GFIs and Fire Investigation

Mark E. Goodson, P.E.

Ground Fault Interrupters (GFIs) have become common place over the last 20 years. The use of GFIs is now mandated in many parts of a residence, to include garages, bathrooms, kitchens, hot tubs, outside outlets, and swimming pools. The purpose of the GFI is to prevent deaths caused by exposure to electrical current.

The GFI is a relatively simple device. The amount of electrical current that flows through an energized conductor (phase or hot wire) is magnetically sensed within the GFI, as is the amount of current returning through the corresponding neutral wire. If the two currents are equal, the magnetic fields cancel each other out and the GFI allows power delivery. If the hot and neutral current differ by more than 6 mA, the GFI senses this imbalance and power is removed; i.e. the GFI trips. The assumption made is that a portion of the electrical current has been diverted to ground, as would be the case when someone was electrically shocked. The GFI will respond in a time period specified in the requirements of UL 943, *Standards for Ground Fault Circuit Interrupters*.

The formula specified by UL is

$$\text{Time} = (20/\text{Current})^{1.43},$$

where

Time is in Seconds, and
Current is the fault current in milliamperes.

This equation is suitable for the range of 6 mA to 264 mA. The latter figure, 264 mA, is the current assumed when a 500-ohm fault is placed across a nominal 120 volt line that has a 10% overvoltage condition present. The 500 ohm figure is presumed to be the lowest resistance that a human body would reasonably have when being exposed to a 120 VAC shock. Using the above equation, a GFI must respond according to the following table:

Fault current, mA	Maximum Trip Time, seconds
6	5.6
50	.27
100	.10
250	.027

It should be noted that even though the trip times are allowed to be up to several seconds (per the UL spec), in actuality most GFIs will typically trip much faster than the UL requirements. Trip times of 20 to 50 mS are very typical for even low level faults.

A second function of GFIs, which is not as well known, is to prevent 'double grounds' from occurring. In the United States, it is common for the neutral and ground connections to be bonded together at the circuit breaker panel, and at no other place downstream. Thus, the single grounding point at the main breaker panel insures that the grounding conductors throughout a building do not normally carry current; this assumption fails if there is a neutral to ground fault. To detect neutral to ground faults, some GFIs are designed to inject a small signal on the neutral wire and then to look for such a fault. While this type of fault (neutral to ground shorting) would usually not cause a fire, its existence can indicate that a cable has been physically damaged. By causing the GFI to trip, power has been removed from what is possibly a damaged cable.

While GFIs have their place in the prevention of electrical shock injuries, their presence must also be considered when investigating a fire. GFIs have the ability to both prevent fires and also to make some fire investigations more difficult. Described here are both theoretical predictions and actual lab results of the effects of GFIs on fire prevention and fire investigation.

FIRE PREVENTION

GFIs were not designed to prevent fires; rather, they were intended to prevent persons from being injured by electrical shock. Their ability to prevent fires is brought about because they can sense a low current grounding type of fault and thereafter remove power. Consider a standard piece of NM cable, which in a residence is often 14/2 or 12/2 AWG copper with a ground. The design of this cable is such that the ground conductor is placed between the hot and the neutral conductor. If the cable is damaged by rodents, mechanical abrasion, or poor installation, it is entirely possible that we can have two parallel conductors (hot and ground) that lie adjacent to one another that now are insulated by only an air gap. While it is certainly unsafe to have bare wires separated by a small distance and no insulation, there will normally be no arcing unless the wires physically touch one another (a line voltage of 120 VAC is assumed). If a semi-conductive substance were to find its way to the adjacent damaged and bare conductors, this substance could bridge the gap between the hot and the ground wires, and electrical current would flow. This scenario could lead to a fire over time. If, however, a GFI is present, the GFI will remove current once the 6 mA threshold is exceeded. It is this ability to remove power at low fault currents that make the GFI useful. The 6 mA fault level is certainly much less than the current necessary to trip a standard Molded Case Circuit Breaker, MCCB. An MCCB would require 40 amperes of current (assuming a 20 amp breaker) to trip in 2 minutes or less, with 2 minutes being the maximum trip time allowed by UL / NEMA. The difference in wattage is .72 watts for the GFI versus 4800 watts for the MCCB. If we consider energy in Joules, and assume a 50 mS trip time for the GFI, and a 1 minute trip time for the MCCB, the energy allowed before removal of current is .036 joules (GFI) and 288,000 joules (MCCB). Clearly, the GFI can work to prevent a fire better than an MCCB *in some instances.* It is for this reason that some heat tape manufacturers recommend that their products be powered from GFI protected circuits.

The instances in which a GFI will not work to prevent a fire are those instances in which there is no ground fault. If we consider a typical 16 AWG stranded lamp cord with two separate conductors, hot and neutral, often there will not be a ground fault if the cable is damaged. If the cord is damaged such that the hot and neutral short one to another, arcing can result, with the amount of current leaving the hot wire the same as will return through the neutral wire. In this case, there is no current imbalance and the GFI will not respond. An exception to this would be if there were a grounded metal surface, and some of the current from the hot wire leaked to the ground path. If water were to leak between the exposed hot wire and the grounded surface, the GFI would trip. With some of the electrical current traveling through this grounded piece of metal, we would once again have a ground fault that the GFI can respond to.

The investigator should also note that some types of NM cable are round, rather than flat, and this has an effect on whether a GFI will or will not respond. With a flat cable, the ground wire is centered between the neutral and hot. Damage that occurs to the hot lead may also cause damage to the ground, thus eventually creating a ground fault and tripping the GFI. With round cable, the hot conductor is adjacent to both the hot and the neutral conductors. Damage that occurs to a hot wire may also damage a neutral *or* a ground wire (or both). The hot-neutral fault, as already explained, will not work to trip a GFI, because there is no current imbalance.

There are instances in which the rapid tripping of a GFI will not prevent an electrical fire, even though the GFI has detected and reacted to a ground fault. If two wires, hot and ground, touch such that arcing occurs, a readily flammable or explosive atmosphere can still be ignited by the arcing. The GFI will trip, and the MCCB may trip, depending upon the nature of the fault. Nevertheless, with the right atmosphere, the arcing can cause ignition even though the GFI will respond.

FIRE INVESTIGATION

When GFIs are present at a building and a fire occurs, their presence can impede a good understanding of the fire and its progression. One well-appreciated way of understanding fire spread is to examine the electrical arc damage to wiring in a building. As an example, consider a fire that occurs in a large house and which in fact reduces the house to several feet of debris with no walls standing. Examination of the electrical system remains shows every room to be serviced with 12 and 14 AWG type NM, which is now all bare secondary to the fire. Inspection of the many wire remains shows that there is arcing in a bedroom, and that the arcing is not present anywhere else in the electrical system. In an interview with the neighbor who first spotted the fire, it is learned that this neighbor saw smoke and then immediately turned off power to the house at the disconnect. This removal of power explains why there are numerous bare wires but very limited arcing. The location of the arcing gives us a very good idea of what part of a structure the fire started in. The arcing does not indicate that this electrical fault was the *cause* of the fire (it might be), but it does indicate that the fire first damaged the electrical system at this point, relative to the rest of the building. By studying electrical damage and breaker trip positions, one can often better appreciate the way in which a fire traveled in a building.

As an example of how GFI-protected wiring can affect a fire investigation, let us assume a fire that can be isolated to having started in a bathroom or an adjacent bedroom. It is our intent to use any evidence of electrical arcing to help determine the room where the fire started. Our scene work shows that the bedroom has two separate runs of type NM wiring present, each with arcing. Examination of the breaker panel shows that the both of the breakers serving the bedroom are tripped. In the bathroom, the wiring is examined and in no case is arcing found, even though the wiring is often bare secondary to the fire. The breaker is in the ON position. *Clearly the fire started in the bedroom, one concludes, based on the arc damage there and the lack of arcing on the bathroom wiring.* In fact, this assumption could be wrong.

When a fire is in progress, the heat will break down the insulation on wires. This pyrolysis will create carbon products, which serve as sources of leakage. In a fire, enough leakage will occur as the insulation breaks down so as to cause a GFI to trip. Modern day bathrooms are wired such that the wiring is protected by GFIs. In the above example, a possible reason that the wiring is bare in the bathroom (without arcing) and yet the breaker is not tripped is the presence of a GFI. The fire may have well started in the bathroom, penetrated the NM cable, and enough leakage current flowed to trip the GFI. The GFI thus tripped before arcing could occur in a manner such as to cause the circuit breaker to trip. The fire continued to spread, damaging the adjacent bedroom and creating the arcing observed there. If one neglects the action of the GFI, the wrong conclusion could be arrived at.

LAB TESTING

In order to experimentally show what effect a GFI will have on current flow between insulated conductors when their insulation breaks down as a result of an external flame, a series of tests was run. The tests all involved flat NM cable (copper), 12 / 2 AWG w/ ground. The cables were powered via 120 VAC, and then fed through a 20 ampere circuit breaker followed by a GFI receptacle. No load was supplied from the NM after it left the GFI. The tests made use of a propane torch for a heat source, with the heat applied to a section of the cable portion that was downstream from the GFI. Thus, the circuit breaker and / or the GFI would only respond when the fault current was occurring because of thermal damage to the cable (ie, hot to ground faulting). Current through the hot lead was monitored via a digital oscilloscope and a hall-effect type current probe placed on the hot lead.

In 15 separate tests, using flat NM cable, the GFI responded and tripped before physical contact and subsequent arcing between the hot and ground could occur. Thus, in every case, the GFI's action would have prevented arc damage from occurring to what was otherwise a normally energized wire. Radiographs (x-rays) were taken of each wire specimen after it had been tested, and distances between adjacent conductors were never closer than approximately 20 mils (.5 mm). This distance offers one explanation as to why there was no arcing; the wires never touched. In addition, before high current leakage paths and resultant arcing through the char could develop in the somewhat-pyrolyzed insulation, the power was removed by the GFI. Typical test results, as determined by the oscilloscope, showed that a propane fueled flame would cause a leakage current of 10 mA to flow at about 20 seconds after initial flame impingement, tripping the GFI.

DISCUSSION OF TEST RESULTS

The lab tests, as definitive as they were, must not be interpreted in a vacuum. In real life, wires are not damaged just by direct flame impingement. Wiring will be subjected to abrasion, heating (without flame impingement), and other forms of mechanical and possibly electrical stress. There will possibly be some fires in which GFI protected circuits are victims of a fire and in which arcing can and does occur. Factors other than mechanical ones that would have a bearing on hot to ground arcing on a GFI protected circuit include timing (at what point in the sine wave the fault occurs), the trip characteristics of the circuit breaker or fuse, and the type of insulation present on the wiring. Should a question arise as to how a GFI operated in a given fire, the investigator is advised to try and duplicate the electrical system, and to perform tests to determine how the GFI responds under fire and flame conditions.

SUMMATION

GFIs have benefits that go beyond prevention of electrical shocks - namely, they will prevent some fires. In particular, they can prevent some fires which are brought on by physical damage to energized cables. The geometry of the cable, the manner in which the cable is damaged, and the atmosphere in which a fault is located will all have bearings on whether or not a GFI will prevent a fire in a particular circumstance. GFIs also have some relevance to the way in which electrical fires are investigated. The investigator must always understand how a GFI works and its implications on a fire scene before determining what role, if any, that electrical wiring had or did not have in causing a fire.✧

About the Author

Mark E. Goodson is a P.E. in Denton, Texas.

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Ed Comeau, Chief Fire Investigator
NFPA Fire Investigations Team
One Batterymarch Park
Quincy, MA 02269 USA
ecomeau@nfpa.org
www.nfpa.org/investigations.html