Unit 20 Norton's theorem

- Any linear two terminal electronic system can be fully modelled by a current source, I_S, in parallel with a shunt impedance Z_{out}.

- A current source drives a constant current through any circuit connected to it. The circuit symbol used for a current source is two intersecting circles as shown in the diagram.

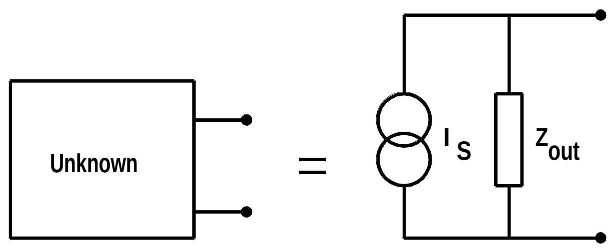

Figure 20.1: Norton equivalent circuit.

This theorem is the complement of Thévenin's theorem but uses current sources and can therefore give an alternative analysis viewpoint for circuits. The one disadvantage is that examples of constant current sources are not as readily available as examples of voltage sources.

Perhaps the simplest way of viewing a current source is to visualize it as a high voltage source in series with a large series resistor, as shown in Figure 20.2.

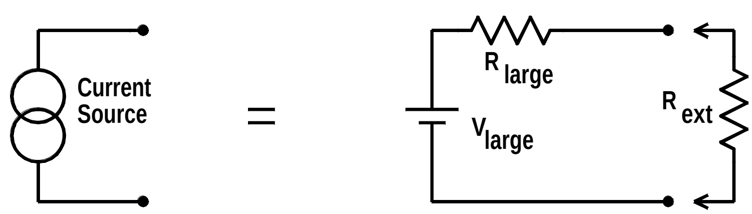

Figure 20.2: Current source.

For a wide range of externally connected resistors, the current will be essentially independent of the external resistance because if:

$$R_{large} \gg R_{ext} \quad \text{then} \quad \frac{V_{large}}{R_{large} + R_{ext}} \approx \frac{V_{large}}{R_{large}} = I_S$$

For comparison purposes, the characteristic curves for a voltage source and for a current source are shown in Figure 20.3.

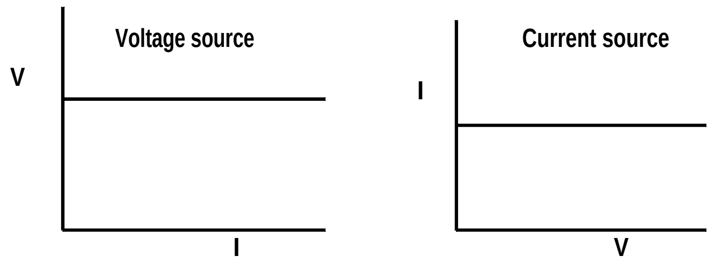

Figure 20.3: I–V characteristics of voltage and current sources.

In modelling circuit devices and systems, either the Thévenin or the Norton approach can be taken but the characteristics of the device being modelled should be examined and if the characteristics approximate to those of a voltage source (see Figure 20.3) then the Thévenin method is appropriate. If the device characteristic approximates the current source, then the Norton approach is more appropriate.

Examples of devices and systems where the Thévenin approach is appropriate are: batteries, diodes, DC constant voltage power supplies, audio and RF signal generators, lead acid battery chargers. Examples of suitable applications of the Norton analysis approach are: photodiodes in reverse bias, output characteristics of transistors and FETs in amplifiers, NiCd battery chargers, constant current supplies for fluorescent lamps and laboratory spectral lamps.

We will see in the worked examples that it is easy to convert from one model to another so it is possible to model circuit systems quite effectively using either method. However, some insight into the circuit system is lost if an inappropriate model is used.

There is frequently a control panel adjustment for the Thévenin voltage or the Norton current source which allows the operator to set the output to the required value. Once set, the system then gives constant output. You should take care with the usage of the terms variable, fixed and constant as applied to voltage and current sources.

In order to measure the Norton equivalent of any circuit, it is only necessary to measure the open circuit voltage and the short circuit current.

- The current source is given by: I_S = Short circuit current.
- The output impedance is given by: $Z_{out} = \frac{V_{open\ circuit}}{I_{short\ circuit}}$

20.1 Examples

20.1 Convert from Thévenin to Norton equivalent circuit: calculate the Norton equivalent circuit of the Thévenin circuit shown in Figure 20.4.

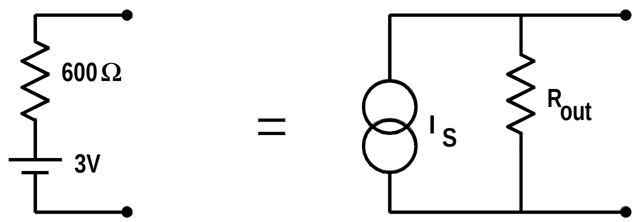

Figure 20.4: Example 20.1.

Short circuit current:

The Norton current source is given by:

$$\begin{aligned} I_S &= I_{short\ circuit} \\ &= \frac{V_{out}}{R_{out}} \\ &= \frac{3\,\mathrm{V}}{600\,\Omega} \\ &= 5\,\mathrm{mA} \end{aligned}$$

Open circuit voltage:

The output voltage from the Norton circuit is:

$$\begin{aligned} V_{out} &= V_{open\ circuit} \\ &= I_S \times R_{out} \\ \text{Therefore} \quad 3\,\mathrm{V} &= 5\,\mathrm{mA} \times R_{out} \\ R_{out} &= \frac{3\,\mathrm{V}}{5\,\mathrm{mA}} \\ &= 600\,\Omega \end{aligned}$$

20.2 Convert from Norton to Thévenin equivalent circuit: calculate the Thévenin equivalent of the Norton circuit shown in Figure 20.5.

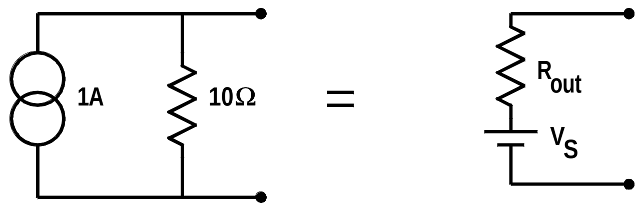

Figure 20.5: Thévenin equivalent of Norton circuit.

$$\text{Open circuit voltage } V_{out} = I_S \times R_S = 1\,\mathrm{A} \times 10\,\Omega = 10\,\mathrm{V}$$

$$\text{Short circuit current } I_{short\ circuit} = \frac{V_S}{R_{out}} = 1\,\mathrm{A}$$

$$\text{Therefore} \quad R_{out} = \frac{10\,\mathrm{V}}{1\,\mathrm{A}} = 10\,\Omega$$

20.2 Problems

20.1 Calculate the Norton equivalent of the circuit shown in Figure 20.6.

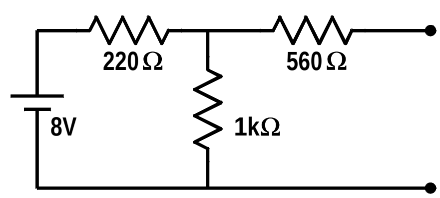

Figure 20.6: Problem 20.1.

20.2 Calculate the Norton equivalent of the circuit shown in Figure 20.7.

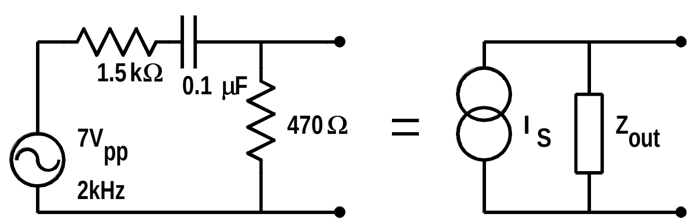

Figure 20.7: Problem 20.2.