HISTORICAL NOTE: The Electric Light

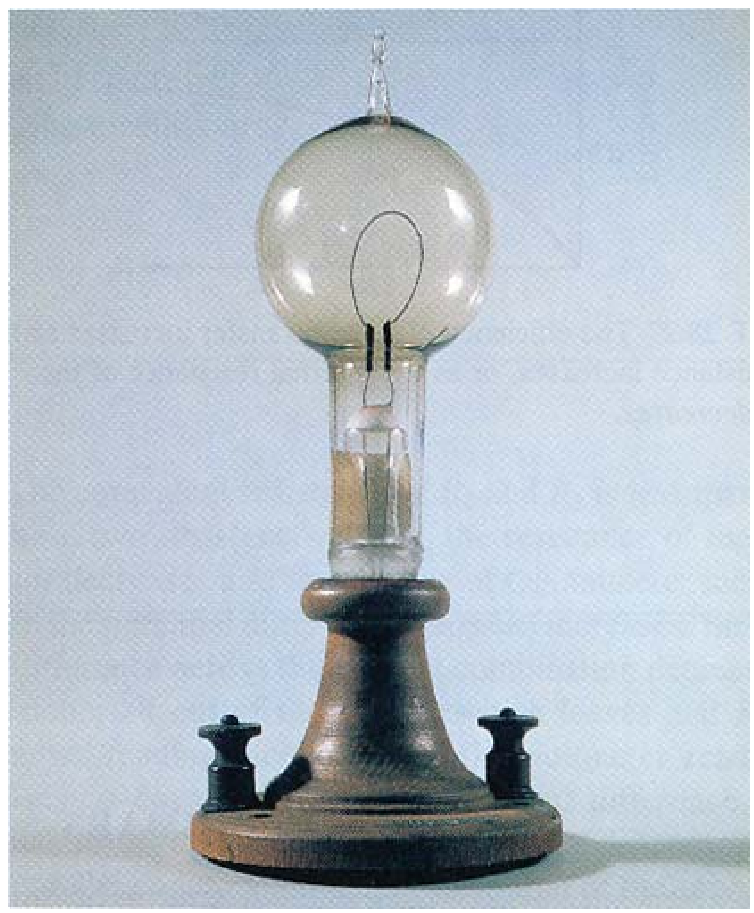
In the early 19th century, gas lighting was commonplace. By 1850 however, the arc light, produced by electrical discharges between two carbon rods held a small distance apart, was used in lighthouses, in railway stations, and for street lighting. When Thomas Edison, inventor of the phonograph, visited one of the first displays of arc lights in 1877, he was entranced and immediately thought of the possibility of installing electric lights in every home and office. However, arc lights were very bright and produced noxious fumes, which meant they were suitable only for large open spaces. He decided that the incandescent lamp, in which light is given off by an electrically heated filament, would produce a softer illumination and was therefore a better source of light---although such lamps had not been very successful thus far.

In 1878 Edison boldly set up the Edison Electric light Co. and, on the strength of his reputation, got financial backing for it. Edison boasted that he would soon develop a complete distribution system for electricity that would run lights and electric motors, and serve other industrial purposes. Because of the publicity, gas company shares fell sharply both in the United States and in England. A committee of the British parliament, aided by prominent scientists, was appointed to look into the feasibility of Edison's plans.

An important feature of the gas distribution system already in use was that each consumer could switch the supply on or off. Any electrical system would clearly have to allow a similar "subdivision of the electric light." Arc lights had a resistance of about 5 Ω and required a current of 10 A. They were normally connected in a series circuit of about ten lamps. Of course, if one lamp was disconnected, all the lamps went out. In order to allow some lights to be on while others were off, they would have to be connected in parallel. But ten arc lights in parallel would require 100 A---which was already beyond the capability of any existing electrical generator. The few short-lived incandescent lamps that had been produced up to that time had resistances of about 0.5 Ω . If the power required by each incandescent light was about the same as that for an arc light, the current required would be much greater. Yet Edison was talking of thousands of lights! The transmission cables would have to handle very high currents without overheating, which meant that vast amounts of copper would be required. The British committee concluded that the "subdivision of the electric light" was an impossibility. But, as Napoleon once said, "Impossible is a word in the dictionary of fools." Edison felt much the same way. If gas could be subdivided, why not electricity?

A New Lamp

From the equation for power, $P = I^2R$ Edison realized that a given quantity of power could be delivered either by a large current to a low resistance, or, by a low current to a large resistance. To minimize the current in the transmission lines, he needed a lamp with a *high* resistance. His initial attempts with carbon filaments were unsuccessful because they tended to burn up (oxidize in the air that remained in the glass bulbs). Other materials met the same fate. In January 1879 he was able to borrow a new vacuum pump and with it attained the highest vacuum that had ever been achieved (10^{-6} atm). Nonetheless, after one year of work, his best effort was a Pt-Ir spiral whose resistance was 3 Ω . He then read an article in the July issue of *Scientific American* describing the carbon filament lamp of the Englishman Joseph Swan. It had worked only for a few hours. Edison had not tried carbon with the new vacuum pump, so he returned to carbon. By November 1879 he had developed a carbonized filament that had a resistance of 100 Ω . Over a period of about 15 months, he had tried over 1600 materials! Figure 1 shows an early filament lamp.



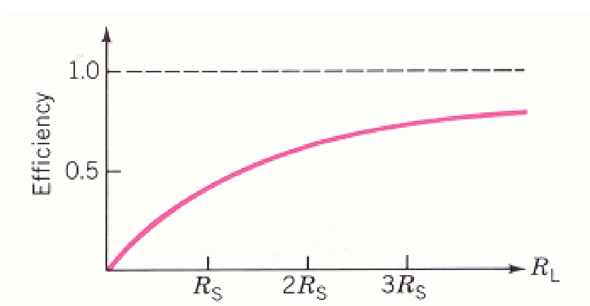
FIGUE 1. An early filament lamp

A New Generator

It was shown in Example that maximum transfer of power occurs when the internal resistance of the source of emf is equal to the external resistance. All previous electrical generators had been designed with this principle in mind. Furthermore, their efficiency in converting mechanical energy to electrical energy was under 40% and each could supply only a few arc lights. With great insight, Edison saw a flaw in this approach. The efficiency *of* power transfer can be defined as the ratio

$$Efficiency = \frac{P_L}{P_S + P_L} = \frac{R_L}{R_S + R_L}$$

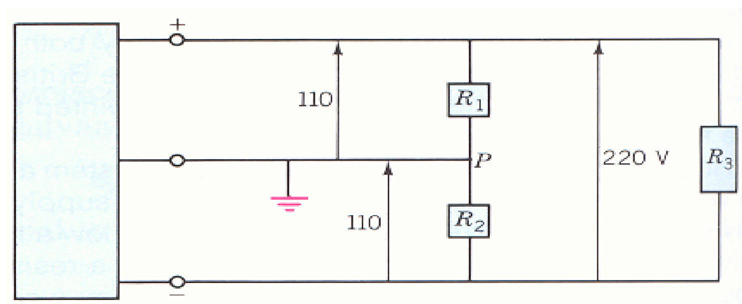
where $P_L = I^2R_L$ is the power delivered to the load resistance R_L and $Ps = I^2R_S$ is the power lost in the source resistance *Rs*. When $Rs = R_L$ fully one-half *of* the electrical power generated is lost in the generator itself. The power transferred is a maximum, but the *efficiency* is only 0.5 or 50%. Figure 2 shows how the efficiency of power transfer varies with the external resistance. The efficiency approaches 1 as $Rs \rightarrow 0$ or $R_L \rightarrow \infty$. Clearly, the greatest efficiency is obtained when the internal resistance of the source is as *small* as possible and the external resistance is as *large* as possible. With this new insight, Francis Upton, an electrical engineer hired by Edison, designed a new type *of* dc electrical generator that included many of the latest developments. It converted mechanical energy to electrical energy with an efficiency of 90% and produced a relatively constant 110 V even if the output current varied.



FIGUE 2. The efficiency of power transfer increases as the load resistance increases, or as the internal resistance of the source *decrease.*

A New Distribution System

Edison next devised a three-wire system for distributing electrical power that is still used to supply homes and offices---although nowadays it operates an alternating current rather than direct current as he had envisioned. Figure 3 shows a source of emf with three terminals. (Edison actually used two generators in series.) A potential difference of 110 V exists between the center terminal and each of the other two-one positive and the other negative. The 110-V loads are represented by two resistors R_1 and R_2. If only R_1 or R_2 is connected, current will flow through the ground wire and one of the other wires. When both resistors are connected, the current in the central ground wire, $Ig = I_2 - I_1$, is determined by the potential at the point *P* relative to ground. However, if $R_1 = R_2$, the potential at *P* will be midway between +11 0 V and -110 V---that is, it will be zero. Therefore, if the loads are "balanced," there will be *no* current in the ground connection. Instead of heating losses in all three transmission wires, there are losses only in the "hot" wires. A further advantage of the three-wire system is that two potential differences are available: 110 V for light duty, and 220 V for heavier-duty appliances, such as ovens and clothes dryers, which are connected between the two "hot" wires.



FGURE 3. Edison's three-wire system for electrical power distribution. By having the load resistances R_1 and R_2 almost equal, the point *P* is kept close to the ground potential or the center terminal or the source. Consequently the power loss in the middle wire is very low.