Electrical Tech Note — 216

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Electrical Shock and Safety

Prevention of electrical shock begins with being especially careful when there is a danger of making contact with energized conductors. Always remember that prevention of electrical shock is more important than damage to equipment or facilities. For example, if some electrical equipment falls into a wet area, resist the temptation to retrieve the equipment. Think first of the potential shock hazard, **disconnect power,** then retrieve the equipment. *Do not attempt to retrieve the equipment before disconnecting power.*

Avoid working where accidental contact with energized conductors can occur. Sometimes trained personnel find it necessary to work around energized conductors. It is reported that the majority of fatalities due to shock occur by making contact with 120 volts. Even much lower voltages can be fatal. When it becomes necessary to work near energized conductors, it is important to understand how the body can become a part of a circuit. *Figure 216.1* shows a person making contact with a piece of equipment with exposed metal where an internal fault in the wiring has resulted in the frame being in contact with an internal 120 volt conductor. Since many electrical systems are grounded to the earth, the person completes a path between the equipment and the earth resulting In a current flow through the person's body.

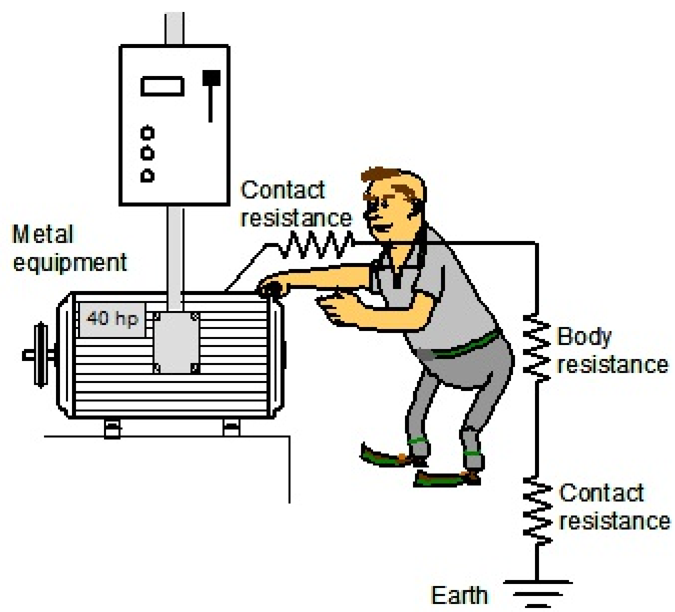

Figure 216.1 *An internal fault in equipment can result in contact between a live conductor and the frame of equipment. When a person or animal makes contact with the equipment a circuit is created where the current level depends upon the voltage on the equipment and the resistance of the path through the person or animal.*

Electrical Current Causes Shock: *Electric shock in humans and animals is the result of current flow through the body or a part of the body.* The body produces electrical current flow to control body activities. Electrical current from external sources may pass through the body on occasion and go unnoticed because the current level is below the threshold for perception at the nerve endings where perception can occur. Perception as well as damage to body tissue is the result of excessive levels of current flow and length of time of exposure. Exposure to an electrical current for a fraction of a second may cause pain, while exposure to that same level of current over a longer period of time may result in damage to the body. The concept is similar to touching a hot object. A quick touch reveals the object is hot. Contact for a longer time may result in damage of the skin. A level can be reached, however, when even a short exposure causes damage.

Body Path Resistance: The amount of electrical current that will flow through the body of a human or animal depends upon the resistance of the body current path and the voltage. The resistance of the body path consists of the resistance of the body and the contact resistance of the body with conductive surfaces as illustrated in *Figure 216.1.* Electricians wear insulating gloves and stand on insulating surfaces when working near live conductors to create a very high contact resistance that limits body current flow to an insignificant level. The major part of the electrical resistance of the body is through the skin. When dry, the skin has a resistance in the tens of thousands of ohms. When wet, such as standing in a swimming pool, the resistance of the body path can be less than 1000 ohms. When body resistance is very low, only a few volts can result in perception.

In situations where working around exposed energized conductors is unavoidable, steps must be taken to make sure the body does not complete a circuit. When standing on a concrete or other conductive floor surface, the person who may become exposed to contact with energized conductors should stand on a layer of insulating material. Also it is important to avoid making contact with conductive surfaces such as concrete walls or metal equipment. When applying pressure, make sure a slip will not result in losing balance and falling into energized parts. Also when applying pressure, avoid grasping objects such a metal pipe in order to apply pressure. It is important to think about the path current will travel if accidental contact occurs. Make sure the chest is not in the path between potential entry and exit of current during accidental contact. It is also important to work in such a way that if the body does become part of a current path, a person does not become frozen in such a way that contact cannot easily be broken. An example of a dangerous practice is holding onto a metal object with one hand while cutting a potentially live conductor with pliers in the other hand. If a shock should occur, the person may be unable to let-go of the object and the pliers.

Effects of Continuous AC Current on Humans: Humans are highly variable as to what may occur when exposed to electrical current. Frequency (cycles per second or Hertz) of alternating current is a factor. It is important to understand that the body of humans and animals is affected by only small fractions of an ampere. The unit of measure of electrical current flow is the ampere. One ampere is a large quantity when it comes to shock, therefore, thousandths of an ampere or milliamperes (mA) is the common unit of measure. It takes 1000 mA to equal one ampere. *Table 216.1* gives values that are for continuous exposure to 60 Hz alternating current when a person is working and not particularly aware that shock may occur. The values of current in *Table 216.1* are considered to be lower levels for the stated result. For difficult breathing, or heart fibrillation, the chest is a part of the current path. Perception can occur for some humans below the level stated. Pain generally occurs for most humans above the level stated, although there may be difficulty distinguishing between being startled and pain. There are many factors that must be considered when determining effects of electrical current on humans and animals that go well beyond threshold levels. *Table 216.1* is intended only as a general guide to create an awareness for the purpose of encouraging safety when working with electrical equipment or working in a situation where a person may make contact with energized conductors or equipment.

Table 216.1 *Human exposure to continuous 60 Hz alternating current through the body and the lower threshold levels generally required to result in the states effect. Shock is caused by electrical current flow. The higher the voltage the more likely the values of current shown in this table may occur. These values are "effective" ac current levels. See Tech Note 205 for explanation of "peak" current and "effective" current values.*

Perception	1 mA
(Ground-fault circuit-interrupter trips)	5 mA
Pain	8 mA
Let-go	15 mA
Difficult breathing	20 mA
Fibrillation of the heart	30 to 50 mA

Purpose of Equipment Grounding: *The purpose of equipment grounding is to provide a conductive path from the exposed frame of metal equipment back to the electrical source that is of low enough resistance to prevent humans and animals from being exposed to damaging levels of current.* Ideally the equipment grounding conductor will carry ample current to quickly cause the overcurrent device (fuse or circuit breaker) to open and de-energize the circuit. Frequently the fault condition is of such high resistance that enough current will not flow to open the overcurrent device. It is under these conditions that equipment grounding is especially important. In this situation, the equipment grounding conductor will carry enough current to prevent the voltage on the equipment from getting to high enough level to cause harm to humans and animals. *Figure 216.2* illustrates a case of what is known as a high resistance fault in a piece of equipment where the equipment grounding conductor is not present. A dangerous level of voltage is present on the equipment and human or animal contact can result in serious injury or death.

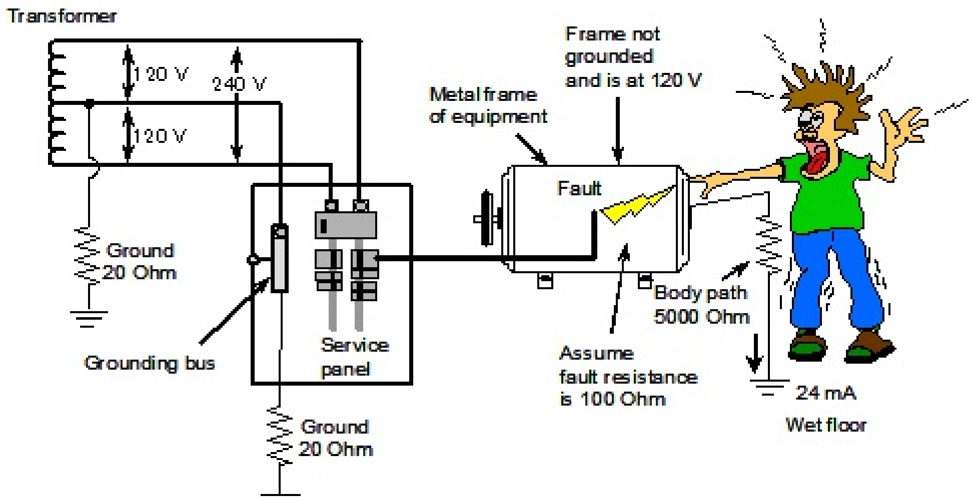

Figure 216.2 *An internal fault has occurred in the equipment allowing contact between the live conductor and the frame of the equipment. When the person touches the equipment and completes a path to earth enough current can flow to cause serious injury or death. A safety equipment grounding conductor is not connected to the frame of the equipment in this case.*

In *Figure 216.2* the overcurrent device does not open since the contact between the live wire and the equipment frame is at a level of 100 ohm. For this example the frame of the equipment is at 120 volts at the time the person makes contact. *Figure 216.3* is an electrical circuit diagram of the situation illustrated in *Figure 216.2.* For this example the resistance of the path through the person is assumed to be 5000 ohm. The current level through the person in this example is 23 mA which is at a dangerous level depending upon the length of time of exposure. The total resistance of the current path through the person is 5110 ohm. For a discussion of how to analyze such a circuit refer to *Tech Note 215*.

$$\text{Current through person} = \frac{120\text{ V}}{5110\text{ Ohm}} = 0.023\text{ A} = 23\text{ mA}$$

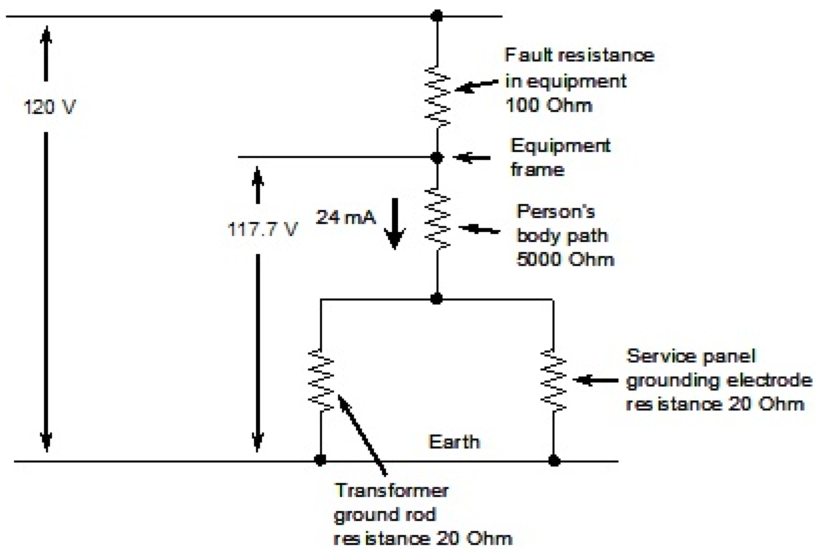

Figure 216.3 *This is an electrical circuit diagram of the shock situation depicted in the previous illustration which can be used to determine the level of current that potentially will flow through the person's body if contact with the equipment occurs.*

Essential for electrical safety is the equipment grounding wire that is required by electrical codes to be connected from the exposed metal frame of equipment to the grounding point or grounding bus at the main electrical service panel. The neutral wires for 120 volt circuits are also connected to this same equipment grounding bus. This grounding bus is shown in *Figure 216.2* and *Figure 216.4.* Note that in *Figure 216.2* the grounding wire to the equipment is missing thus not available to serve it's purpose of protecting a person or animal from a serious shock. Note in *Figure 216.4* that a grounding wire is run from the service panel grounding bus to the frame of the equipment. The equipment in both cases is subjected to the same internal electrical fault where a hot wire is making contact to the metal frame. The equipment grounding wire in this case offers a 1 ohm path for fault current to flow back to the service panel grounding point as compared to a 5000 ohm path through the person. There is still a small current flowing through the body of the person, but in the case of *Figure 216.4* the current level is only 0.2 mA and is below the level of human perception.

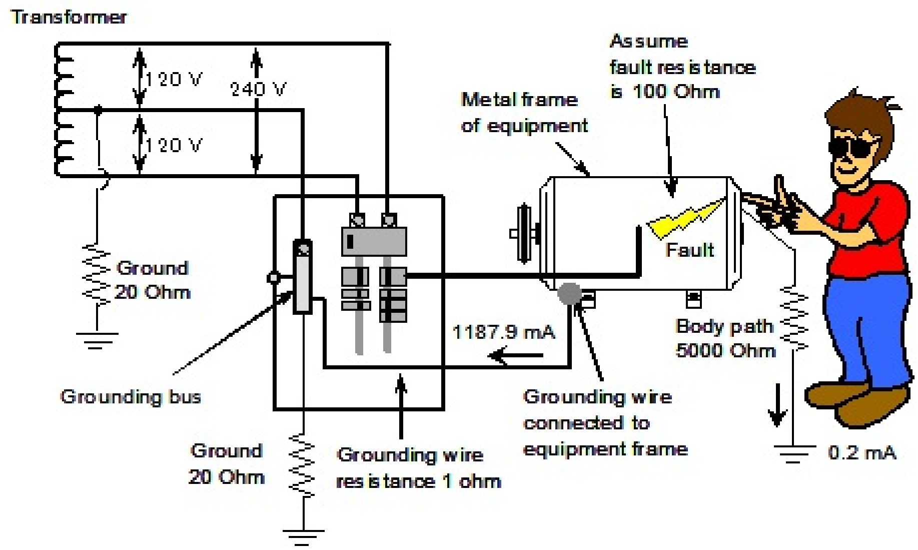

Figure 216.4 *With an equipment grounding wire connected to the frame of the equipment the fault current flows back to the source on the equipment grounding wire thus preventing the person touching the equipment from receiving a serious electrical shock.*

The electrical circuit for the case depicted in *Figure 216.4* is shown in *Figure 216.5.* Compare the circuit of *Figure 216.5* with that of *Figure 216.3* and note that the only difference is the addition of the 1 ohm ground wire from the frame of the equipment to the grounding bus of the service panel. In this case the current flowing on the grounding wire is not enough to trip the circuit breaker. In most cases the circuit breaker will trip when a fault in the equipment occurs. Note that the current through the person's body in this case is only 0.2 mA.

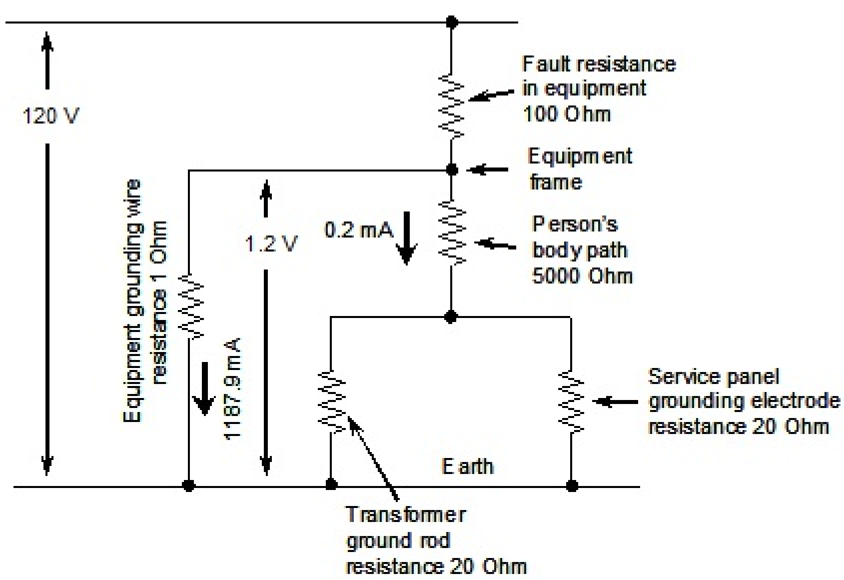

Figure 216.5 *This is the same circuit diagram as Figure 216.3 except an equipment grounding wire with a resistance of 1 ohm is connected between the frame of the equipment and the grounding bus of the electrical panel. The majority of the fault current flows safely back to the source on the equipment grounding wire preventing serious electrical shock to a person touching the equipment.*

The total resistance of the circuit of *Figure 216.5* is 101 ohms which results in 1188.1 mA total current flow with a 120 volt fault to the frame of the equipment. Remember that in this case the hot wire contact to the frame is at a resistance of 100 ohms. In most cases the fault resistance is much lower resulting in enough current flow to immediately trip the circuit breaker. In the case of *Figure 216.4* and *Figure 216.5* there will be 1.2 volts between the equipment frame and the earth resulting in only 0.2 mA current flow through the body of the person.

Ground-Fault Circuit-Interrupters: Ground-fault circuit-interrupters (GFCIs) are required by electrical codes to be installed in many potentially wet locations where exposure to dangerous levels of voltage may occur and humans can become a part of the current path. A ground-fault circuit-interrupter functions by measuring the current in the conductors to see if there is any leakage. *Table 216.1* shows that these devices trip when they sense that more than 5 mA is returning to the source by some path other than the circuit conductors. Since the leakage may be through a person, the GFCI will open the circuit and de-energize the conductors.

Conclusions: The level of perception of an electrical sensation for humans is about 1 milliampere (1/1000 ampere), and there is a narrow range between this perception level and a serious shock. The purpose of an equipment grounding wire connected from the grounding point of the electrical service panel to the exposed metal frame of equipment is hopefully to trip the circuit breaker or blow a fuse in case of an electrical fault. If, however, the fuse does not blow or the circuit breaker does not trip a purpose of the equipment grounding wire is to hold the voltage of the exposed metal frame of equipment to such a low level that a person or animal will not receive a serious shock. This is especially important in wet areas and around swimming pools. Since equipment grounding wires can become broken, corroded, or otherwise damaged, a device known as a ground-fault circuit-interrupter (GFCI) is required to be installed on many circuits serving equipment in wet areas. The ground-fault circuit-interrupter senses whether current is flowing in a path other than the circuit wires and disconnects power to the circuit when the fault level exceeds 5 mA.

The National Electrical Code (2023) requires that any alternating current **system** that supplies and operates at 50 volts or more must be a grounded system, 250.20(A).