PART II

AC Power

Back in the late 1880's, there was a series of events called "The War of the Currents." In short, Thomas Edison was backing DC (direct current) systems and George Westinghouse/Nikola Tesla were backing AC (alternating current) systems. There was a major motion picture about it called *The Current Wars*, which starred Benedict Cumberbatch as Edison (even though he's obviously more of a Tesla). DC, while useful in the beginnings of electric power for things like incandescent bulbs and smaller electric motors, struggled when it came to long-distance transmission (more on this in a second). Therefore, many of the loads had to be located relatively close to the DC power generating stations - a major flaw.

The alternating nature of the AC systems, however, meant that these alternating *electric* quantities also generated alternating *magnetic* fields (e.g. Faraday's Law). If you've ever used a wireless charger for your phone or electric toothbrush, you've witnessed the magic of what these magnetic fields can do. Electric current typically only flows through a conductor - usually a wire. However, magnetic fields can flow throughout air more easily, and thus, wireless power transfer. Devices like *transformers* rely on this concept - and can only be effectively utilized with AC and not DC (see Fig. iv).

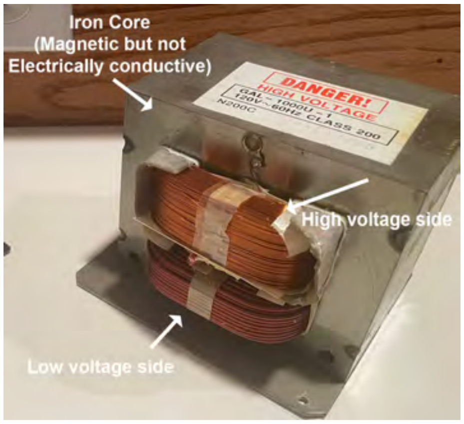

Fig. iv A transformer from a microwave. The copper windings labeled "low voltage side" is connected to the 120 V outlet. The "high voltage side" is the side connected to the microwave, because microwaves require higher voltages (≈2000 V) to operate. The iron "core" surrounding these windings electrically separates them - no electrons from the wall ever flow through the wires connected to the microwave. The energy is transferred via magnetic fields. Note that an inductor has one coil of wire; a transformer has two.

So, that's cool and all, but what does wireless power transfer have to do with making AC more efficient to deliver across distances than DC? Because *alternating* current means that transformers can be used in order to *efficiently change voltage levels* using the generated magnetic fields. And as we saw with the microwave, a lot of devices in your home use different voltage levels, meaning that being able to change them efficiently is key. Higher voltage also means lower levels of current for the same amount of power transfer, which has multiple benefits, including more efficient long-distance transmission.

Take a look at Fig. iv again. There are two sets of copper windings, each with a different number of turns of the wire, and different wire sizes, too.

Ignoring losses for a second (transformers are actually very efficient!), we can assume the power going into the transformer (coming from the wall) equals the power going out (to eventually heat your food). If power is a function of both voltage and current, we know that for a fixed level of power, if voltage goes up, current must go down, and vice versa. That means the high voltage side has a lower current than the low voltage side. This makes sense when we look at the size of the wires - the low voltage side has bigger wires, indicating that those wires are sized to have more current flowing through them.

Current flows from the outlet where the microwave is plugged in through the low voltage (120 V) side, and that alternating current generates an alternating magnetic field, wirelessly transferring energy to the high voltage (2000 V) side. The number of times the copper wire is wound around the iron core affects the voltage change. You can see that the high voltage side has smaller wires (for the smaller current needs) but a lot more turns of the wire, which creates a larger voltage drop on that side of the transformer.

The iron core helps facilitate this energy transfer - iron has good magnetic properties. So, we were able to transfer power and change the voltage, efficiently, with a transformer. We could change what voltage we wanted on the output by changing the number of times the wire was wrapped around the core, too (making sure the size of the wire changed to be able to carry enough current without overheating, of course!).

The ability to more efficiently change the level of voltages using transformers was a key reason that AC "won" the current wars. Being able to cost effectively transmit power at higher voltages lowered the amount of current flowing through the wires, which 1) made wires smaller, and thus lowered the materials required to deliver the same amount of power; and 2) lowered the amount of heat generated in the wires, which lowered losses. This allowed many more consumers to access electric power, not just those close to generating stations. The importance of transformers cannot be understated.

Now, with great AC power comes great AC responsibility. A byproduct of using AC power is that, unlike DC power, we now have *different types of power*. With DC circuits, power is equal to voltage multiplied by current ($P = IV$). In AC circuits, this gets a bit more complicated. The next few sections will help us understand what these types are, where they come from, and their importance in the power grid.

Transformers. Transformers are devices that are used to change voltage and current levels throughout the grid. They rely on using changing magnetic fields, which only AC power generates, to transfer power wirelessly from the input to output sides of the transformer.

The voltage on the output side of the transformer V_{out} is related to the input voltage V_{in} via a simple ratio of the number of turns of copper wire on the output side N_{out} and number of turns of wire on the input side N_{in}:

$$V_{out} = \frac{N_{out}}{N_{in}} V_{in} \tag{1}$$

In practice, many transformers have the ability to change N_o (either manually or automatically) to raise or lower output voltages to adjust to grid needs. These are called "tap changing transformers." There are a *lot* of different types of transformers, but this is the basic idea. Two that you may see around your neighborhood supplying power to homes are shown in Fig. v.

Fig. v Pad-mounted transformer (left), indicating underground distribution lines, and pole-mounted transformer (right), indicating above-ground lines.