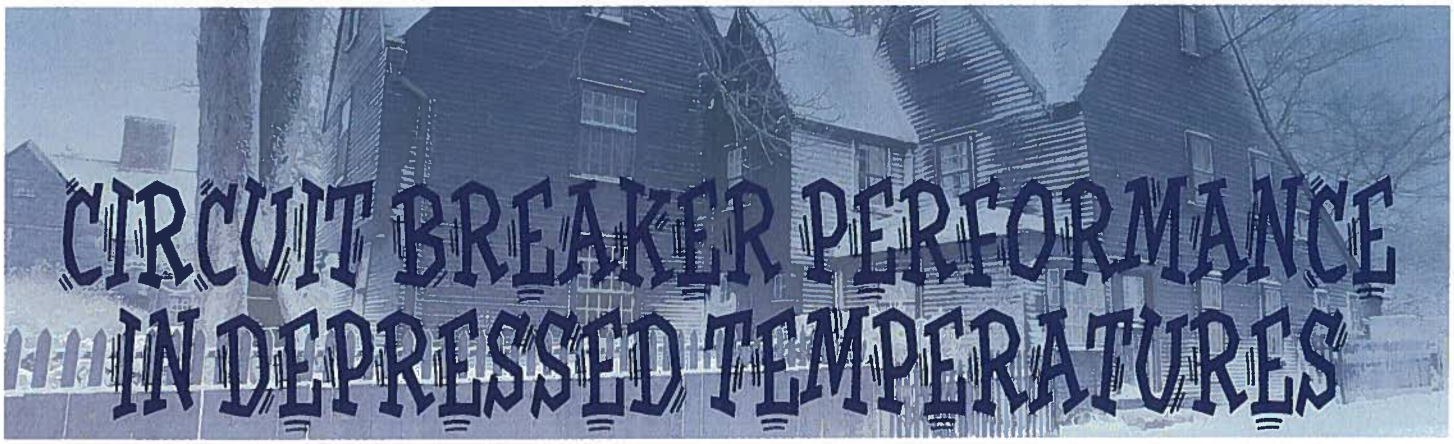


CIRCUIT BREAKER PERFORMANCE IN DEPRESSED TEMPERATURES

MARK E. GOODSON PE, TONY PERRYMAN AND KEN MC KINNEY, DENTON, TEXAS—Circuit breakers are the main devices by which wiring within residences and commercial buildings is protected from electrical faults. Typically, a circuit breaker panel (or several) will be installed with various size breakers to protect the electrical loads in a building. The size of each breaker (current rating) will depend upon the load connected to it; duplex outlets and lighting loads will usually have 15 or 20 ampere circuit breaker ratings, while larger loads (furnaces, AC units, ovens, clothes dryers) will have breakers rated at 30 amperes or more.

... 25 amperes would be flowing, rather than the maximum of 20 amperes. The thermal portion of a conventional circuit breaker would be expected to respond to this type of problem.

The function of a circuit breaker is to remove current should a short circuit or overcurrent condition develop. Inherent in the design of residential (and many commercial) breakers is the presence of two separate operating mechanisms: a thermal trip mechanism for overcurrent situations, and a magnetic trip mechanism to protect against short circuits. An overcurrent situation is defined as current flow in excess of the breaker rating; if the current flow is substantially greater than what the load wire is rated for, the current can generate enough heat to damage the insulation on conductors. Theoretically, this situation can exist for a 20 ampere breaker whenever a 12 AWG copper wire is carrying more than 20 amperes. In actuality, the 20 ampere rating is quite conservative and damage will usually not occur until currents of 50 or 60 amperes are flowing in the same wire. One way to create an overcurrent situation is to place a large load on a branch circuit in a controlled fashion; as an example, running thirty 100 watt light bulbs on a 20 ampere circuit is an overload. In this instance 25 amperes would be flowing, rather than the (theoretical) maximum of 20 amperes. The thermal portion of a conventional circuit breaker would be expected to respond to this type of problem. Table 1, taken from NEMA publication AB1, lists common breaker sizes and the appropriate wire sizes that these breakers are tested with[1]. The National Electric Code similarly prescribes breaker sizes based on the ampacity of a conductor protected by a breaker[2].

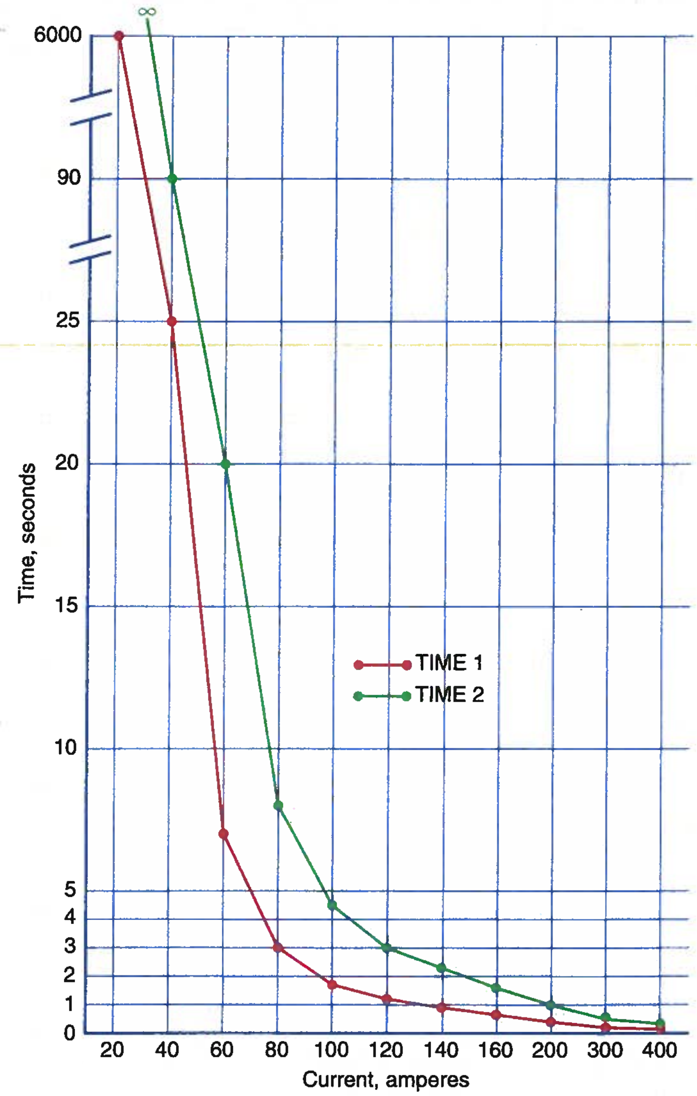
TABLE 1
MINIMUM WIRE SIZE FOR CIRCUIT BREAKERS*

BREAKER RATING (AMPERES)	LOAD WIRE SIZE COPPER, AWG (60° C WIRE)	LOAD WIRE SIZE COPPER AWG (75° C WIRE)
15	14	14
20	12	12
25	10	10
30	10	10
40	8	8
50	6	8
60	4	6
70	4	4
80	3	4
90	2	3
100	1	3
110	1	2
125	0	1
150	-	0
175	-	00
200	-	000

* SOURCE: NEMA AB-1, TABLE 4-6

A short circuit is different than an overload, and is associated with large amounts of current and a literal electrical fault. If a cable feeding a motor were to short out, the voltage would be expected to drop due to the short, and the current could easily reach several hundred or even several thousand amperes. As the current immediately increases rap idly, the magnetic portion of the circuit breaker responds and causes it to open.

FIGURE 1
TIME, CURRENT CURVES FOR 20 AMPERE BREAKER



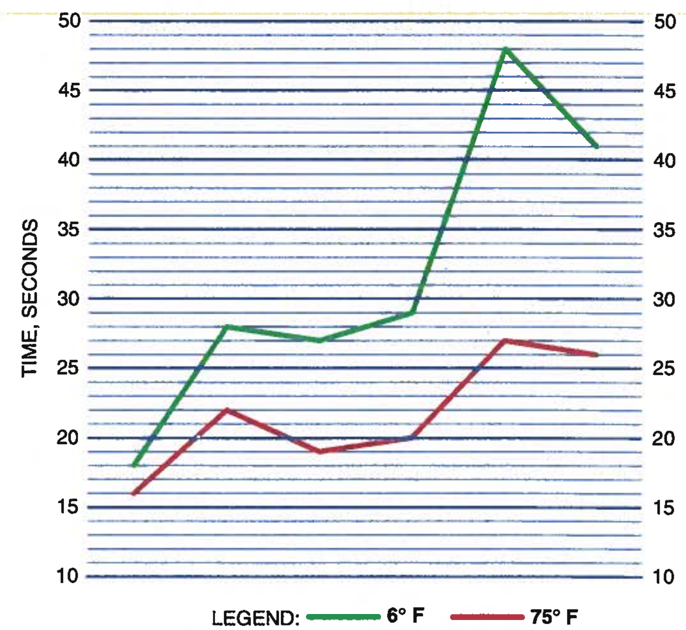
The typical circuit breaker has a set of performance 'curves' associated with it. These curves describe an inversely proportional time-current relationship for a given breaker. This relationship indicates that the greater the current overload, the faster the response time will be. This inverse time relationship applies only to the thermal portion of the breaker. The magnetic portion of the breaker will not trip appreciably faster when greater amounts of current flow. Figure 1 shows the inverse-time relationship of a typical 20 ampere breaker. It is a common misconception for residential breakers that they trip for current levels immediately above their rating; i.e., a 21 ampere load will cause a 20 ampere breaker to trip. The curves show, however, that this 20 ampere breaker will require between 25 and 90 seconds to operate at the 40 ampere (2x) level. Similarly, at the 60 ampere level, the trip time for the same 20 ampere breaker is between 7 and 20 seconds. The fastest trip time is seen at a current level of greater than 400 amperes. It is at this point that the magnetic portion of the breaker takes over, responding to a short circuit condition before the thermal portion of the breaker can take effect. As an example, a fault of 600 amperes on the same 12 AWG wire would cause the breaker to trip in less than .12 seconds.

Effects of Atmosphere

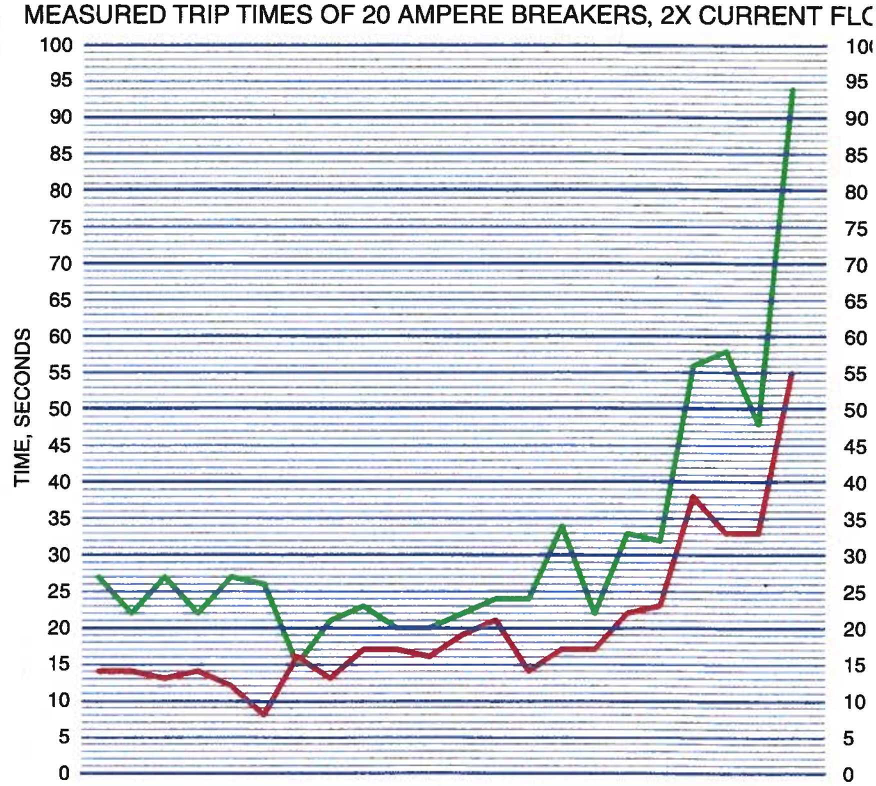
Research was carried out by the writers to determine the effects that depressed temperatures have on circuit breaker performance, and in particular the thermally actuated portion of the circuit breaker. The operation of this thermal portion of the circuit breaker centers around a bimetallic strip which deflects due to the heat generated in an overcurrent condition. This heat generation occurs in accordance with the usual formula for power, *Power (watts) = Current (amperes)^2 x Resistance (ohms)*, where the amperes is the current flow through the breaker and the resistance is the resistance in that portion of the breaker which is designed to heat up and cause tripping. When heat is generated within the breaker, the speed (time) in which the breaker will respond and trip is a function of the level of current, the resistance, and the atmosphere.

TABLE 2

MEASURED TRIP TIMES OF 15 AMPERE BREAKERS, 2X CURRENT FL(



MEASURED TRIP TIMES OF 20 AMPERE BREAKERS, 2X CURRENT FL(



When the term 'atmosphere' is used in this article, it is primarily referring to the ambient temperature of the mounting location of the breaker, in most cases other factors in the environment (humidity, wind velocity) can be disregarded due to the lesser role they play in heat dissipation. NEMA standards regarding molded case circuit breakers state that the ambient air temperature shall not fall below 23 degrees Fahrenheit or above 104 degrees Fahrenheit; outside this range, the manufacturer is to be consulted[3]. This is a critical temperature spectrum, due to the fact that circuit breakers are calibrated for optimal performance in this temperature range. Placement of circuit breakers in an environment colder than 23 degrees Fahrenheit theoretically can allow a circuit breaker's performance to be retarded by the colder temperatures. Many readers have seen circuit breaker boxes placed in garages or even outside of houses. In a hot summer, the excess temperatures are a problem because they create nuisance tripping on the thermal mechanism of the breaker. In the winter, the question has to be asked: can a wire overheat in a house from an overcurrent situation because the circuit breaker, mounted outside, failed to trip when exposed to depressed temperatures? If the answer to this question is YES, then we have a situation where a fire could develop.

The writers conducted a series of tests on a total of 30 circuit breakers rated at 15 and 20 amperes, all in atmospheres less than 23 degrees Fahrenheit. Table 2 shows the results of these tests. In general, breakers which responded with mean or average trip times of 20 seconds at the 2x current level at 75 degrees Fahrenheit then had trip times that averaged 32 seconds at temperatures of about 6 degrees. These tests show that breaker trip time is retarded by the presence of the cold atmosphere, as would be expected. In these tests, however, the trip times were still below the 120 second trip time allowed per NEMA AB1[4].

Discussion

In any discussion of time-current relationships of a circuit breaker, one must always understand that the surrounding atmosphere will have an effect upon the response time of the thermal portion of the circuit breaker. Through the testing of circuit breakers at depressed temperatures described earlier, it was concluded that the trip time of the circuit breaker will only increase by approximately 65 percent under the given test conditions. The testing confirms that there is a relationship between trip time and ambient temperature. The colder that the outside temperature is, the longer a given circuit breaker will take to trip in an overload situation. At some point, a temperature will be reached where the circuit breaker will not respond to an overcurrent condition. Simply put, the air will be so cold that the heat generated internally by the resistance in the bimetal will all dissipate to the air before the breaker trips. The circuit breaker manufacturers recognize this, and recommend the derating of any circuit breaker used outside of the manufacturer's temperature specifications; one manufacturer, Square D, recommends derating any of their thermal breakers that are used outside of temperatures between 14 and 75 degrees Fahrenheit[5].

As to under what circumstances a fire might break out, consider the following situation:

A residence was being constructed in winter in a town where the nightly temperature was -17 degrees F. The house was well insulated, and in fact, was almost finished. Painters were warming one room of the house with 5 1500 watt resistance type heaters in order to encourage the stain in this room to dry. The house was still receiving its electrical power from a 'T pole' (temporary pole) located about 40 ft. from the house; on this T pole, a circuit breaker rated at 20 amps was located, and was the breaker being used for the duplex outlets in the room. The painters had spliced the #12 run from the T pole to the #12 'home run' circuit for this room.

Outside the house, the #12 wire run that ran from the T pole to the house was in good condition after the fire, with no evidence of overcurrent. In the house, a small fire occurred within the wall space where the #12 wiring was located. The fire was confined to several adjacent stud spaces, and died from a lack of oxygen. The wall spaces were heavily packed with thermal insulation.

The fire event in this case was brought on by an overloaded circuit carrying a load current of ~62 amperes on a wire rated at 20 amperes. Compounding the problem was that the wiring in the wall space was well insulated, trapping heat from the wire. When this same wire was tested in free air, it rose to a temperature of ~ 130 degrees Celsius; when heavily insulated by thermal insulation (fiberglass), the electrical insulation failed from overheating at the same current level. A further factor in the fire was the fact that the breaker was outside; testing revealed that the circuit breaker would never trip in an atmosphere of -17 degrees Fahrenheit when a load current of 62 amperes was flowing.

The above example represents a comedy of errors in which (fortunately) no one was injured. But it demonstrates the underlying idea behind this paper—***circuit breakers must be used in the same atmosphere as the load wiring they protect.*** If they are not, trouble will occur. In a hot atmosphere, the breaker will often trip in nuisance fashion. In cold atmospheres, they will trip in a retarded manner or not at all.

When investigating a fire where breaker function and placement are in question, the parameters that one must define are load (amperage), wire size, thermal rating of the insulation on the wiring, and atmosphere for both wiring and the breaker. Many of the factors can be determined at the scene, while a check with a local newspaper or the weather service (NOAA) can be used to establish temperatures. Once these variables are known, it is possible to simulate a fire scene using an environmental chamber, the same circuit breaker (if it is undamaged), and the same type of wiring and appropriate loading means (load banks, power supplies, etc.). Shown in Table 3 are the maximum trip times for 200 percent current tests described in NEMA AB1. Testing should be carried out to determine both trip times in the cold atmosphere as well as the temperature rise of the load wiring. If at the fire scene the wire was surrounded by thermal insulation, then the experiment should use the same type and thickness of insulation. If the actual breaker was damaged by fire, then it is necessary to test a number of breakers of the same rating and manufacturer; similarly, the appropriate curves from the manufacturer should also be referred to.

TABLE 3

ALLOWABLE TRIP TIMES FOR BREAKERS, 2X CURRENT FLOW*

BREAKER RATING (AMPERES)	TRIP TIME IN SECONDS (MAXIMUM)
0-30	120
31-50	240
51-100	360
101-150	480
151-225	600

* SOURCE: NEMA AB-1, TABLE 4-2

The NEMA data shown in Table 3 is useful, but only to a point. If we assume that a breaker that is required to trip in 120 seconds actually takes 5 minutes to trip at a 2x current level, certainly that breaker has failed. That does not imply, however, that this will cause a fire. Only actual testing of the breaker in combination with identical wiring in the same atmosphere can establish if a fire will occur.

Summation

The thermal portion of conventional circuit breakers is indeed affected by temperature. If a breaker is placed in an abnormally hot atmosphere, nuisance tripping can occur. In cold atmospheres, the breaker response times will be retarded, such that conditions for a fire occurring may be created. The NEC rating of conductors is extremely conservative, such that even if a breaker is substantially slowed in its trip time for an overload condition, a fire will usually not occur. It is only in rare conditions that a fire will occur. One would require both extremely cold temperatures for the breaker atmosphere, a large overload (perhaps 3x or greater), and wiring that is usually situated so as to trap heat. As with all fires, its is advisable to try and duplicate the fire scenario before reaching the conclusion that indeed this scenario occurred. ●

References

1.) National Electric Manufacturers Association, NEMA AB 1, Molded Case Circuit Breakers and Molded Case Switches, page 19, 1994.

2.) National Fire Protection Association, National Electric Code 1996, 1996.

3.) NEMA, ibid, page 8.

4.) Ibid, page 15.

5.) Square D Company, Thermal-Magnetic / Magnetic Only Molded Case Circuit Breakers, page 11, 1991.

About the authors

Mark E. Goodson, PE

Mark Goodson is the principal of Mark E. Goodson, PE Consulting Engineers of Denton, Texas. After receiving a BSEE degree from Texas A&M in 1979, he carried out graduate studies in both fire investigation and forensic medicine. Papers authored by Mr. Goodson have appeared in Fire and Arson Investigator, Journal of Forensic Sciences, Forensic Sciences Gazette, and the American Journal of Forensic Medicine and Forensic Pathology. Mr. Goodson provides services to many medical examiner offices and governmental agencies with regards to electrical deaths.

Tony Perryman

Tony Perryman is a Graduate Engineer with Mark E. Goodson, PE. He received a BSEET from the University of North Texas in 1999. He recently sat for his EIT examination. Mr. Perryman's specializes in instrumentation and thermal imaging of fire scenes and live burns.

Ken McKinney

Ken McKinney is a senior mechanical engineering student at the University of North Texas in Denton. Ken recently sat for the EIT examination. Following receipt of his BS degree, Ken will pursue a MS degree in mechanical engineering with a materials science specialization.

DORAN FIRST TO EARN FREE MEMBERSHIP

Congratulations to Robert J. Doran II of Winter Park, Fla., the first IAAI member to earn a free membership for 2002. A member of the board of directors since 1999, Doran signed up five new recruits for IAAI. He works for Engineering Fire Investigations (E.F.I.). "Doran sold the new recruits on the benefits of belonging to the IAAI. You can earn a free membership, too. Talk to your fellow firefighters, law enforcement officials and investigators. Tell them about the advantages, including support for testing and research projects related to fire investigation, a quarterly magazine and membership directory, representation in Washington D.C. and NFPA committees, plus the Certified Fire Investigator Program and the John Charles Wilson Scholarships for college students," says Alan Clark, IAAI Executive Director. For more information about IAAI, call 314-739-4224 or fax 314-739-4219. You and your recruits may also apply on-line at the IAAI website, www.firearson.org.