD: -1.161	DA: 2.755	---	0.194	10.9
AD: -2.748	DB: 0.874	BC: 0.408	CA: 1.402	-0.066	-4.87

Table 4. Tabulation of currents leaving several nodes for the circuit of Figure 2.

branch: current [mA]			i [mA]	% error
AB: -0.21	AD: 0.35	AC: -0.15	-0.01	-4.22

Measurement of the voltage drops around two closed paths in the circuit of Figure 2 are given in Table 3. Table 4 shows the results of current measurements at node A of Figure 2. Note that the currents rumored in Table four ar in [A] and not [mA] as in Table two. Tabulation of p.c errors was performed as in Tables one and a couple of.

Nevertheless, it is reasonable to explore their accuracy through experimentation.

The present work documents Associate in Nursing experiment designed to check the validity of Kirchhoff's

Laws. Ohm's Law was not examined here. To test KVL and KCL, two resistive circuits were constructed. The circuits were similar except that one was engineered with resistors within the vary of 1[k] and one with resistors within the vary of 10[M]. These 2 configurations were chosen as a result of if was deemed vital to check KVL and KCL underneath conditions during which typical circuit currents were on the order of mA as well as A. In every circuit, measurements were made of the sum of the voltages around several closed paths and of the sum of the currents at several nodes. It was found that inside experimental error, KCL successfully predicted the sum of the currents at a node in all configurations tested. However, KVL was found to be accurate only on the circuit containing resistors in the 1[k] range and predicted poorly the voltages around two closed loops in the circuit containing resistors in the 10[M] range. The results obtained within the high resistance circuit aren't presently understood, however many attainable explanations are explored within the Discussion section.

Research question & Data survey chart

Although we have a tendency to assume that Kirchhoff's Voltage and Current Laws square measure correct, which they apply to circuit theory that one encounters in associate technology program, we have a tendency to withal want to explore them in the laboratory. To that finish, we have a tendency to cause the subsequent analysis queries.

> To what extent can Kirchhoff's Voltage and Current Law be validated using standard, bench-top laboratory equipment? What errors arise in investigating KVL and KCL?

Background & Figure

The predictions of Kirchhoff's Laws square measure summarized during this section. A discussion of KVL and KCL is also found in most books on circuit theory .

Kirchhoff's Voltage Law states that "the algebraical add of all the voltages v around any closed path in an exceedingly circuit equals zero" , that is,

$$\sum_i v_i = 0,$$

where the sum is taken around a closed path. Kirchhoff's Current Law states that "the algebraical add of all the currents i at any node in a very circuit equals zero" , that is,

$$\sum_i i_i = 0,$$

where the sum is carried out at a particular node. The sums are illustrated in Figure 1, where a simple resistive circuit is shown along with one closed path and one node at which KVL and KCL may be evaluated. Included in the figure are equations for the KVL and KCL corresponding to the path and node in the figure.

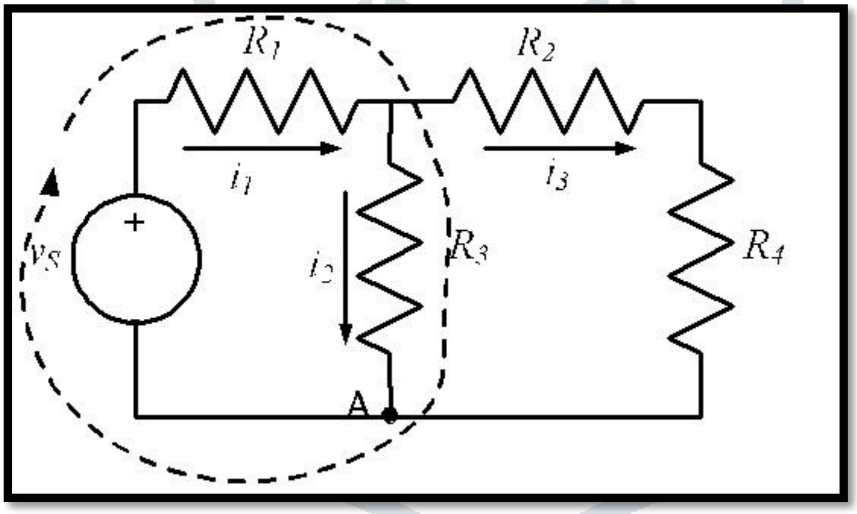

Figure 1. A simple circuit to illustrate KVL and KCL. A dotted line indicates a path along which we may apply KVL: $-v_S + i_1R_1 + i_2R_3 = 0$. Also, an essential node "A" is indicated, at which we may apply KCL: $-i_2 - i_3 + i_1 = 0$.

It is interesting to introduce simple physical interpretations of KVL and KCL. Kirchhoff's Voltage law arises from the nature of the electric field and the electrostatic force, which are conservative. Thus, the work done in moving a charged particle in the presence of a force depends only on where the charged particle starts and ends and not on the path in between. That the electric field is conservative allows us to write

$$\oint \bar{E} \cdot d\bar{l} = 0,$$

where E is the electric field and the integral is taken around a closed path. It can be shown that KVL follows from the application of Equation to an electric circuit.

KCL is based on conservation of charge, and the notion that charge does not “pile up” at a node in a circuit. Current is a flow of charge; if the number of electrons entering the node were not equal to the number leaving it, charge would build up at the node. That would result in generation of electric fields that would resist further build up of charge and tend to redistribute it away from the node. Further, conservation of charge implies that charge cannot leave the node by simply disappearing! KCL is a consequence of these ideas.

Proposed enhancement

These 2 laws change the Currents and Voltages in an exceedingly circuit to be found, ie, the circuit is claimed to be “Analysed”, and therefore the basic procedure for exploitation Kirchhoff’s Circuit Laws is as follows:

1. Assume all voltages and resistances are given.(If not label them V1, V2,… R1, R2, etc.)

2. Label each branch with a branch current. (I1, I2, I3 etc.)

3. notice Kirchhoff’s initial law equations for every node.

4. notice Kirchhoff’s second law equations for every of the freelance loops of the circuit.

5. Use Linear equation pro re nata to seek out the unknown currents.

As well as using Kirchhoffs Circuit Law to calculate the various voltages and currents circulating around a linear circuit, we can also use loop analysis to calculate the currents in each freelance loop that helps to cut back the quantity of arithmetic needed by exploitation simply law of nature. In the next tutorial concerning DC circuits, we'll look into Mesh Current Analysis to try and do simply that.

Conclusion

We have tested the predictions of Kirchhoff’s Voltage and Current Laws by measuring the sum of voltages around several closed paths, and the sum of currents at several nodes in two resistive circuits. The “low resistance” circuit was built using resistors in the range of 1[k], and the “high resistance” circuit was built using resistors in the range of 10[M]. Measurements on the low resistance circuit gave voltage and current sums very close to zero, and thus conformed to the predictions of Kirchhoff’s Laws.

Measurements on the high resistance circuit conformed to KCL; however, the sum of voltages around two closed paths in the circuit gave significant errors. We investigated several possible sources of error, but could not account for the discrepancies observed. We suspect that these errors arise from operation of the voltmeter where large resistances are present, but we do not know in detail what is causing the error.

Aside from the question of voltage measurements across large resistors, we conclude that

Kirchhoff’s Voltage and Current Laws accurately predict the sum of the voltage drops around a closed path and the sum of the currents at a node in the resistive circuits examined here. Further, because of the random nature of the circuits investigated here, we feel confident in concluding that in fact KVL and KCL accurately predict the behaviour of resistive circuits.

Recommendation

In general, the results obtained during this experiment were needless to say from thought of

circuit theory. The results of measurements on the “low resistance” circuit of Figure one, that got in Tables one and a pair of, agree well with the predictions of KVL and KCL. The sums of voltage drops around 3 closed ways were no over 2[mV] in magnitude, giving errors on the order of zero.1%; the sum of currents at a node was zero in one case and solely 39[mA] (2.47% error) in another.

The results of measurements on the “high resistance” circuit of Figure 2, given in Tables 3 and 4, were not as easy to interpret. The percent error in the current measurement was higher than that for the low resistance circuit, perhaps because typical current in the high resistance circuit was small. However, absolutely the error was quite tiny (-0.01[mA]) and that we feel even in suggesting that KCL was verified during this case. Interestingly, a discrepancy between theory and experiment for the high resistance circuit arose within the KVL measure. There we observed absolute and percent errors much larger than in any other measurement, so that it is not completely clear that KVL was verified. The reason for this discrepancy is not understood, but we consider possible sources of error in the following discussion.

We discovered throughout the course of those measurements that the worth of the voltage supply was “drifting”, i.e., dynamic slowly with time. The rate of drift was quite tiny (perhaps zero.05[V] over several minutes), so that the voltage source changed negligibly during the course of a single KVL or KCL measurement. Therefore, drift within the voltage supply is perhaps not liable for the massive errors in Table three.

The only probably remaining supply of error in Table three is that the meter itself. We checked for drift within the reading by keeping the probes connected to the circuit for regarding one minute, but did not notice a significant change. We so suspect that the errors in Table three are because of details within the operation of the meter once giant resistances are gift. We are presently planning new experiments to test this idea.

Acknowledgement

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