Open Neutrals – The Signs and Symptoms

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An open or floating neutral is an abnormal condition in an electrical system in which the electrical path to ground through the neutral is not continuous. The neutral in an electrical system serves as a reference to ground and is a return path for electric current to flow back into the electrical system. When this current path is lost, the voltages on the system can fluctuate depending on the loads applied to the system.

A typical electrical system in the United States (120/240 VAC, 60Hz) is shown in Figure 1. In this system, the voltage between either ungrounded (live or hot) conductor and the neutral is 120VAC. The voltage between the two ungrounded conductors is 240 VAC. The neutral and grounding conductors are usually tied together within the main distribution panel of a home.

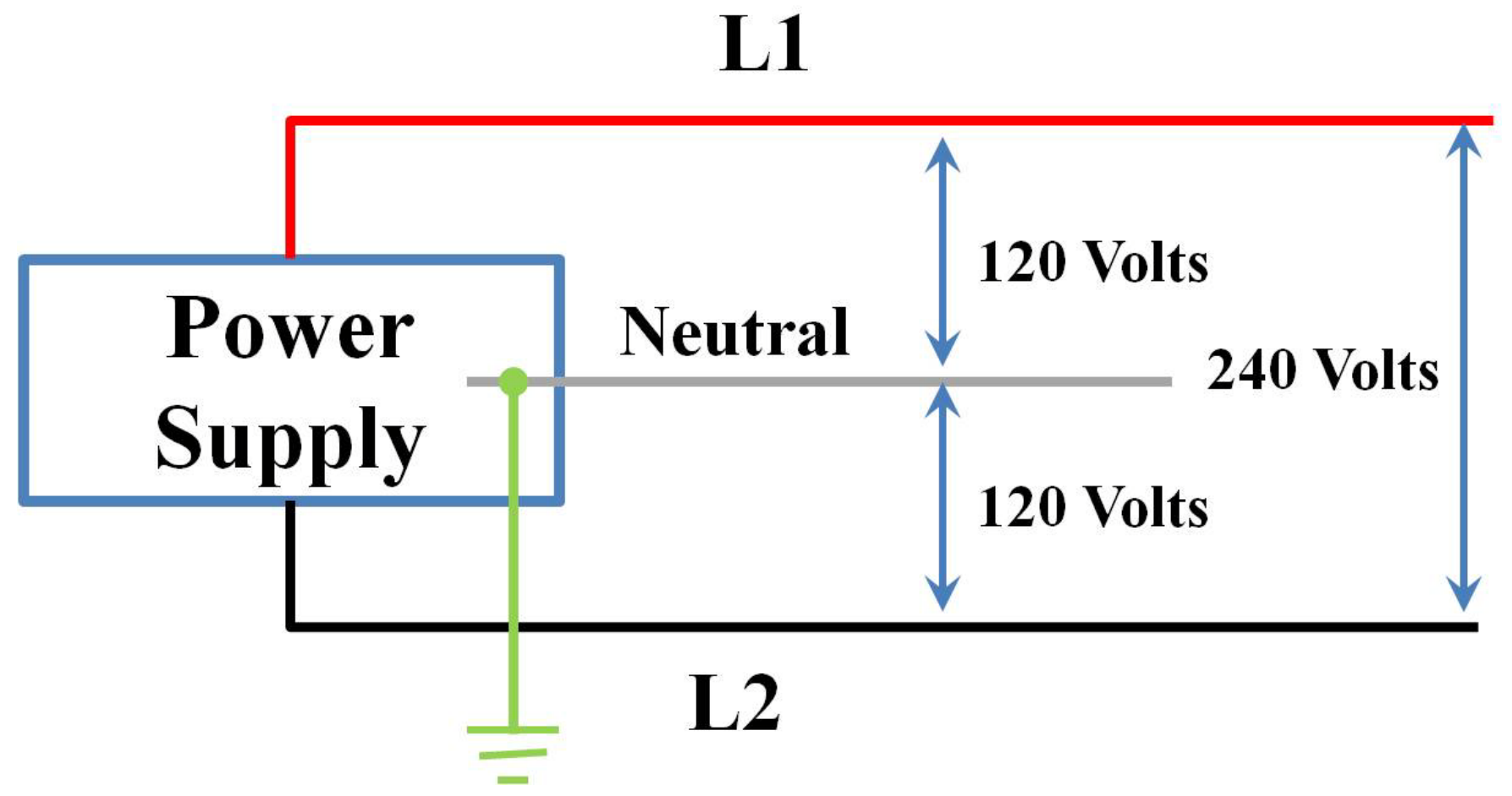
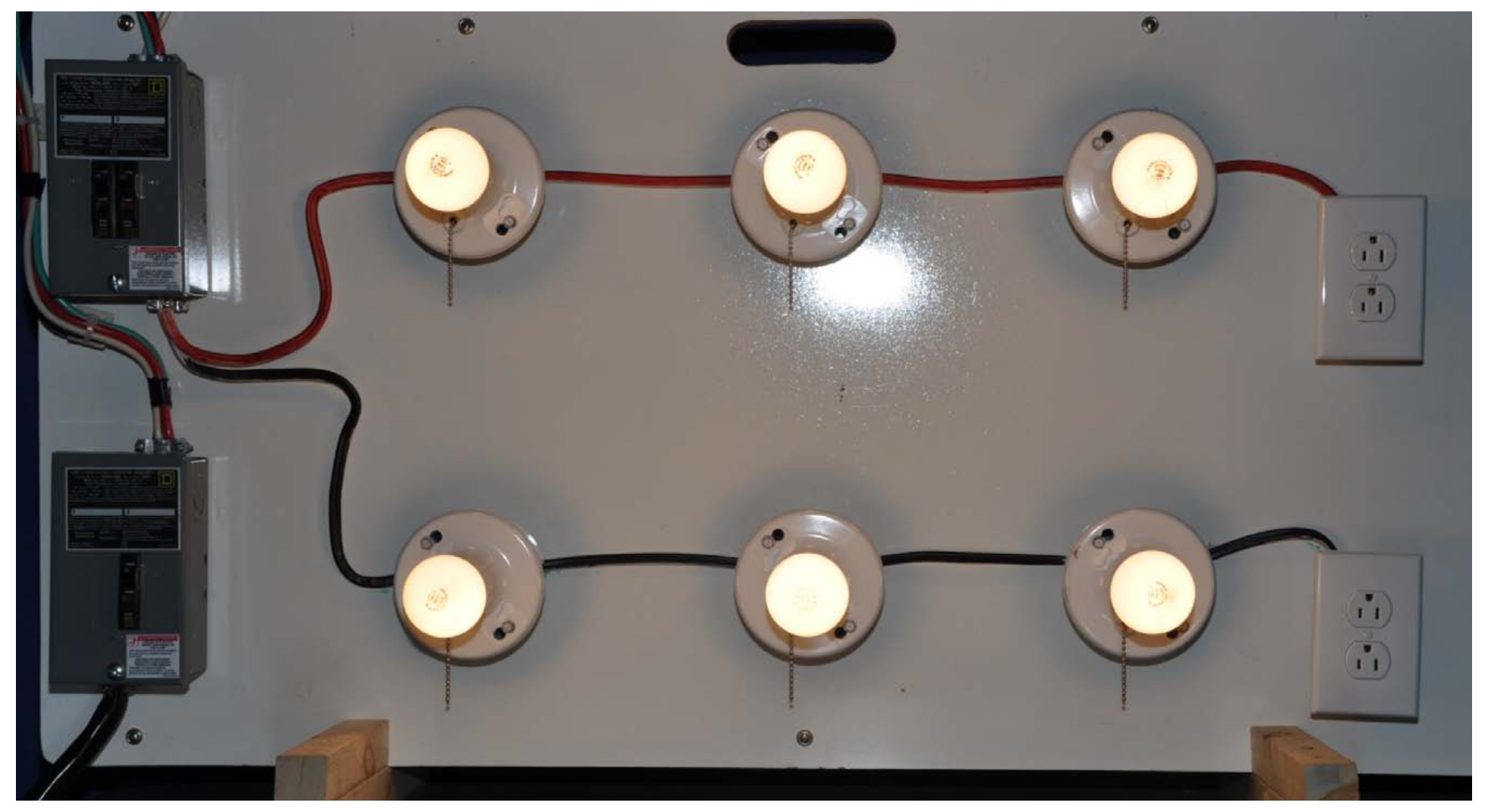
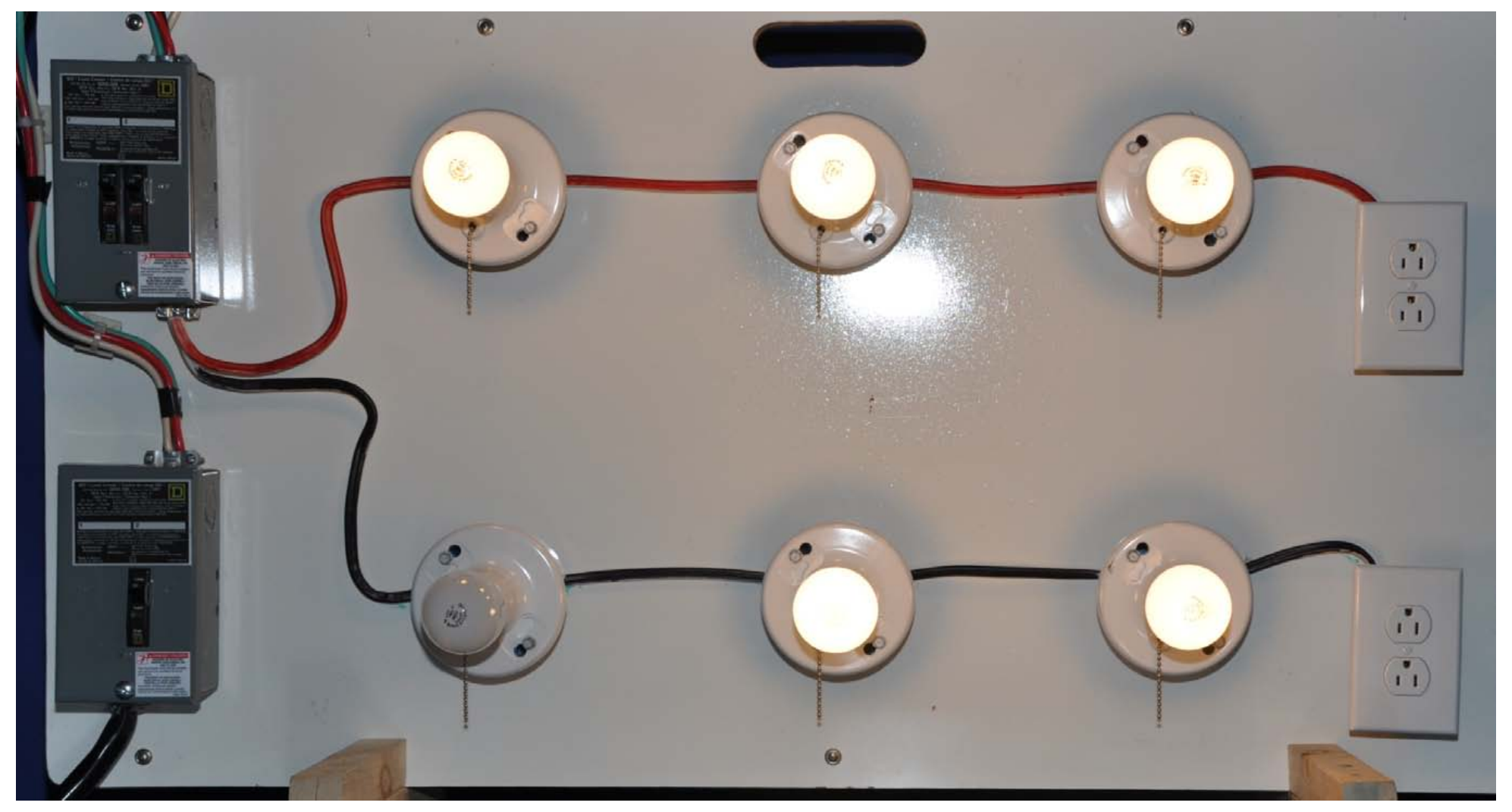


Figure 1: Schematic representation of a residential electrical system in the U.S.

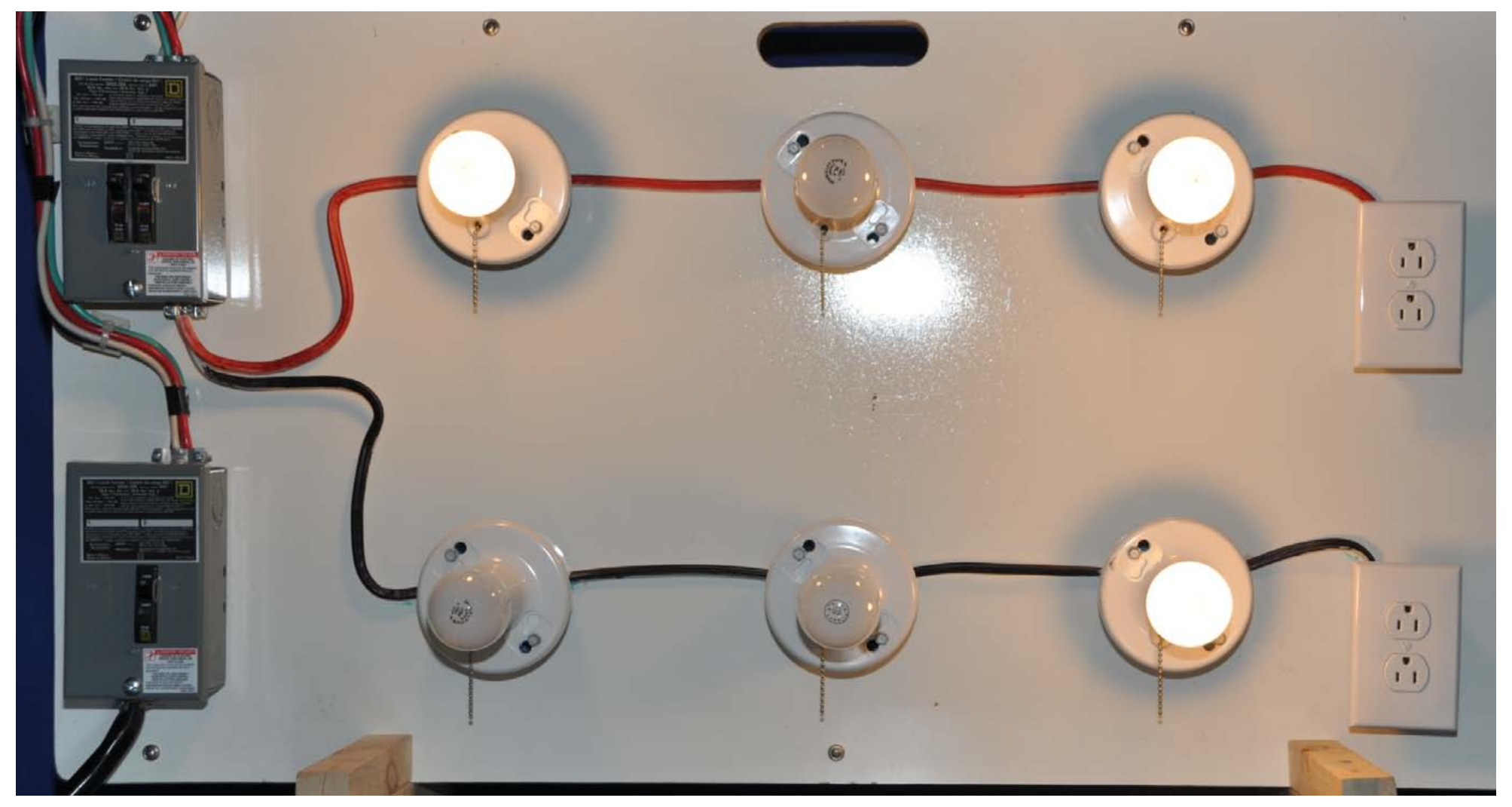
When the neutral is intact, changing the loads on the electrical system has no effect on the loads themselves. This is evident in Photographs 1-3. In these photographs you can see that as the lights are turned on and off, their intensity stays constant.



Photograph 1: Demonstration board with intact neutral.

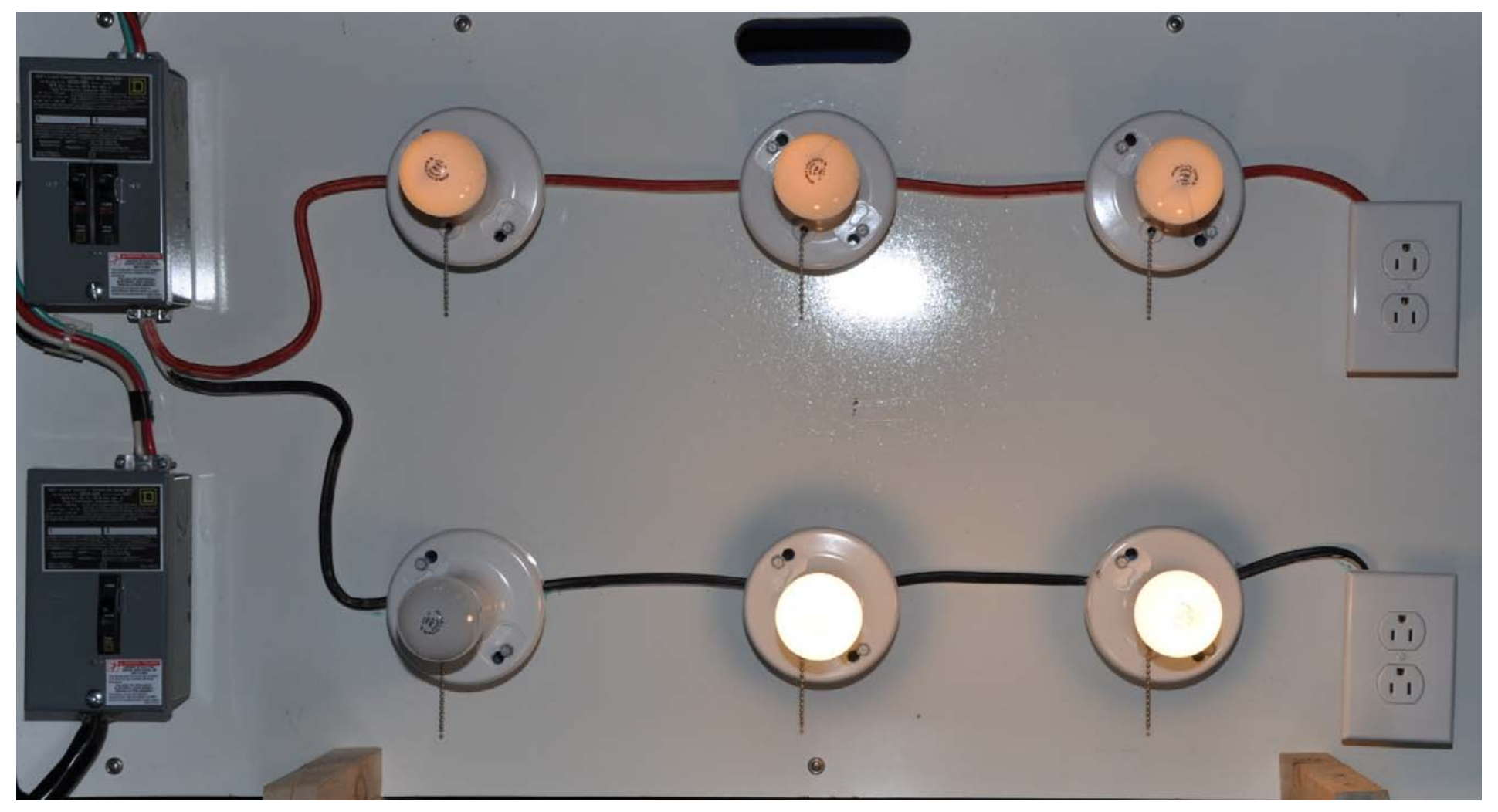


Photograph 2: Demonstration board with intact neutral.

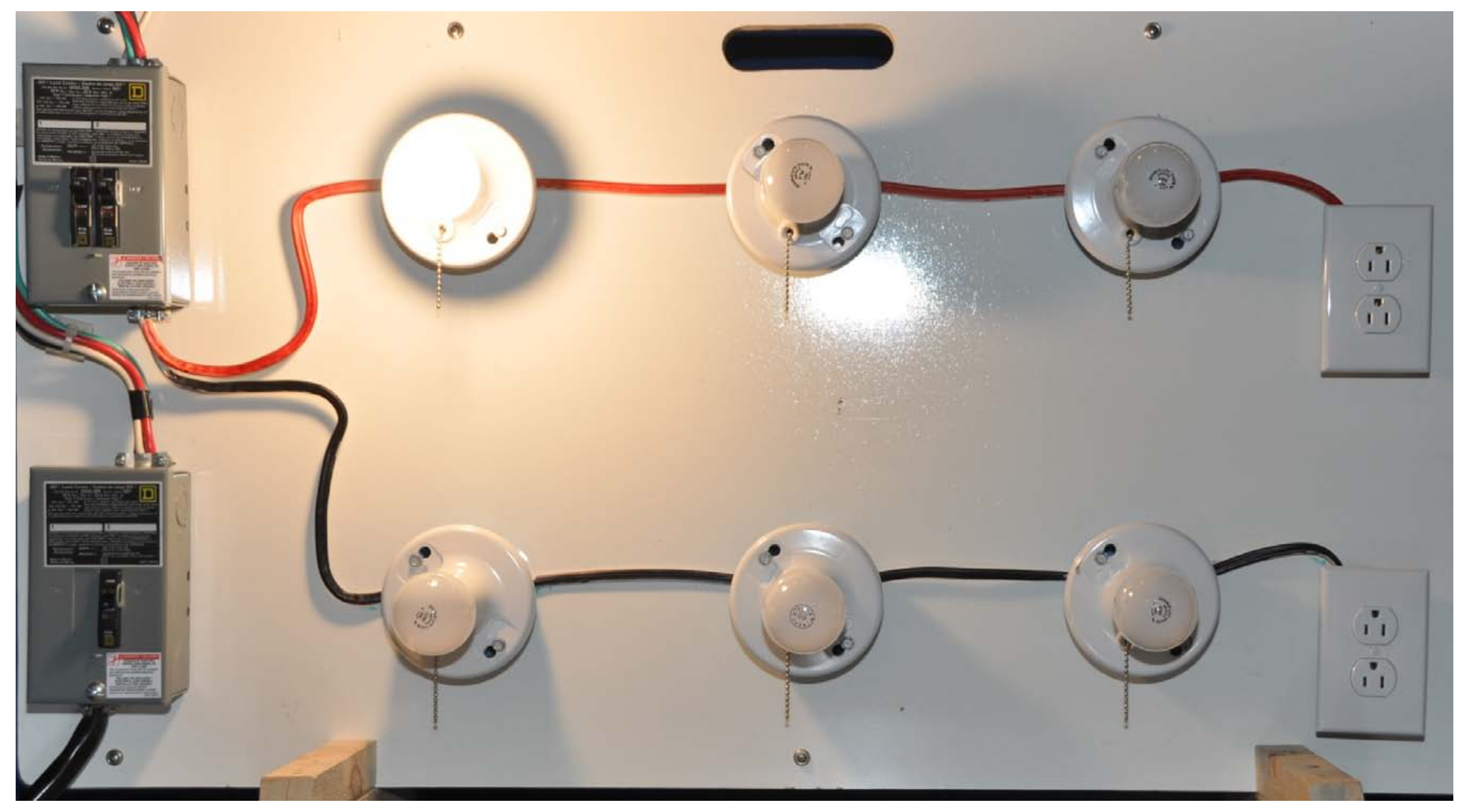


Photograph 3: Demonstration board with intact neutral.

However, when the neutral is lost and the loads change, the voltage drop across those loads also changes, as seen in Photographs 4 and 5.



Photograph 4: Demonstration board with open neutral. One light has been turned off on the bottom row.



Photograph 5: Demonstration board with open neutral. Two lights have been turned off on the top row. The bottom row of lights is still on.

So why does this happen? The answer is in the math. To start with, it is important to know how to calculate the equivalent resistance of a several parallel resistances, where you would use Equation 1.

$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}} \qquad \textbf{Equation 1}$$

The voltage drop across any resistance would be calculated using Equations 2 and 3.

$$V_{drop\ R1} = V * (\frac{R1}{R_{total}}) \qquad \textbf{Equation 2}$$

$$V_{drop\ R2} = V * (\frac{R2}{R_{total}}) \qquad \textbf{Equation 3}$$

The equivalent circuit with an open neutral is shown in Figure 2. Here we have six light bulbs as the load to replicate our demonstration board. You can see that the individual resistance of each 60W bulb is approximately 18 ohms. The parallel combination of each circuit (L1 and L2) gives us a total equivalent resistance of 6 ohms on each leg.

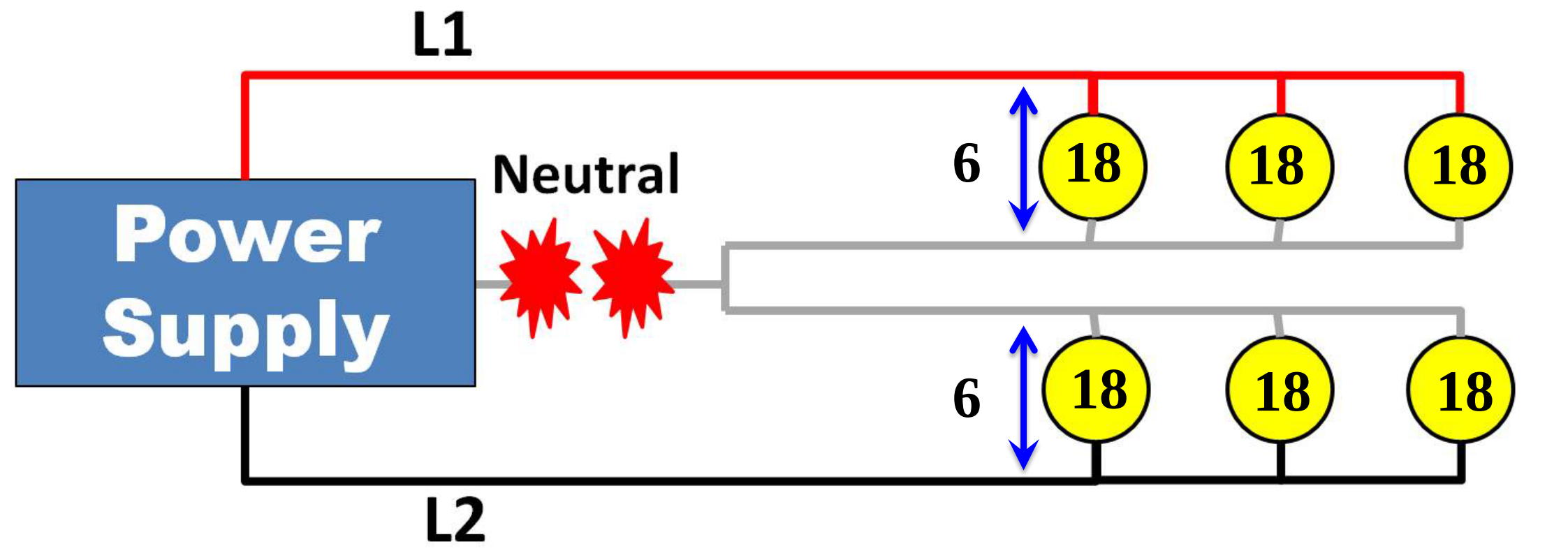


Figure 2: Schematic representation of an equivalent circuit with an open neutral.

With all six lights on, the parallel combination of resistances on each leg are equal, and therefore share an equal portion of the voltage, as shown in Equation 4.

$$V_{drop} = 240 * \left(\frac{6}{6+6}\right) = 240 * \left(\frac{6}{12}\right) = 240 * \left(\frac{1}{2}\right) = 120V \qquad \textbf{Equation 4}$$

With one light turned off on L1, the equivalent resistance of that circuit would be 9 ohms. Therefore the voltage drop across that leg would be greater (See Figure 3 and Equation 5, and Photograph 4).

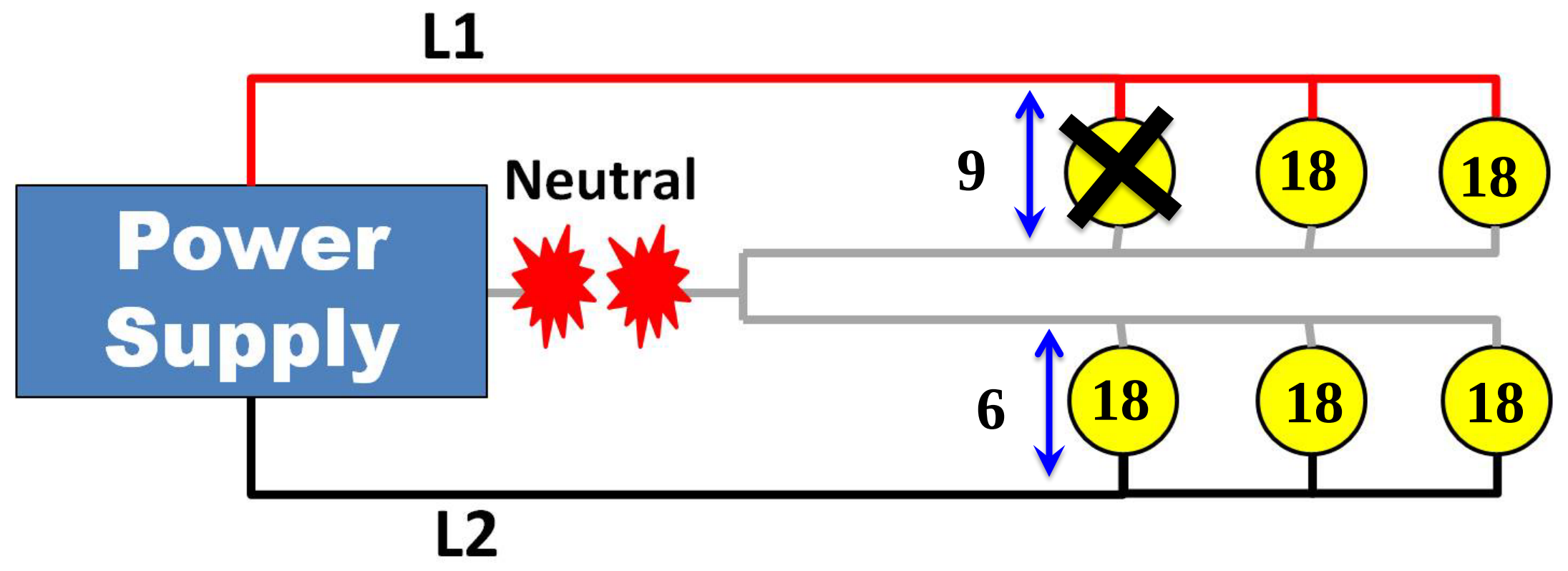


Figure 3: Schematic representation of an equivalent circuit with an open neutral and one light turned off.

$$V_{drop} = 240 * \left(\frac{9}{9+6}\right) = 240 * \left(\frac{9}{15}\right) = 240 * \left(\frac{3}{5}\right) = 144V \qquad \textbf{Equation 5}$$

With two lights turned off, the equivalent circuit would look like that shown in Figure 4. Now with only one light on, the resistance would be that of the single light, or 18 ohms. The voltage drop across that circuit would then be that calculated in Equation 6, or 180V. You can see that on L1, with only one light turned on that remaining light burns extremely bright, while those on L2 are so dim they are barely noticeable in Photograph 5.

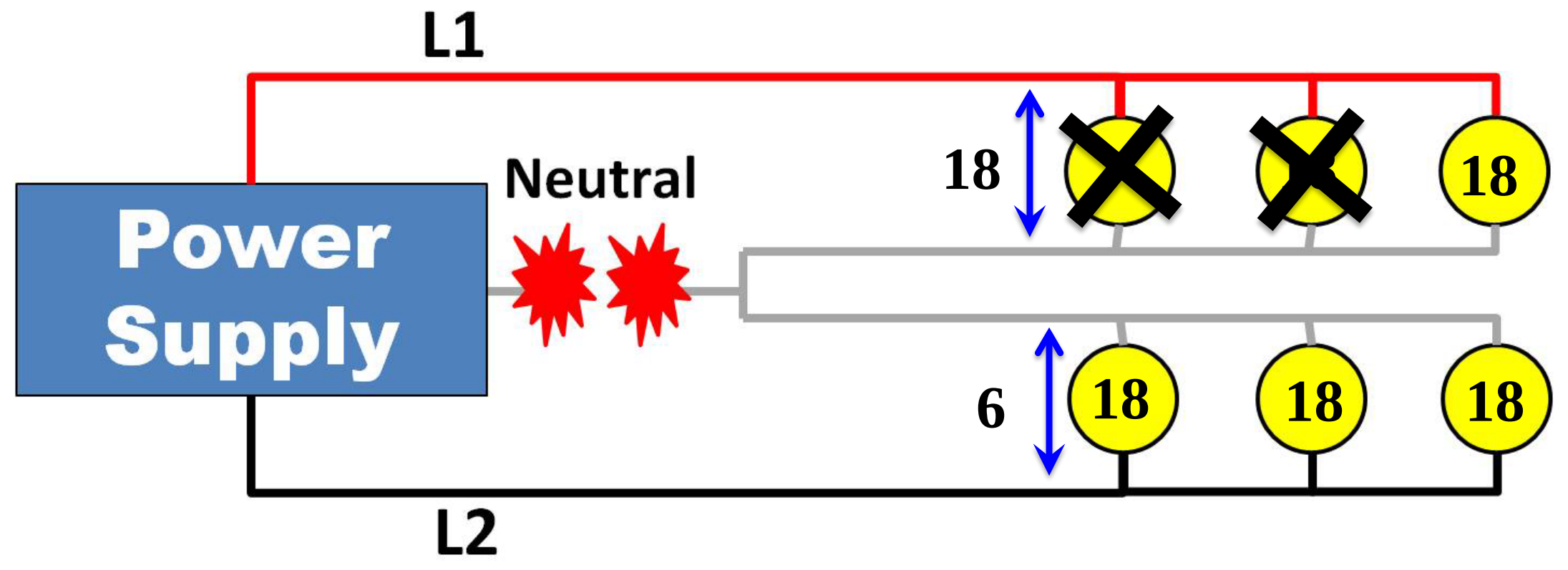


Figure 4: Schematic representation of an equivalent circuit with an open neutral and two lights turned off.

$$V_{drop} = 240 * \left(\frac{18}{18+6}\right) = 240 * \left(\frac{18}{24}\right) = 240 * \left(\frac{3}{4}\right) = 180V \qquad \textbf{Equation 6}$$

In each of these three scenarios, the corresponding voltage across L2 would be 120, 96, and 60V. So it is easy to see that an increase in the resistance on one leg leads to an increase in the voltage drop, and consequently an increase in the intensity of the light. The opposite is true with the other leg. With this information in mind, it is important for the fire investigator to ask any occupants of a structure if there were lights that would burn brighter or dimmer than others, or would appliances or devices behave differently with changing loads on the electrical system.

Open neutrals are dangerous for a wide range of reasons. They can create a shock hazard as electric current tries to find a path to ground. This can lead to items such as the lathe in a wall, or the normally-grounded cases of appliances or devices becoming energized, creating the potential for an electric shock. Electronics and motors can be damaged by voltages that are higher or lower than their intended ratings, possibly leading to a fire. It is also possible for items that normally do not carry current to do so, potentially leading to heating at connections, or overloading of wiring or other conducting mediums above their rated ampacity. All of these should be investigated when an open neutral is suspected.