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COURSE **:** ECS 204 Basic Electrical Engineering Lab
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WEB SITE : http://www2.siit.tu.ac.th/prapun/ecs204/
EXPERIMENT : 02 Network Theorems I: Thevenin & Norton Theorems.

I. OBJECTIVES

1. To verify Thevenin's theorem for resistive circuits.
2. To verify Norton's theorem for resistive circuits.
3. To learn how to construct a current source from the power supply.
4. To become familiar with potentiometer.

II. BASIC INFORMATION

Let's consider a linear circuit whose two terminals *a* and *b* are connected to an arbitrary load. Thevenin's and Norton's theorems assert that the circuit can thus be replaced by either a **Thevenin** or a **Norton equivalent circuit**, which acts like the original circuit across the load connected to the two terminals. Thevenin and Norton theorems are very useful in circuit analysis for simplifying parts of complicated circuits.

For resistive circuits, the Thevenin equivalent circuit (shown in Figure 2-1) simply consists of a Thevenin voltage source V_{TH} in series with a Thevenin resistance R_{TH}, while the Norton equivalent circuit (shown in Figure 2-2) consists of a Norton current source I_N in parallel with a Norton resistance, which is the same as R_{TH}. V_{TH} can be determined from the open-circuit voltage across terminals *a-b*, i.e., the voltage across the two terminals when the load is disconnected. R_{TH} is the equivalent resistance of the circuit with respect to terminals *a-b* after ***deactivating*** all independent sources in the circuit and disconnecting the load. I_N can be determined from the short-circuit current at terminals *a*-*b*, i.e., the current flowing through the short-circuit connecting terminals *a*-*b*.

Reminders:

(1) A voltage source is deactivated when it gives 0 V. In which case, it becomes a short connection.

(2) A current source is deactivated when it gives 0 A. In which case, it becomes an open connection.

(3) We may use the terms "turn off" or "disable" instead of "deactivate". They do not necessarily mean powering off the power supply.

II.1. Thevenin's theorem

Thevenin's theorem provides a method for simplifying a circuit to a standard equivalent form. As shown in Figure 2-1, the Thevenin equivalent circuit consists of

a) a Thevenin equivalent voltage source (V_{TH}) in series with

b) a Thevenin equivalent resistance (R_{TH}).

V_{TH} and R_{TH} can be found, when R_{Load} is disconnected from nodes a and b. The Thevenin voltage V_{TH} is defined as the open-circuit voltage between nodes *a* and *b*. R_{TH} is the total resistance appearing between *a* and *b* when all sources are deactivated. This series combination of V_{TH} and R_{TH} is ***equivalent*** to the original circuit in the sense that if we connect the same load across terminals *a*-*b* of each circuit, we will get the same voltage and current at the terminals of the load. This equivalence holds for all possible values of load resistance.

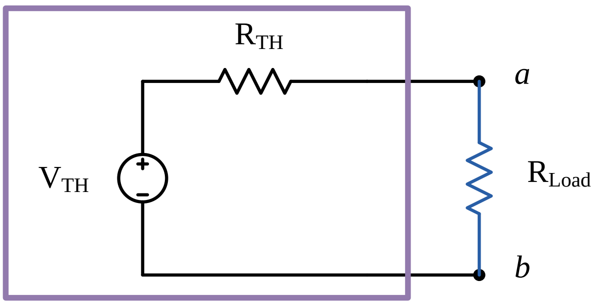

Figure 2-1: Thevenin equivalent circuit.

II.2. Norton's theorem

The Norton equivalent circuit consists of *an independent current source* (I_N) in parallel with an equivalent *resistance* (R_N), arranged as shown in Figure 2-2. We can simply derive this equivalent circuit from the Thevenin equivalent circuit by using the source transformation concept. Thus, the Norton current actually equals the short-circuit current at the terminals *a-b*, and the Norton resistance is identical to the Thevenin resistance.

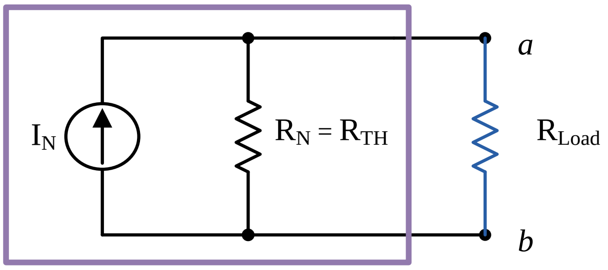

Figure 2-2: Norton equivalent circuit.

Example: Figure 2-3-a shows an example of a circuit whose ***load resistor is disconnected*** to nodes a and b, creating an open circuit, so that the Thevenin voltage V_{TH} can be measured between nodes a and b (e.g. using a voltmeter). In addition, Figure 2-3-b illustrates the same circuit, with the load resistor disconnected, allowing measurement of the Thevenin resistance R_{TH} (e.g. using an ohmmether across nodes a and b) when all voltage sources are replaced with a short circuit and all current sources are replaced with an open circuit.

Figure 2-3-c shows an example of a circuit whose ***load resistor is disconnected*** from nodes a and b and then a short circuit is created between the two nodes so that a Norton current I_N can be measured (e.g. using an ampmeter). In addition, the Norton equivalent resistance R_N can be obtained in a similar manner as R_{TH} shown in Figure 2-3-b. Figure 2-3-d illustrates the Thevenin and Norton equivalent circuits derived in this example.

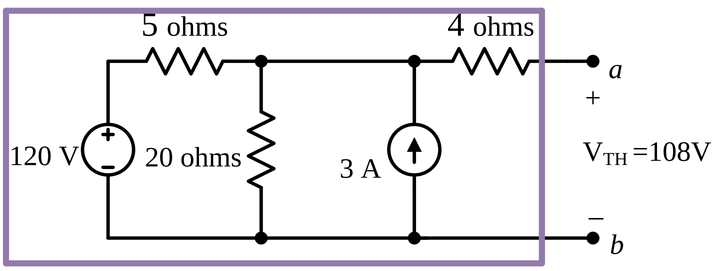

Figure 2-3-a: A circuit used for illustrating the Thevenin's and Norton's theorems.

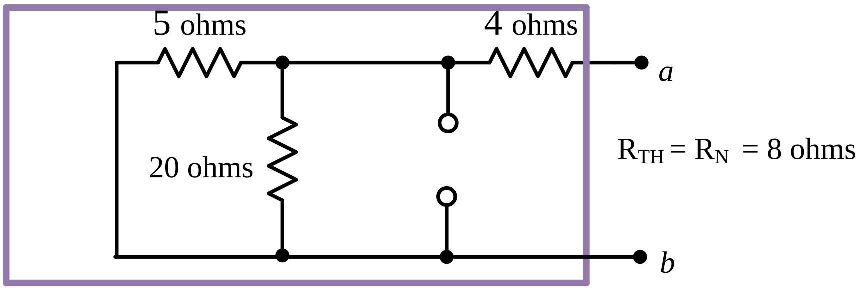

Figure 2-3-b: The circuit with the voltage and the current sources deactivated to find R_{TH}.

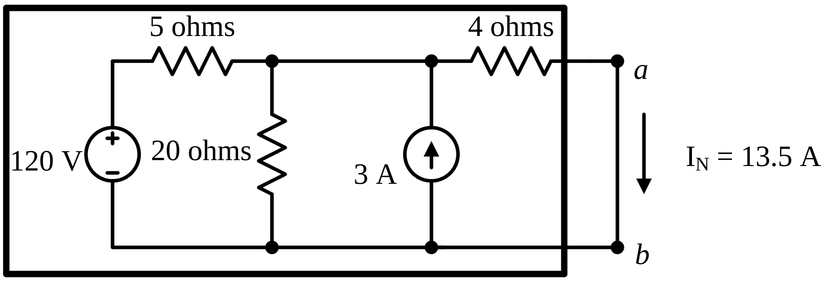

Figure 2-3-c: The circuit with the short-circuit between *a*-*b* for finding the Norton current.

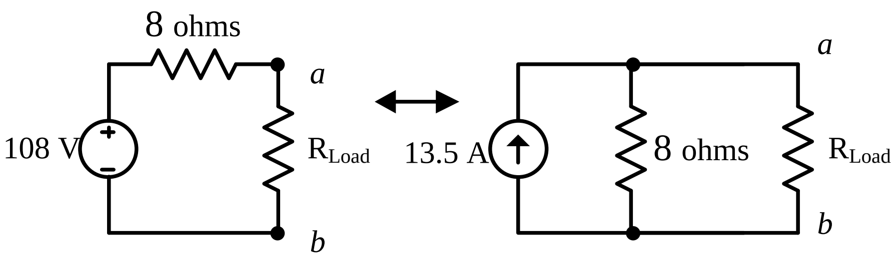

Figure 2-3-d-: The Thevenin and Norton equivalent circuits.

Note that $V_{TH} = I_N \times R_{TH}$.

III. MATERIALS REQUIRED

- DC power supplies
- Multi-meters
- Resistors (1/4-W):

  470-Ω, 1.2-kΩ, 10-kΩ, two of 330-Ω, and a potentiometer (variable resistor).

IV. PROCEDURE

Part A: Thevenin equivalent circuit

1. Let R_1= 330 Ω, R_2 = 470 Ω, R_3 = 330 Ω, and R_L = 1.2 kΩ. Use a DMM to measure the resistance of each resistor, and record the values in Table 2-1.
2. Turn on the power supply, and measure its output voltage V_{PS}. Adjust V_{PS} to 12 V. Record the measured value of V_{PS} in Table 2-1.
3. Connect the circuit in Figure 2-4.

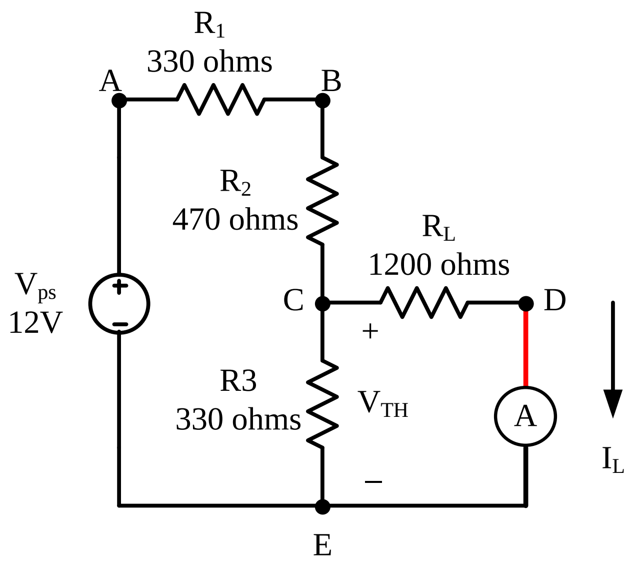

Figure 2-4: The circuit for verifying Thevenin's and Norton's theorems. The current I_L through the load is measured by the ammeter A.

4. Measure I_L (the current through R_L), and record this value in Table 2-1, under the column "Original circuit."
5. Disconnect and remove R_L from the circuit, and measure the voltage across node C-E. This is V_{TH}. Record the value in Table 2-1 under the "V_{TH} Measured" column.
6. **Turn off** the power supply, and **disconnect** it from the circuit.
7. **Short A-E** by connecting a wire across node A and E.
8. With R_L still disconnected, measure the resistance across nodes C and E. This is R_{TH}. Record the value in Table 2-1 under the "R_{TH} measured" column.

9. Now we will build the Thevenin equivalent circuit. The circuit shown in Figure 2-5 is our implementation of Figure 2-1. To do this, adjust the power supply so that V_{PS} = V_{TH}, which has been previously measured. Connect a DMM in the resistance measurement mode across the potentiometer, and adjust its resistance until the value of R_{TH} is obtained. Record the values of V_{TH} (across the power supple) and R_{TH} (across the potentiometer) in Table 2-1.
10. Connect the circuit as in Figure 2-5. This is the Thevenin equivalent circuit of the circuit in Figure 2-4.

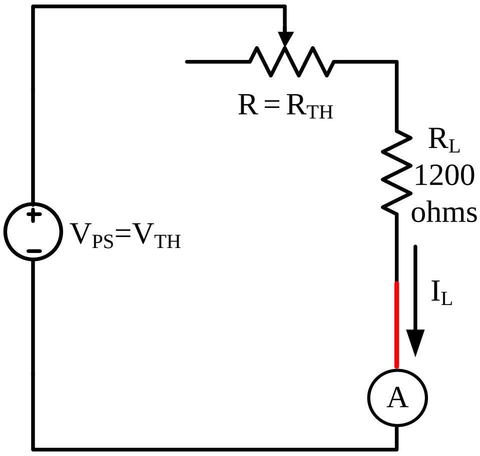

Figure 2-5: Thevenin equivalent circuit. The current I_L through the load is measured by the ammeter A.

11. Measure I_L, and record the value in Table 2-1 under the "Thevenin equivalent circuit, measured" column. Turn off the power supply.
12. Use the values of V_{PS}, R_1, R_2, and R_3 to calculate V_{TH} for the circuit in Figure 2-4. Record your result in Table 2-1 under "V_{TH} calculated."
13. Calculate R_{TH} in Figure 2-4 using the values of R_1, R_2, and R_3. Record your result in Table 2-1 under "R_{TH}, calculated."
14. Use the calculated values of V_{TH} and R_{TH} to calculate I_L. Record the result under "I_L calculated."

Part B: Norton equivalent circuit

1. From the value of I_L and R_{TH} in Part A, **copy** values of I_L and R_{TH} in Table 2-2, under "I_L measured, Original circuit" and "R_N calculated," respectively.

2. Turn on the power supply, and adjust it back to V_{PS} = 12V. Record the measured value of V_{PS} in Table 2-2. Connect the circuit in Figure 2-4 again.

   To measure I_N, short circuit across R_L (from node C to node D), and measure the short-circuit current.[1] Think about why R_L does not have to be removed.

   Record the value in Table 2-2 under the column "I_N Measured."

3. Now we will build the Norton equivalent circuit. The circuit shown in Figure 2-6 is our implementation of Figure 2-2. To do this, first adjust the potentiometer until the resistance value is equal to the value of "R_{TH}, measured" in Table 2-1 recorded from step A.9. (It should already be at this value.) This will be your R_N. Record the actual (remeasured) resistance value across the potentiometer in Table 2-2 under the column "R_N Measured."

   Now, for the current source, set the output of the power supply to its lowest value, i.e., 0 V. Connect the circuit shown in Figure 2-6. Meter A1 will be used to measure the Norton current source IN in step 4. Meter A2 will be used in step B.5 to measure the load current I_L. Note that with one DMM, use it as Meter A1 here and then use it as Meter A2 in step 5.

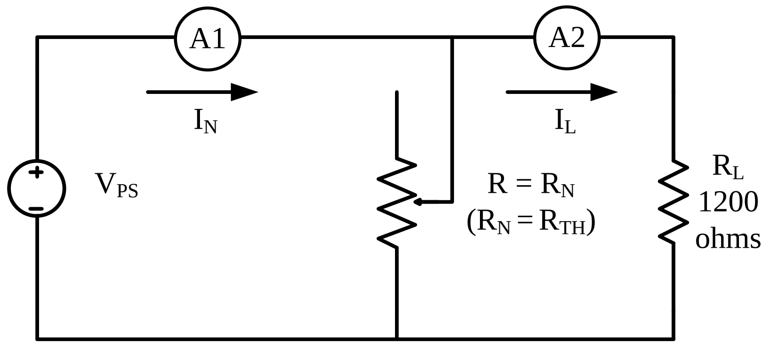

Figure 2-6: Norton equivalent circuit. Note that in step B.2 the DMM is used as ammeter A1 to measure the amount of current flowing out of the power supply. Then, it is used as ammeter A2 in step B.5.

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[1] Note that this is the same as putting an ammeter across R_L in Figure 2-4. The ammeter itself acts as the short circuit across R_L and it also displays the value of the short-circuit current. Alternatively, to measure I_N, we can simply replace R_L with an ammeter.

4. Turn on the power supply and **slowly** increase the output of the supply until the current measured by DMM A1 is equal to the value of I_N, which has been previously measured. Record the value of I_N that you get from DMM A1 in Table 2-2. Also, Record the power supply voltage V_{PS} that achieves this value of I_N in Table 2-2.
5. Record the load current I_L measured by DMM A2 in Table 2-2 under the "Norton equivalent circuit, measured" column. Turn off the power.
6. Calculate the value of I_N from the circuit of Figure 2-4, and record your result in Table 2-2 under "I_N calculated."
7. Calculate I_L by using the calculated values of I_N and R_N. Record your result in Table 2-2 under "I_L, calculated".

Remark: Since the current source is not available in the lab, this part of the experiment is modified to suit our objective by adjusting V_{PS} in order to obtain the current I_N.

Tips: From now on, when you are asked to use a current source, replace it by a power supply (voltage source) and connect the rest of the circuit. Then, adjust the value of the output voltage of the power supply so that the required amount of current passes through it.

Caution: Because power supply is not a true current source, when you make any change to the circuit connection, the value of the current that pass through the voltage source may change. You will need to ***readjust*** the voltage value of the power supply (voltage source) so that the required amount of current passes through it every time that you make any change to the circuit.

Caution 2: DO NOT connect the DMM in its ammeter mode directly to the power supply. The amount of current coming out of the power supply when there is nothing connected to it except the DMM is meaningless.

Table 2-1: Thevenin equivalent circuit

Measured: R_1 = ___________ R_2 = __________ R_3 = ____________ R_L = ____________

V_{PS} = ____________ (A.2)

V_{TH}		R_{TH}		I_L		
				Measured		
Measured	Calculated	Measured	Calculated	Original circuit	Thevenin equivalent circuit	Calculated
A.5	A.12	A.8	A.13	A.4	A.11	A.14
A.9		A.9				

TA Signature:

Table 2-2: Norton equivalent circuit

V_{PS} = ____________ (B.2)

V_{PS} = ____________ (B.4)

I_N		R_N		I_L		
				Measured		
Measured	Calculated	Measured	Calculated	Original Circuit	Norton equivalent Circuit	Calculated
B.2	B.6	B.3	B.1	B.1	B.5	B.7
B.4						

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V. **QUESTIONS**

1. Consider the circuit given in Figure 2-4.

   If R_3 is replaced by a 1200-Ω resistor, find the following values.

   V_{TH} = ____________ V

   R_{TH} = ____________ Ω

   I_L = ____________ mA

   If R_L is also replaced by a 120-Ω resistor, determine the voltage and current at R_L.

2. In step 2 of part B, we tried to measure I_N. Why can we leave R_L in the circuit?

3. For the circuit below, suppose $R_N = R_L = 4$ kΩ. What is the value of the voltage source that will produce the current $I_N = 3$ mA?