Environmental Potentials

Power Quality For The Digital Age

SYSTEM GROUNDING AND GROUND LOOPS

AN ENVIRONMENTAL POTENTIALS WHITE PAPER

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There is no such thing as an absolute ground. It is necessary that this fact be kept in mind in order to understand the reasoning for the many different practices used in proper grounding. Engineers have worked for years trying to change this, but no matter how hard they try, there will always be a difference in potential in the ground connection because of resistance. Everything has resistance, even wire. So the point in grounding is to minimize this resistance as much as possible by using low resistance grounding procedures.

A typical power distribution system will usually consist of sources and loads connected together through lines forming closed loops, as shown below:

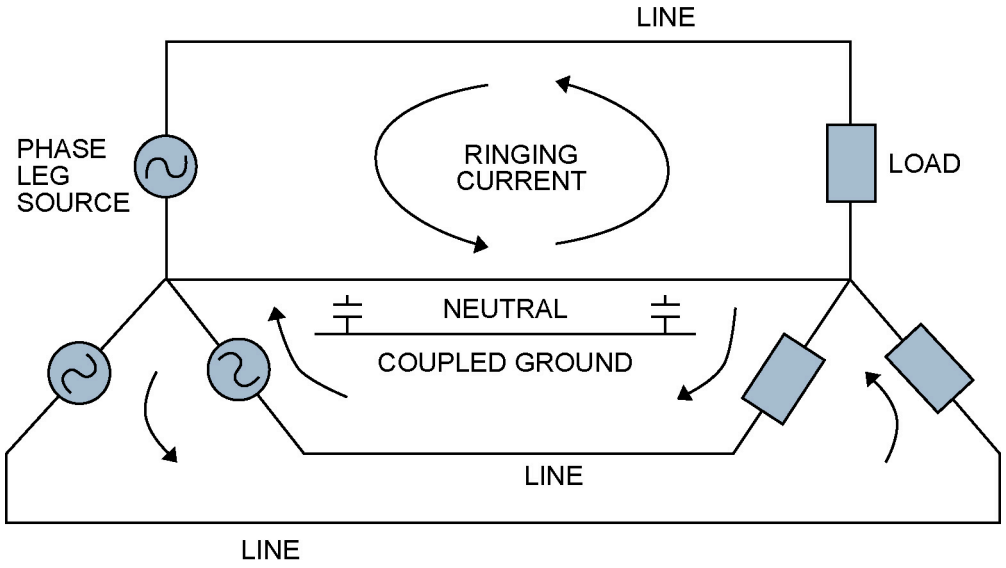

Figure 1 - Typical Power Distribution System

A 'LINE' can be a phase line, neutral line, or ground conductor. These lines all form the total circuit of the system, and all function as a part of a closed loop. A closed loop consists of a source, a forward line conductor, a load, and a return line conductor back to the source. The 'LOAD' can actually serve as a 'SOURCE' when it acts as a reactive element, because volt-amperes are reflected back throughout the network.

Kirchhoff's current law states that at any point in a circuit, the sum of all the currents entering and leaving that point will equal zero. This means that current doesn't just disappear when it is shunted to ground. So, whether this current is coming up from the ground back into your system through another piece of equipment; or whether it makes it all the way back to the transformer it's coming from, whatever is sunk into the ground must come back out. Thus, the majority of the current will follow the path of least resistance to get there.

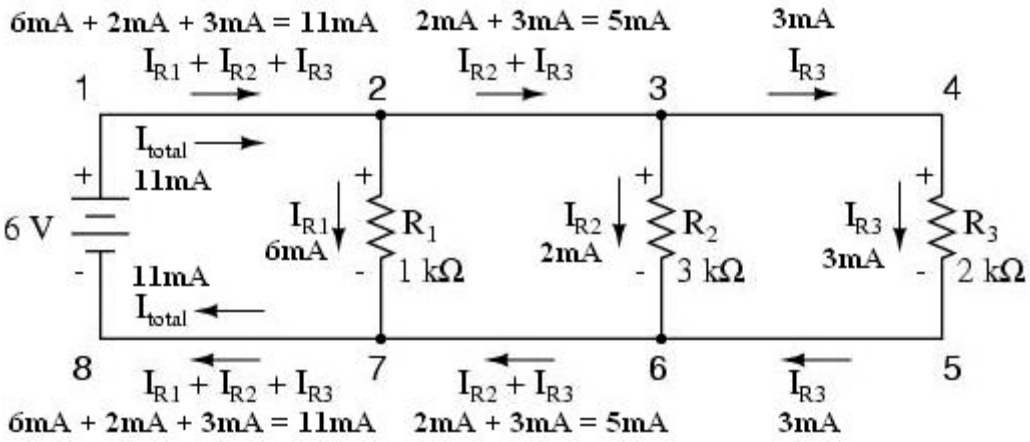

Figure 2 - Simple Circuit with Multiple Current Paths

In the figure above, there are 3 different current loops. For purposes of simplification, it is assumed in this example that wire has no resistance, so the resistance of the wire will not be accounted for. Even though the majority of current will take the path of least resistance, if there is a path that can be taken, it will be. This is shown by comparing the amount of current through the 3 kΩ resistor, R_2 and the 1 kΩ resistor, R_1. Also, at any given point in the circuit, the sum of all the currents at that point equal zero. For example, at node #2 there is a total of 11 mA feeding into that node from the 6 V source. This means that there has to be a total of 11 mA leaving that same node. By using Ohm's Law, which states that voltage divided by resistance equals current (V/R=I) we find that there is 6 mA going thru R_1. This leaves 5 mA from the 11 mA total to be split between R_2 and R_3. Because R_2 has the highest value of resistance, it carries the least amount of current, 2 mA. This leaves the remaining 3 mA to be carried thru R_3. This will remain true for any of the other seven nodes in the circuit. Since there are no other paths for the current to flow at nodes #1 and #8, the amount of current leaving the source at node #1 must be the same as the amount of current returning through the loop to the source at node #8.

Kirchhoff also discovered another law that applies to the voltage in a system. Much the same as his current law, Kirchhoff's Voltage Law states that the sum of all the voltages around any given loop is equal to zero.

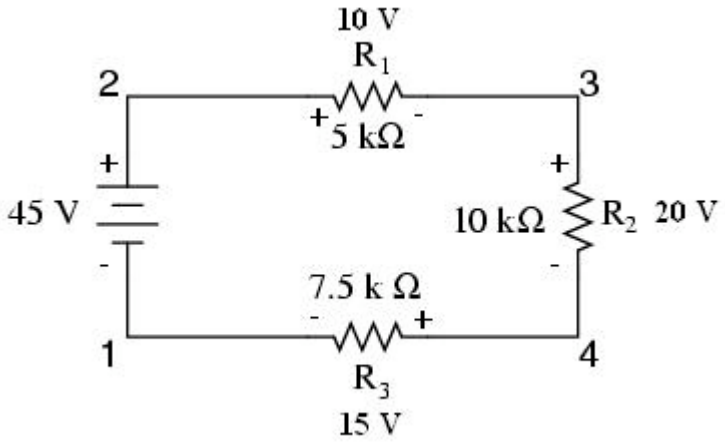

Figure 3 - Simple Circuit with Multiple Voltage Drops

Once again, it is also assumed in this example that wire does not have resistance. In the circuit above, there are no places for the current to branch off and change value. Because of Kirchhoff's current law, we know that the current must remain constant thru the entire circuit, which means that each part has exactly the same amount of current flowing thru it. This allows us to use Ohm's law to find out how much voltage is being dropped across each part in the circuit. By adding together the resistance of each individual part in the circuit, we can come up with a total resistance of 22.5 kΩ. To find the current, we take the total voltage (45 V) and divide it by the circuit resistance (22.5 kΩ). This gives us a value of 2 mA. By multiplying current and resistance, we find that R_1 drops 10 V, R_2 drops 20 V, and R_3 drops 15 V. So, as we go around the circuit, we have a gain of 45 V at the source, a drop of 10 V across R_1, a drop of 20 V across R_2, and a drop of 15 V across R_3, which leaves us with 0 V left over. Every volt in the loop is accounted for.

So, let's suppose that we have a 120 V circuit with a motor as the load. Yet, when the voltage across the motor is measured, there is only 115 V. That means we're missing 5 V. But according to Kirchhoff's Voltage Law, this isn't possible. So where is the other 5 V?

Each line in the system will have a certain resistivity, depending upon the characteristics of the material (copper, aluminum, etc.) with which it is made, its length, cross-sectional area, and the frequencies of the current flowing through the wire. The longer the wire, the more resistance to electrical flow it will present. In opposition, the larger the cross-sectional area of the wire, the lower the resistance to electrical flow it will present. This is why larger gauges are recommended for longer lengths of wire.

Another factor that affects the resistance of the wire is referred to as skin effect. Skin effect is the tendency of an alternating electric current to distribute itself within a conductor so that the current density near the surface of the conductor is greater than that at its core. This increases the resistance of the wire, creating heat and a greater difference in the voltage potential from one end of the wire to the other. In the example above, one possibility for the missing voltage would be that the motor is being fed by a length of wire that is either too long for the gauge that is being used, or it contains a large amount of high frequency noise that is forcing the current to flow near the surface of the wire, and it is the wire that is dropping the other 5 V.

Another possibility for the lost voltage could be due to the change in the type of material being used as the conductor. If the line conductor changes in its material composition, so that its resistivity value changes, then as current passes in the line, a potential difference will take place at the junction. This is because of Ohm's law, which states that voltage difference is proportional to the product of current and resistance.

An example of variation in effective resistance due to a change in the material composition of a conductor is that of an earth grounding grid. This may be depicted as shown below:

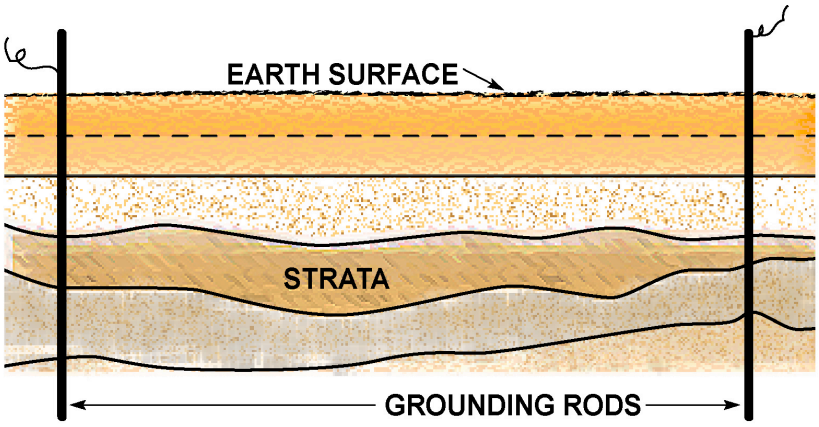

Figure 4 - Earth Grounding Grid

It is important to keep in mind that with any discontinuity of line resistance (given by the relationship R, proportional to media resistivity, length of line, and cross-sectional area), there will be a reflection of the current due to the potential difference. These multi-path connections through the ground also result in an uncontrollable and unpredictable current

following the path of least resistance to the nearest ground rod. This gives an infinite number of locations where the conductor material is changing, resulting in an infinite number of locations where reflections can occur. Reflections like this will bring about increased disturbances in the loops enclosed by the phase line, neutral, and the ground grid. These reflected disturbances are more commonly known as harmonics or high frequency noise.

The most popular conductors, copper and aluminum, have very low values of resistivity, which is what makes them good conductors. Copper has a resistivity of 1.724×10^{-8} Ω-m. Aluminum is higher, 2.62×10^{-8} Ω-m. (This may be compared to silver, which is 1.60×10^{-8} Ω-m). But in the earth, the various strata of composition may vary between different compositions of clay ($.1 - 4 \times 10^{3}$ Ω-cm), various mixtures of sand ($1 – 8 \times 10^{3}$ Ω-cm), and forms of rock or gravel ($6 - 25 \times 10^{3}$ Ω-cm). Even the ideally conductive earth that is extremely moist and high in salt content is still more than ten-million times more resistive than copper.

Temperature can greatly affect the resistance of the ground connection, especially when the temperature of the soil falls below freezing. For example, clay can have a soil resistivity of 15 Ω-m at 10° C, 20 Ω-m at 0° C, and 1000 Ω-m at -15° C. An even more drastic example of temperature affecting the quality of the ground connection comes from Fairbanks, Alaska. In Fairbanks, there is a silt-type soil that has a resistivity of around 300 Ω-m down to freezing, but 8,000 Ω-m at -15° C.

The resistance of the ground rod is vital to the electrical system for several reasons. In the case of surge suppression, a low resistance ground connection is necessary if a lower rated surge arrester is to be used. The lower the resistance that the surge arrester has to over come to dissipate the energy of a surge, the more effective it will be in keeping the clamping-voltage level down. There are few, if any, exceptions where a line-ground type surge suppression system will function effectively. All other systems require the use of line-to-line surge arresters. In most cases, however, using both the less effective line-to-ground and line-to-line methods increases the cost of the surge arrester product because of the additional components included. And all of this for a connection to ground that has a higher resistance than the equipment that the surge arrester is supposed to be protecting, making it the least likely path for the current to flow.

So if the earth is used as a return path for current, is there a possibility for a loss in the voltage that actually appears across the circuit load? The

answer is a definite yes. Using earth ground as a part of the circuit will always result in a voltage loss.

It is also important to note that any connection from the equipment to earth ground is a backdoor inviting power quality problems into the facility, bypassing any power quality equipment that may have been installed at the main panel in an attempt to keep it out. This typically happens because engineers either design the equipment or they design the power distribution system, thus introducing a degree of incompatibility. This typically results because in distribution design, the ground is included as a safety measure. Yet, in equipment design, the ground is often looked at as a shielding or a sink for electronic noise. Not much thought is given to the combination of equipment and power distribution as a whole, and ground loops are formed as a result. These ground loops can cause damage to equipment or decrease its functionality by inducing parasitic signals. In the case of Audio/Visual equipment, these parasitic signals often result in a hissing sound, static, a decrease in the clarity of high frequencies, a 60 Hz hum, black bars across the screen, or tearing in the upper corner of the screen. In electronic circuit boards, they can be the cause of error in data transmission, excessive heating of delicate circuit board traces, damaged parts, faulty readings from measurement equipment, or jitter in clock signals. In transformers, they can cause eddy currents, which heat the transformer and decrease its ability to perform the way it was originally designed.