

# Electrical Power

*A brief primer*

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Chances are you haven't given much thought to how electricity shows up at the outlets in your room or apartment. You just plug in your TV, radio, or other device and it works—provided there's no storm that caused a power outage, of course. You might think that the electricity is transmitted from the power station directly to your place, but this is not the case. It's actually transmitted at a much higher voltage, and “stepped down” to a lower voltage through a series of transformers before it ever shows up at your receptacle. The power from your standard outlet is at a voltage of  $120 \text{ V}_{AC}$ <sup>1</sup>, enough to give you a jolt, but generally not enough to immediately kill you (believe me, I know, having often been on the receiving end). However, at the power station it's generated at 6,600, 13,200, or 18,000 V and then for transmission “stepped up” by transformers to anywhere from 22 to 765 kV!<sup>2</sup> The huge voltages are necessary to lower the power lost from ohmic heating due to the resistance of the wires. As voltage is increased, the current in the wires is reduced as is the heating due to the current, as can be seen by the equation  $P = I^2R$ , where  $P$  is power,  $I$  is current, and  $R$  is the wire resistance. At the other end of the transmission system from the power station, the power is stepped down at a substation and then sent to your place. Finally, at your place the voltage is stepped down once more by a transformer (they generally look like a large metal can on a telephone pole), where it enters your house at 240 V. At a manufacturing plant, the voltage most likely enters the building at 600 V or 480 V. Internal to the building, it is further stepped down to 240 V with a transformer.

Let's look at the difference between alternating-current (AC) and direct-current (DC) voltage. DC voltage is constant over time, whereas AC voltage varies in a sinusoidal manner. With DC voltage, what you measure is what you get. That is, if I measure a DC voltage of 120 V, then it's actually 120 V at all times. This is not the case for AC voltage since it is varying. When we say the AC receptacle is 120 V, that's really a root-mean-square (RMS) value. The actual peak voltage is a factor of  $\sqrt{2}$  higher. So, the peak voltage coming out of your receptacle is 169 V. In the U.S., the frequency of the sinusoidal voltage is generally 60 Hz, which means the period is 17 ms since the frequency is the inverse of the period. All this can be seen from Figure 1a below.

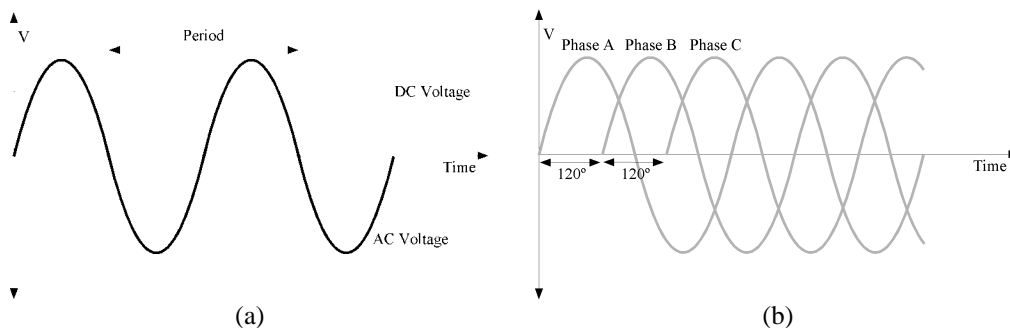


Figure 1: a) Sinusoidal waveform; b) 3-phase power.

<sup>1</sup> From this point on, it is assumed that all voltages are AC voltages, unless otherwise indicated.

<sup>2</sup> Those huge towers carrying power lines crisscrossing the country have huge voltages on them. Something interesting to think about: on a damp night, if you hold a fluorescent light bulb vertically under one of these lines it will glow faintly—why is this?.

Typical industrial devices such as motors, heaters, blowers, etc., will generally use what is known as 3-phase power at 208 V.<sup>3</sup> The phases are 120° apart from each other (see Figure 1b). In this case, the plug for the apparatus will have 4 prongs, one for each “hot” phase and one for “ground” or “neutral.” The typical 120-V system will only provide single-phase power, hence the familiar two prongs for neutral and “hot”. But the two systems are linked because the 120-V single phase is just one of the three phases in the 208-V, 3-phase system (the voltages work out such because  $208\text{ V} = \sqrt{3} \times 120\text{ V}$ ). Figure 2a shows how the two are linked. For lighting systems inside a building or plant and for small motors, single-phase power is preferred. The single-phase voltages generally available are 240 V and 120 V. Figure 2b shows how these two are related.

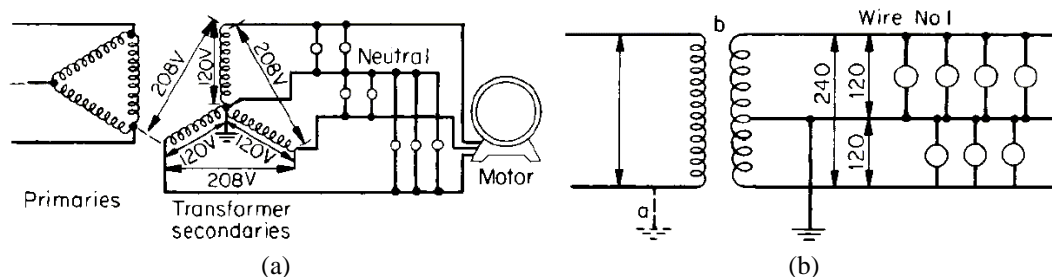


Figure 2: a) 3-phase 208/120-V power distribution; b) 240/120-V single phase power.

To calculate power used by an AC circuit, we need to know the phasing between the voltage and current. For a resistive load (such as a heater or a toaster), the two are exactly in phase. In this case, the power used is simply  $P = IV = I^2R = V^2/R$ , where voltage,  $V$ , is the RMS value. If the load is not purely resistive but also reactive (such as a motor), then voltage and current will not be exactly in phase and the amount of power used is reduced by the cosine of the difference in their phase, which is known as the Power Factor (PF). Another way of saying this is that the PF is the ratio of the actual to the apparent power, where apparent power is simply the product of the voltage and the current. A resistive load would thus have a PF of 1, whereas a completely reactive load would have a PF of 0. Since you pay the power company only for the actual power you use, the higher the power factor of the device, the more you pay.

### References

*Marks Standard Handbook for Mechanical Engineers*, 10<sup>th</sup> Ed., Chapter 15: on reference in Engineering Library, TJ151.M3701.

<sup>3</sup> 3-phase power is many times preferred because the output of synchronous motors and other rotating machinery is from 60 to 90% greater when operated than if single phase; core losses are greatly diminished; and power fluctuations are greatly reduced. In addition, you will note that when all three phases are added together, the result is zero voltage.