

Real Power Sources: Static Characteristics

The primitive elements which have been defined so far are intended to describe aspects of energetic behavior and they can be used in the construction of detailed models of specific physical systems. We should also be able to use energetic considerations to draw some general conclusions about behavior common to all physical systems; after all, that is one of the advertised benefits of an energy-based formalism. In this section we will briefly consider some physical limitations of real power sources (or sinks). Real power sources will exhibit dynamic behavior, but we will confine ourselves for the present to their static characteristics.

As defined above, an ideal effort source could sustain that effort even if its output flow grew to infinity and therefore, in principle, it could deliver infinite power; the same is true for an ideal flow source. This is unlikely, to say the least; the amount of power which can be delivered by any real device built to date is limited. The static behavior of any power supply may be characterized as a relation between effort and flow. The maximum power output defines a hyperbola on the effort-flow plane

$$e f = P_{\max} \quad (3.33)$$

where P_{\max} is the maximum power output. If its output power is limited, the effort-flow relation of the power source must remain within this bound, therefore the effort developed by any real power supply must decline as the output flow becomes sufficiently large. Conversely, the flow produced must decline as the effort required grows sufficiently large.

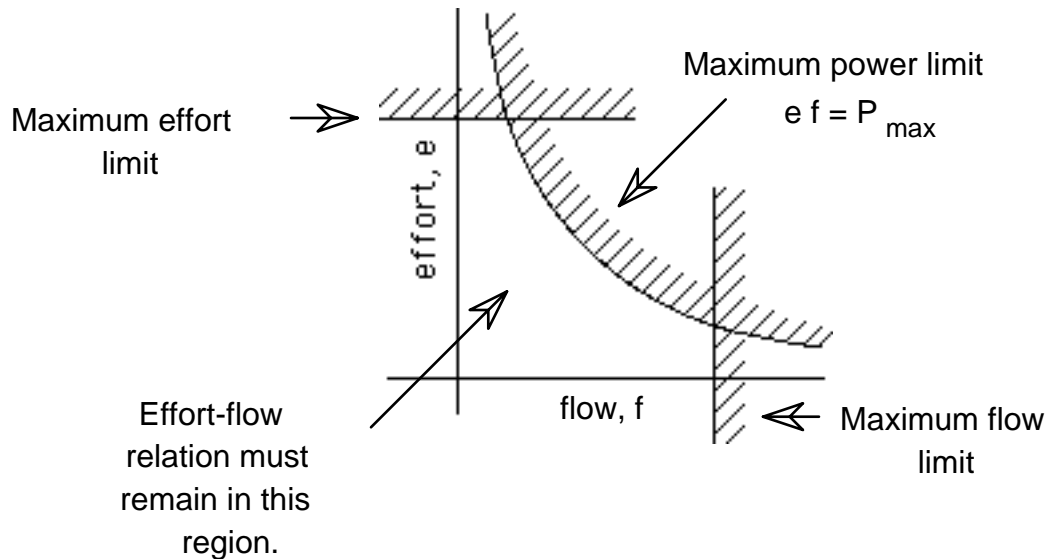


Figure 3.33: Common limitations of real power sources.

The limitation on power output does not preclude infinite effort at zero flow, nor infinite flow at zero effort, but no real device can generate infinite flow or withstand infinite effort. The maximum effort limit is a horizontal line on the effort-flow plane; the maximum flow limit is a

vertical line. All of these limitations are illustrated in figure 3.33 for the first quadrant¹. The effort-flow relation of the power source must stay below and to the left of these bounds. Similar limitations apply in the other quadrants.

Reasoning this way, we may conclude that all real power sources must exhibit some dependence of effort on flow (or vice versa). A relation between effort and flow suggests a dissipator and if the effort-flow relation is limited as described above, it is possible to describe this aspect of any real power source by a combination of an ideal source and a dissipator as we did for the battery. There are two possible forms. One is a combination of an ideal effort source and a resistor coupled to a one junction as shown in figure 3.34. This is a generalized *Thevenin equivalent network* and the figure is a bond graph version of figure 3.3.

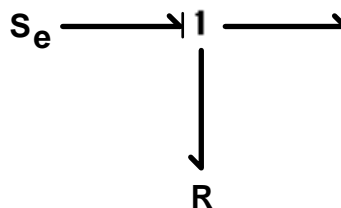


Figure 3.34: Bond graph symbol for a Thevenin equivalent network.

In this bond graph, the half arrows indicate that positive power is directed out of the ideal source element and also out of the network; a reasonable choice for a model of a power source. Following convention, positive power is directed into the dissipator.

The other form uses an ideal flow source and an ideal resistor coupled to a zero junction as shown in figure 3.35. This is a generalized *Norton equivalent network*.

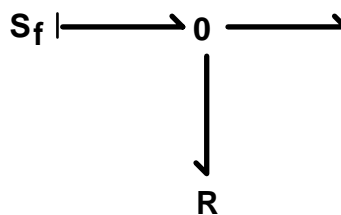


Figure 3.35: Bond graph symbol for a Norton equivalent network.

These two networks provide versatile, general-purpose models for describing the static characteristics of real power sources. Note that if the constitutive equation of the dissipator in these models can be inverted, the two networks are *duals* and may be interchanged freely.

¹ Note that in this figure we have assumed that positive power flow is directed out of the device.