Circuit breakers: The myth of safety

by Frederick F. Franklin

"Contrary to popular opinion, the use of circuit breakers and fuses does not guarantee that short-circuit fires will be prevented." This was the lead sentence of an article regarding electrical fires the author published in the National Fire Protection Association (NFPA) *Fire Journal* in 1984.[1]

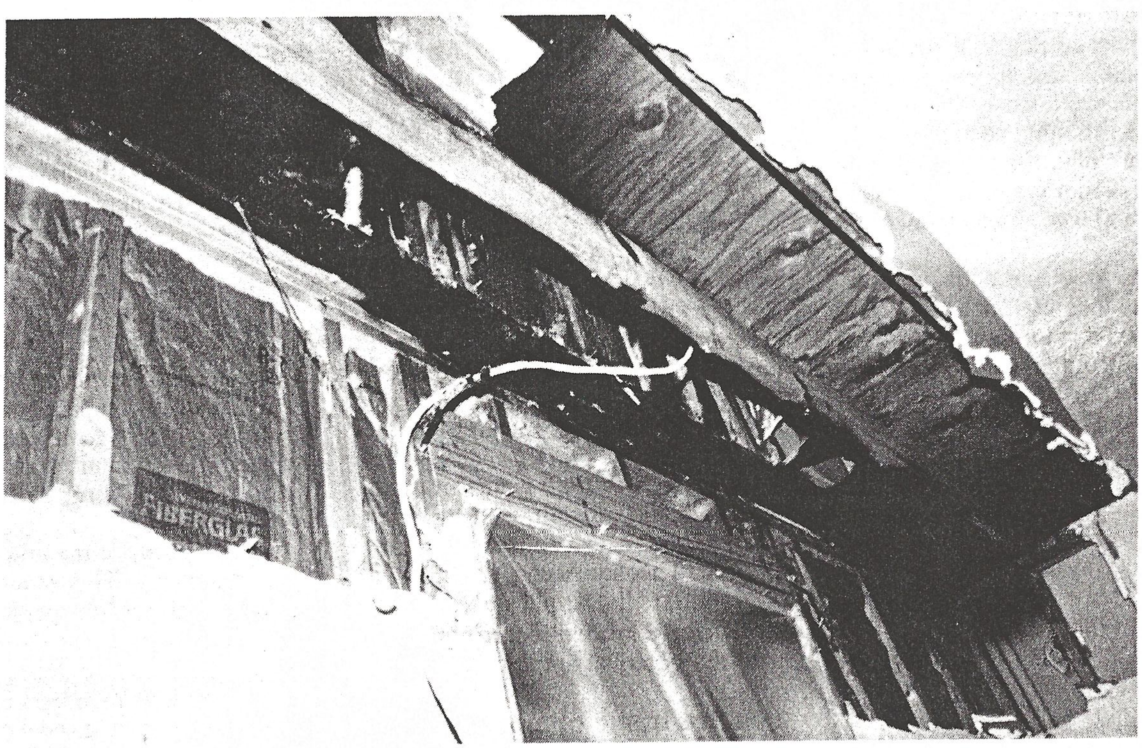
After further research, he patented a simple electronic circuit to be added to circuit breakers to prevent short circuit fires. But a year later, he discovered that European circuit breakers have the same effect, because they use a (9-turn) solenoid coil inside the circuit breaker to make them more sensitive. Efforts are under way to persuade American manufacturers to change to this European style.

By simulating 120 volt short circuit arcs, it was discovered that the arcs have a significant electrical resistance of their own, which can be as high as 0.5 ohm. This keeps the electrical current below the magnetic or instantaneous trip level of most North American circuit breakers.

Most people do not realize that small 15- and 20-ampere branch circuit breakers have two modes of tripping. The first is the well-known bimetallic strip that opens thermally like the thermostat in a home. But circuit breakers also open instantaneously (like a relay) whenever the magnetic field induced by the electrical current reaches a certain threshold. Unfortunately this magnetic tripping threshold is set too high in almost all North American circuit breakers.

Short circuit currents are simulated by burning through the insulation on conductors and by cutting on their insulation to create arcing shorts. It was discovered that the electrical current levels in 120-volt arcing short circuits are almost always between 150 and 400 amperes, with most levels congregating around 200 to 250 amperes.

Hundreds of arcs have been created and an arcing current below 100 amperes has never been observed. These current levels may be



This photograph shows a small fire which began in a nonmetallic sheathed (NM) cable thirteen years after it was installed inside a closed ceiling space. The cable was fed by a properly sized, 12X circuit breaker. It is not unusual for cables or power cords after being damaged to take years before their insulation finally breaks down enough to allow short-circuit current to begin flowing.

Power cords usually short-circuit because they have been pinched or otherwise damaged by their users, but when NM cables inside walls short-circuit, usually only the original installer can be blamed. (Professional Analytical and Consulting Engineers, Inc. has never found a short circuit actually caused by a mouse chewing on the wiring.) If a new generation of circuit breakers prevented fires, there would be no need to decide blame.

compared to the magnetic or instantaneous trip levels of 15-ampere North American circuit breakers:

- Brand A: 120 to 180 Amperes
- Brand B: 120 to 230 Amperes
- Brand C: 150 to 350 Amperes
- Brand D: 325 Amperes
- Brand E: 360 Amperes
- Brand F: 800 + Amperes
- Brand G: 800 + Amperes

The corresponding levels for 20 ampere breakers are:

- Brand A: 160 to 240 Amperes
- Brand B: 150 to 280 Amperes
- Brand C: 200 to 465 Amperes
- Brand D: 435 Amperes
- Brand E: 480 Amperes
- Brand F: 1065 + Amperes
- Brand G: 1065 + Amperes

It may be observed that most of these tripping levels are well above short-circuit arcing current levels.

There is another way to compare circuit breakers (and fuses), which is to measure their opening times at 200 and 250 amperes, the range of most 120-volt short-circuit arcs. See Table 1.

A third way of comparing circuit breakers and fuses is to compare relative energy as a function of current. It may be observed in Figure 1 that the let-through energy (I^2t) for a 5X European breaker falls drastically at about 75 amperes. This is because it suddenly begins opening much more quickly.

The let-through energy for the midrange American breaker does not begin to drop dramatically until 400 amperes (27X).

The Europeans insert a coil of nine turns or so in each circuit breaker to greatly increase the magnetic forces (see Figure 2, page 30). This lowers the magnetic trip level to 75 amperes for a 15-ampere circuit breaker (5X) and 100 amperes for a 20-ampere breaker (5X).

Thus at all current levels above 100 amperes, European 5X circuit breakers trip in 0.004 second. This reduces the energy in the arc to negligible levels, for a reported additional manufacturing cost of only $0.30. This addition would reduce American fires by 20 percent, or roughly $1 billion per year. Even if short circuits accounted for only two percent of fires, this change would still prevent over $100 million of fire loss each year.

OPENING (TRIPPING) TIMES IN SECONDS

Type of Fuse	200 AMPS	250 AMPS
ABC-8 Glass Fuse	.005	.003
ABC-10 Glass Fuse	.008	.006
MDA-15 Glass Fuse	.015	.008
ABC-15 Glass Fuse	.015	.005
AGC-20 Glass Fuse	.033	.021
TL-15 Plug Fuse	.025	.012
TL-20 Plug Fuse	.063	.016
T-30 Plug Fuse	.375	.080

Type of Circuit Breaker	200 AMPS	250 AMPS
European 5X	.004	.004
Brand A 15 Ampere	.008-.075	.008-.032
Brand A 20 Ampere	.125-.133	.051-.058
Brand B 15 Ampere	.004-.112	.004-.008
Brand B 20 Ampere	.008-.275 +	.004-.152
Brand C 15 Ampere	.310-.450	.192-.256
Brand C 20 Ampere	.100-.650	.006-.368
Brand D 15 Ampere	.250	.160
Brand E 15 Ampere	.360	.230
Brand F 15 Ampere	.650	.420
Brand G 15 Ampere	.290	.180

Table 1

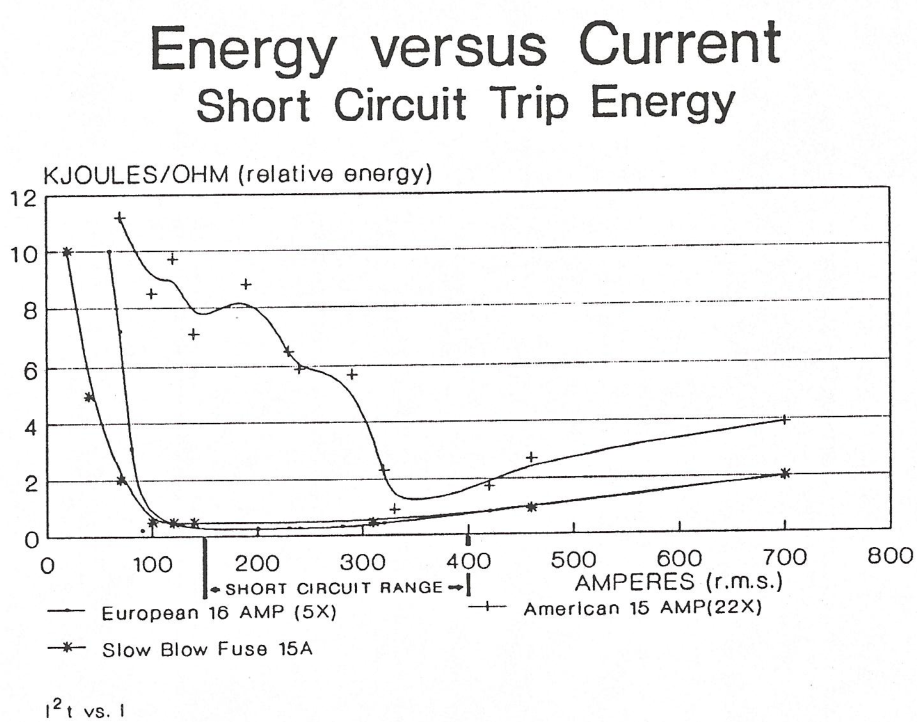


Figure 1

Video tapes and slides

On February 7, 1989 the American product safety engineers for the television and audio manufacturers, such as Sony, RCA, G.E., and Magnavox, flew to Cincinnati for a special meeting at which video tapes and slides were shown to illustrate these views. Afterward, this R-1 Safety Committee of the Electronics Industries Association (EIA) voted unanimously to petition UL, the NFPA, the NIST (formerly the National Bureau of Standards), and the circuit breaker manufacturers' organization, NEMA, for change. Paragraph 2 of their Position Paper says:

The greatest potential for

reducing the risk of fire from arcing shorts in the power supply system as a whole appears to lie in significantly reducing the initial "let-through" energy under arcing short conditions of branch circuit breakers so that they instantaneously trip at or about five times their nominal current rating.

After this meeting the author and other members of the EIA were invited to NEMA headquarters in Washington, D.C. A task force had been formed at NEMA to study these views, and on May 9, 1989, the same video and slide presentations were given to them.

One video tape shows a power cord lying on a burning piece of cardboard and plugged into a 20-ampere outlet. The power cord short-circuits over 30 times and for two minutes before popping the 20-ampere circuit breaker.

In a later video, this test is repeated with blankets lying next to the cardboard. Flying copper globules from the arcs ignite three blankets before popping the 20-ampere breaker. Both of these videos were taken the first time the tests were conducted.

For over a decade the insurance industry and the electrical industry have argued about electrical fires. Many in the electrical industry argued that they could not simulate electrical fires, and therefore, they do not occur. The simulations and video tapes mentioned above should put that argument to rest, but the usefulness of circuit breakers is such an ingrained myth that it may not be soon.

Most people continue to misunderstand electrical fires. Many electrical engineers maintain that *all* shorts are *dead shorts,* and therefore that no short circuit fires occur. Their reasoning is that a dead short (0 resistance) cannot dissipate any heating energy and therefore that it cannot cause a fire.

But on demonstration video tapes, paper is ignited numerous times by simply cutting on a power cord with diagonal cutters. So are blankets. In this type of test, where the diagonal cutters first create a dead short between the conductors, the alternating magnetic forces induced at the short by the high electrical currents push the conductors (the wires and the cutters) apart.

This creates an arc of significant energy (and its own electrical resistance) in the air almost every time. Thus arcs immediately result from dead shorts, unless the conductors are well-bonded mechanically.

The amount of energy allowed into an arc by most American circuit breakers is well-known to electricians. They have developed a common saying, in which they point to circuit breakers in a panel and say, "You can *weld* with them!"

Besides tripping times, another indication of relative safety is the amount of metallic melting allowed at an arcing location by the circuit breakers. It is well-known that a short circuit which causes a fire in building wiring always leaves a melt on the metal conductors. In fact, the energy in arcs which cause building fires is great enough to melt at least one conductor completely apart over 97% of the time.

When a 5X European style circuit breaker is inserted into the circuit for simulations, either no melt at all or a very tiny melt develops. (The same is true of 15-ampere American fuses.) 0.004 second is such a short time that very little arcing energy can develop.

Circuit breakers

If most North American circuit breakers do not prevent short-circuit fires, what do they accomplish? Their usefulness seems to be limited to tripping on dead shorts. Most people think fuses and circuit breakers are useful for preventing overcurrent fires. But overcurrents great enough to overcome the large factor of safety built into wiring insulation are very rare.

As an example, the first video tape shows scenes of a 14-gauge copper romex-type cable through which 100 amperes is flowing, in both the hot and the neutral conductors. Traditionally 14-gauge copper has been rated at only 15 amperes. Yet after one hour, the paper wrapped around the grounding conductor inside the cable is not even scorched. Thus the factor of safety built into the insulation is more than 7:1.

The video also shows scenes of a 16-gauge power cord sandwiched between two layers of carpet and through which 60 amperes flows in both conductors for one hour. The plastic insulation does not even melt, let alone burn. Overloads well above 60 amperes in branch circuits are highly unlikely, because so many appliances would have to be plugged in to draw that much current.

In a career of over 1500 fire investigations, only one overcurrent fire in building wiring was observed. In that case a circuit breaker remained stuck in the "on" position, after a dead short developed in the wiring.

Overcurrent is a myth which developed when firemen repeatedly found 30-ampere fuses and pennies behind fuses at fire scenes. The real danger of the 30-ampere fuses and pennies was that they allowed much more energy into the arc when a

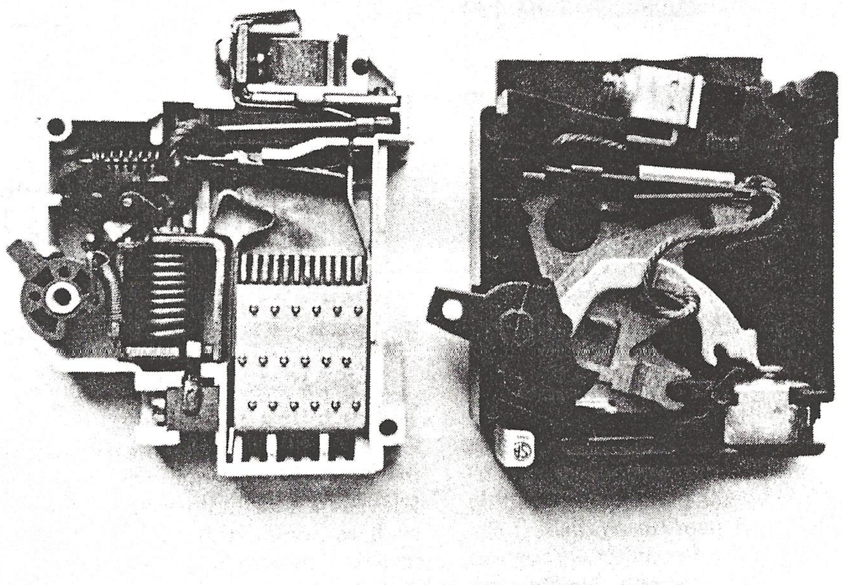


Figure 2. The 9-turn coil used in European circuit breakers makes them much more sensitive to short-circuit arcing than American models.

short circuit occurred than a 15 or 20 ampere fuse would have. Even when a penny was used behind the fuse, there was usually a 60-ampere, or 100-ampere main fuse in place to prevent an overcurrent fire.

The third type of electrical fire is a high resistance connection, which occurs when two conductors pull apart so that only small cross-sectional area remains in contact. It also occurs when aluminum connections oxidize. In 1500 fires, only two (significant) fires were caused by copper connections, and six by aluminum connections.

All of the aluminum connection fires occurred in very large conductors, such as where service entrance cables feed circuit-breaker panels. No (significant) connection fire has ever been confirmed in small branch circuit aluminum wiring. One reason for this low incidence is that most connections are enclosed in a metal or plastic junction box. Thus the flying metallic globules and heating energy are contained.

Many small fires, of the $50 variety, are reported by others in outlets and wall switches, but the incidence of significant fires developing in them are very low. The energy, the flying globules, and any resulting fire are contained very well, even for short-circuit arcing. Conduit has this same effect. Once short-circuit energy is minimized, conduit might not be needed.

Tables A and B list the incidence of various types of fires investigated during the past five years. After finding a short-circuit melt on a conductor at a fire scene, the only way for an investigator to prove that it occurred prior to the fire and not during the ensuing fire is to prove that the melt is located at the point of origin of the burn patterns. Every other cause at that origin must then also be eliminated. Thus an "electrical" fire expert must also be expert at investigating all types of fire causes, including arson. An electrical engineering degree, by itself, is not of much assistance.

TOTAL CAUSES

1.	Electrical	37%
2.	Arson	11%
3.	Flammable Liquids (mostly vehicles)	8%
4.	Fuel Gas	5%
5.	Smoking	5%
6.	Kerosene Heater	2%
7.	Cooking	2%
8.	Other Causes	10%
9.	Undetermined	20%
		100%

ELECTRICAL FIRE CAUSES

1.	Short Circuits	30.0%
2.	Overheating (H.T.L.'s Too Slow)	5.0%
3.	High "R" Aluminum	1.0%
4.	Broken Neutral	0.5%
5.	Overcurrent	0.1%
6.	High "R" Copper	0.1%
7.	Televisions	0.1%
8.	Motors	0.1%
		37.0%

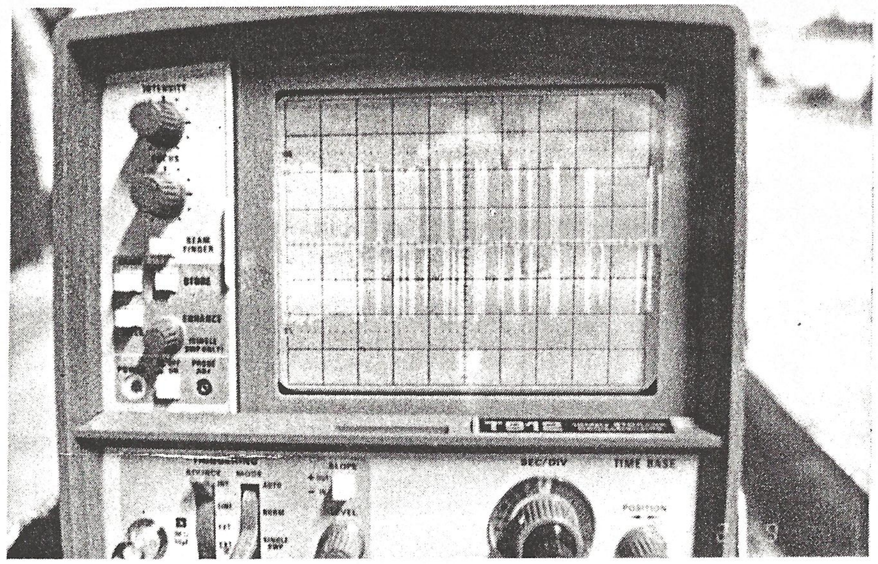


Figure 3. Missing half cycles in short-circuit current waveform.

During short circuit arcing simulations, a phenomenon was discovered which would be useful for preventing short circuit fires in higher current and higher voltage circuit breakers, where the cost of a microprocessor would not be prohibitive. It was found that in virtually all arcs, the arc extinguishes and reignites repeatedly. This almost always results in missing half cycles and quarter cycles in the sine-wave waveform, as shown in Figures 3 and 4.

In quarter cycling, the arc does not reignite until near maximum voltage is reached at the peak of the sinewave. It is believed a computer could easily detect these missing half cycles and quarter cycles, and immediately trip a larger circuit breaker to minimize short circuit energy.

Besides short-circuit arcing, the only other significant cause of electrical fires in the author's experience is high temperature limit thermostats (and fusible elements) which take too long to function after the main thermostat sticks in the "on" position. They function only after the fire has begun, in appliances such as commercial deep fat fryers, electric

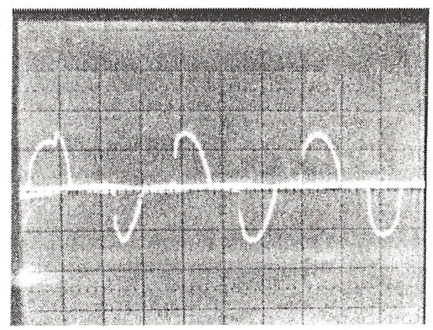


Figure 4. Quarter cycling.

dryers, and coffeemakers. These devices could be given a quicker opening time, by using sold state sensors, etc.

Improving high temperature limits and minimizing short circuit energy would reduce electrical fires to negligible levels and eliminate the most confusing aspect of fire investigation for most people—electrical.

As of this writing the Europeans are not aware that their 5X circuit breakers prevent arcing short-circuit fires so well, because apparently no one there has ever measured the currents in household short-circuit arcs either. The Europeans began using the solenoid coil in their circuit breakers 15 to 20 years ago for other reasons. It is hoped that UL and NFPA will not delay in insisting that North American circuit breakers be changed to the European style, to prevent 20% of our fires.

The tests, measurements and discoveries mentioned in this article are the author's.

Bibliography

1. Frederick F. Franklin, "A Survey of Electrical Fires," *Fire Journal*, Volume 78, No. 2, March, 1984, pages 41-44.