

Ineffective Calibration Testing of Residential Branch Circuit Breakers

JESSE ARONSTEIN  (Life Senior Member, IEEE)

Consulting Engineer, USA (e-mail: AronsteinJ@verizon.net).

ABSTRACT Previous test results demonstrated that some presently-marketed residential branch-circuit breaker brands have a double-digit defect rate. The defective breakers do not trip as required at 135% of rated current. The unique test results reported in this article clearly show that these calibration defects cannot be reliably detected by testing at 200% or 300% of rated current. One hundred defective breakers of three brands from the previous tests are retested. They all fail to trip at 135% of rated current, confirming that they are defective. The defective breakers then all pass the UL489 calibration test at 200% of rated current (must trip within 120 s), and they all also pass the NEMA AB4 calibration test at 300% of rated current (must trip within 50 s). These higher-current tests have a 100% error rate for detection of these improperly calibrated breakers. This explains how defective breakers come to be shipped from some factories. For some residential branch circuit breaker brands, ineffective testing - relying only on high-current calibration testing - has allowed defective breakers into the supply chain for many decades, increasing the risk of fire and injury for occupants of the buildings in which they are installed.

INDEX TERMS Breaker, calibration, circuit, data, defect, electrical, failure, fire, method, quality control, residential, results, risk, safety, test.

I. INTRODUCTION

Circuit breakers that trip (open the circuit) properly are crucial for achieving electrical fire safety in homes. The applicable standard requires that they trip at 135% of rated current. This article examines the question of whether or not calibration testing only at current substantially higher than 135% of a breaker's current rating can be effectively used by manufacturers for quality control of residential branch circuit breakers.

That question arises because previously-published test results have shown that defective circuit breakers, which fail to trip as required at 135% of rated current, have been shipped from certain factories and installed in homes, increasing the risk of fire and injury. This is a substantive electrical fire safety issue.

The performance standards that apply in the United States and Canada are UL489 and its Canadian equivalent CSA C22.2 NO. 5-16 [1], [2]. Both require breakers to "trip" (open the circuit) at 135% of rated current within one hour, and not trip at 100% of rated current, under specified conditions of breaker mounting and ambient temperature. Breakers that do not trip within one hour at the upper limit of 135% of rated

current under those conditions are defective - they fail to meet the standard trip current calibration requirement.

Substandard breakers would be shipped by a manufacturer only if; they are not tested, test results are ignored, or if the calibration test is not effective. The experimental results presented in this paper address the third aspect, determining whether or not proper tripping of a breaker at 135% of rated current can be reliably inferred from calibration testing at higher current. Some manufacturers are calibrating properly and testing effectively. Others are not. Those that are not may be relying on ineffective calibration testing at a current substantially higher than 135% of the breakers' rating.

A. BACKGROUND AND LITERATURE SURVEY

The scope and long-term persistence of this electrical fire safety problem is demonstrated by a combination of documentation and test results. The earliest available indication of defective circuit protection equipment being shipped to market dates to the mid-1950's, about seventy years ago, at about the time that circuit breakers displaced fuses in the market for residential branch circuit overcurrent protection in new construction. Underwriters Laboratories Inc. (UL) brought legal

action against its own client, a circuit breaker manufacturer, to force it to stop shipping products that did not actually meet UL standards and to stop applying UL labels to products that were not UL listed [3]. That particular manufacturer's breakers are hereafter referred to as "Brand X" to comply with IEEE editorial rules that restrict the use of actual brand names.

Reference [3] is a legal document, not a research paper. With few exceptions, there are no publicly-accessible documents and reports with actual data on the calibration performance of residential circuit breakers marketed in the USA and Canada. The manufacturers consider their calibration test practices and data to be confidential and proprietary - not for public release. That also applies to the sampling procedures and test results of entities such as UL that the manufacturers contract with to certify that their breakers meet the applicable standard. Nevertheless, some performance data and quality control information has come to light as a result of lawsuits and government agency actions.

In 1978, E.W. Krawiec, an engineer at the U.S. Consumer Product Safety Commission (CPSC), tested 41 brand-new Brand X residential breakers. He found that 28% of the single-pole breakers and 74% of the double-pole breakers were improperly calibrated, they failed to trip at 135% of rating [4]. These test results were not released to the public.

In 1979, it was reported at an industry association committee meeting that UL tested 55 residential breakers of various brands that were purchased from distributors [5]. The result of the calibration testing was that 5 of the breakers (9%) failed to trip as required at 135% of rated current. Only two of the samples tested met the full requirements of the UL489 standard.

Up to that time, electricians, electrical inspectors, engineers, property owners and occupants were generally not aware that there were any substandard breaker brands. That changed in 1980 when a civil lawsuit involving corporate acquisitions resulted in public disclosure that the manufacturer of Brand X breakers had employed improper testing practices and shipped substandard breakers [6]. Reference [6] is one of many newspaper and trade journal articles that reported on this matter. However, none of the articles provide quantitative performance data or descriptive details of the company's calibration testing procedures. That information was later documented in the legal proceedings of the lawsuit, but it was not released to the public, and the court records were sealed when the litigation was settled.

At the same time, 1980, the CPSC started a formal investigation of the Brand X full-width double-pole breakers. The agency retained Wright-Malta Corp. to develop performance data for Brand X full-width double-pole breakers, both new and "used" (previously installed in houses), before and after repeated mechanical (toggle ON/OFF) operations. The results for the 122 breakers that were tested show that 51% failed to trip as required at 135% of rated current and 10% of the total sample jammed and would not trip at all when tested at 200% of rating and higher on only one of the two poles [7].

The CPSC investigation was limited to the full-size two-pole breaker. No other types of Brand X residential breakers were tested at that time. The manufacturer initially cooperated with the CPSC toward a recall, then changed its position and opposed a recall, claiming that there was no fire hazard associated with their defective breakers. Faced with a budget-breaking legal battle that would be required to force the manufacturer to recall the breakers, the agency abandoned its effort in 1983, issuing an ambiguous press release that could be interpreted to indicate either that the agency did or did not find an abnormal fire risk associated with the defective breakers [8].

The Brand X matter cast a shadow of doubt on the integrity of the residential circuit breaker industry. In response, in 1982, UL engineer R. Eckert wrote an article for a trade magazine on the results of in-situ calibration tests of 266 breakers that had been installed in homes for 10 or more years [9]. The article states that the breakers performed well, but the data that it presents contradicts that conclusion. Three of the six breaker brands tested had one or more breaker that failed to trip at 135% of rated current. For breakers identified as manufacturer A in the article, 11 out of 128 (8.6%) failed to trip at 135% of rated current. Eight of the twelve homes (67%) with manufacturer A breakers installed had at least one defective breaker. Only six breakers of manufacturer D were tested, all in one home. Two of them failed to trip at 135% and one of those also failed to trip at 200% of rated current. All other breakers that did not trip at 135% subsequently tripped when tested at 200% of rated current. The author of the article, reflecting UL's position, implied that the breakers that failed to trip as required at 135% of rated current were nevertheless acceptable if they met the 200% calibration test requirement.

It is important to note that Eckert [9] states that the project was undertaken because no test data existed (in about 1979) for the calibration performance of residential breakers that were actually installed in homes. For more than 25 years thereafter it stood as the only published calibration test results for residential circuit breakers marketed in the U.S.

In 1999, D.J. Friedman, who had been the technical director for the American Society of Home Inspectors requested that J. Aronstein (the author of this article) provide calibration test results for Brand X breakers to substantiate home inspectors' recommendations that they be replaced. This had become a contentious issue. Home inspectors increasingly identified Brand X breakers as a latent defect in homes being sold. The manufacturer, still a legal entity at the time but no longer producing any products, threatened to take legal action against inspectors who did so.

The test results that Friedman requested were known to exist, but public release was forbidden by confidentiality restrictions of the litigation in which the data had been disclosed. Aronstein and Friedman initiated an independent specimen collection and testing project from which the resulting data and conclusions could be released to the public for use by homeowners, inspectors, and others so that decisions

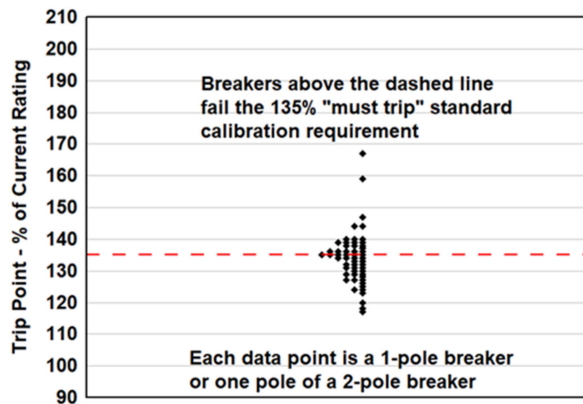


FIGURE 1. Calibration test results for a set of Brand X type circuit breakers.

and actions could be based on test data rather than opinions. On his website (inspectapedia.com), Friedman solicited the donation of full sets of Brand X breakers for testing from homes where they were being replaced due to safety concerns or the need to expand capacity.

From time to time, sets of breakers were received from homeowners and electricians across the USA. Some were also received from Canada. These were primarily branch circuit breakers, single and double pole, rated at 15 through 60 A. They were inspected for signs of damage (mechanical/electrical/corrosion). Damaged samples were discarded. Undamaged breakers were calibration tested with current that ramps up slowly for one hour from 100% of rating to 135%, holding at 135% for an hour, and then continuing the ramp to 200% of rating. The current at which a breaker trips is taken as its calibration point. Breakers that do not trip by the end of the one hour at 135% are defective.

An example of calibration test results for a set of donated breakers is shown in Fig. 1. The set was removed from panels in a house and adjacent utility building on Salt Spring Island, BC, Canada. The breakers, all manufactured after 2000, are essentially identical to Brand X, but they were produced in Canada and sold under a different Brand name.

The arithmetic mean trip point for this set is 134% of current rating, and 38% of the breakers failed to meet the 135% calibration requirement. The worst-case breaker in the set tripped at 167% of its current rating.

The first release of data from this independent testing project was a report issued in 2007 that contained calibration test data for 465 Brand X-type breakers, including results for 120 two-pole breakers showing a 35.5% calibration defect rate and for 345 single-pole breakers with a 20.3% calibration defect rate. That report has been updated from time to time and presently includes data on 2615 Brand X breakers that shows a 23% calibration defect rate for the combined total of both single-pole and two-pole breakers [10]. Calibration test results are also included in [10] for 622 breakers that are the same design as Brand X, but marketed under different Brand names. These Brand X equivalents demonstrated a combined 38% calibration failure rate.

Although it has always been commonly agreed that improperly calibrated breakers increased the risk of fire and injury, there was no data or analysis available that quantified the magnitude of the risk. Aronstein and R. Lowry developed a method of estimating the fire loss due to defective Brand X breakers and presented the work at the 2011 IEEE/IAS Electrical Safety Conference [11]. The annual losses attributable to the Brand X breaker defects were 116 injuries, 13 deaths, and \$40 million property loss. That peer-reviewed published paper helped motivate the CPSC to clarify its ambiguous press release so as to assure that it could no longer be interpreted to mean that the agency found the Brand X breakers to be safe.

On the basis of anecdotal experience, some electricians and inspectors questioned whether Brand X breakers were the only ones with high defect rates. The independent testing project was expanded to include other residential circuit breaker brands. In 2018 Aronstein and D.W. Carrier published the results of calibration tests on a broad spectrum of residential circuit breaker brands, both new and used (previously installed in homes) [12]. A total of 12 brands of breakers were tested to determine their actual calibration (the minimum current at which they would trip) and whether or not they met the standard requirement that they trip in one hour or less at 135% of rated current.

The used breakers tested for [12] were donated by electricians from stocks of used breakers that they kept to install as replacements when new breakers of the required type and rating were not available. The used breakers came primarily from panels that had been replaced when service capacity was increased.

Half of the brands tested demonstrated double-digit failure rates for the 135% calibration test. New samples were also tested, purchased from retail sources, for six of the brands that were still in production. Three of these six brands had similar double-digit calibration failure rates for both their new breakers and those that had been in service in homes. That result demonstrates that, for these three brands, the defective breakers from homes were defective when they were originally purchased and installed. They did not deteriorate in service.

In 2023 Aronstein published calibration test data for newly-purchased breakers of two brands [13]. The previous test results on new samples, purchased four years earlier, published in [12], showed no calibration failures for Brand 3 breakers and a 50% failure rate for Brand 11. The 2023 results showed Brand 3 again with a zero-defect rate, while Brand 11 again had a double-digit defect rate, 28%. The manufacturer of Brand 11 was still shipping improperly-calibrated breakers into the distribution chain.

Reference [5], [7], and [9] through [13] are the only ones available that provide data on calibration failure rates and/or actual trip current for residential circuit breakers produced for installation in the USA and Canada. These references, from three sources: UL; CPSC; and independent—all agree, in that they show a substantial calibration defect rate for some breaker brands, both for new breakers purchased from the distribution chain and breakers that have been installed in homes.

These test results have not been contested. No contradicting data has been published.

For defective breakers to enter the distribution chain there must be failure at three stages.

- 1) They must be improperly calibrated (adjusted) on the manufacturing line.
- 2) The manufacturer's quality control testing is ineffective and does not screen out the defects.
- 3) Periodic oversight and/or testing by any certifying agency, such as UL, is also ineffective.

B. CERTIFICATION AND TESTING

All of the presently-marketed brands of breakers previously determined to have high defect rate were "listed" or "certified" by a reputable Nationally Recognized Testing Laboratory (NRTL), meaning that the particular breakers are included in a list of acceptable equipment published by an NRTL. Each residential breaker shipped from a factory for eventual installation is labeled by its manufacturer as being listed or certified by that NRTL and meeting the performance requirements of the applicable standard. That label is the manufacturer's assurance to electrical installers and inspectors that it conforms to the applicable performance standard. But a substantial portion of breakers of some brands do not actually meet the standard's 135% trip requirement, indicating that those breakers are not actually being tested at 135% of rating at any stage of the manufacturing, quality control, or NRTL oversight process. Testing at 135% of rating is a direct check as to whether or not a breaker will trip at all at that allowable maximum trip current for its rating.

If a breaker is calibrated (adjusted) to trip close to or at the 135% upper current limit, the test can take up to an hour to reveal whether it does or does not actually comply with that requirement. To reduce test time and cost, higher current testing is often employed, for instance using the UL489 calibration test at 200% of rated current or a calibration test at 300% of rated current. The 300% calibration test is suggested by the National Electrical Manufacturers Association (NEMA) in its NEMA AB-4 standard practice to determine whether previously-installed breakers are properly calibrated and can be put back into service [14]. The NEMA test is considered here because it may be employed by some manufacturers and also may be employed by companies that "recertify" and sell used breakers of obsolete and hard-to-find types for use in existing installations.

Underlying the reliance on higher (than 135%) testing is faith in the manufacturer's published current-time (C-T) trip curve, which depicts the required envelope of performance of the breakers. Fig. 2 shows a representative C-T curve for residential branch circuit breakers.

The shaded area in the curve depicts the limits for time to trip at any given multiple of a breaker's rated current. At any given current, a vertical line intersects the shaded zone at the minimum and maximum required trip time at that current. The dashed line represents the 135% "must trip" upper limit specified by the applicable standards.

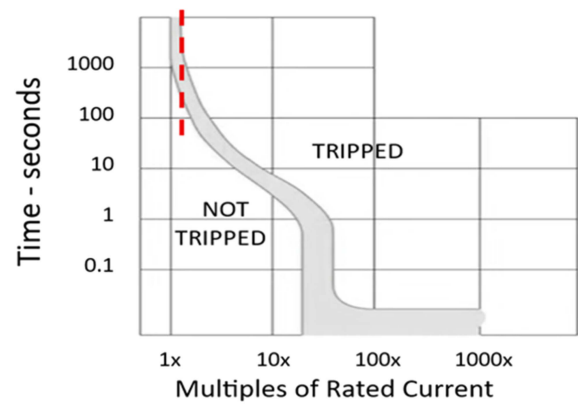


FIGURE 2. Typical C-T curve for residential breakers.

The published C-T charts are essentially specifications, not reflections of available test data for breakers that are in the manufacturing lines or marketing distribution chain.

Some manufacturers and NRTLs apparently assume that if a breaker performs within the boundaries of the C-T curve at one current level, then it will (if tested) perform correctly at any other current. In 1993, the former operations manager of Brand X, the company that was proven to have shipped defective breakers for several decades, stated that assumption explicitly, saying that *"the 200% (test) is chosen because it's a point on a curve, and if that falls in the proper range, then it will meet the other points on the curve based on experience"* [15]. It is apparent that, for many years, some manufacturers and NRTLs relied on testing at 200% of rating or higher to judge whether breakers were properly calibrated. Perhaps worse, it was recently reported that one manufacturer does not test calibration of the finished breakers at all, relying instead on a mechanical adjustment made before they are completely assembled [16].

The question to be answered is whether, for residential branch circuit breakers, time-to-trip testing at substantially higher current accurately reflects a breaker's calibration setting - its minimum trip current. It did not in previous tests at 200% and 300% of rated current using a relatively small sample size of one Brand [13]. This present work was undertaken to determine if the lack of correlation holds true for a larger sample size across multiple brands.

II. BREAKERS TESTED

One hundred defective breakers (single-pole and individual poles of double-pole breakers) were retested. These particular specimens had failed to trip at 135% of rating in previous tests reported in [12] and [13]. They were all manufactured between about 2006 and 2022. They are mostly single-pole, rated 15 and 20 A. Three are rated 30A. Brand identification numbers in this article are consistent with the identification numbers in [12] and [13].

All of the defective Brand 13 breakers tested for this present project are "new", meaning that they were purchased off-the-shelf and were never installed other than for the previous calibration testing. The defective Brand 10 and Brand 15

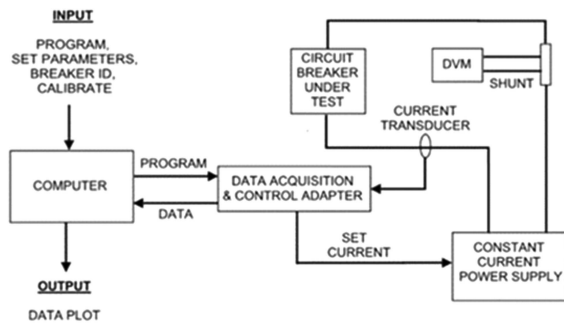


FIGURE 3. Test system.

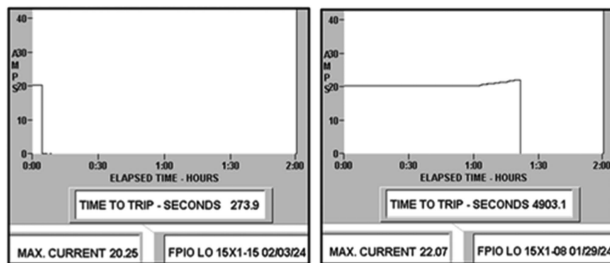


FIGURE 4. Representative Test Records. The test record on the left shows the performance of an acceptable 15 A breaker that passes the UL489 135% calibration test, tripping within one hour at 20.25 A (that breaker is not one of the samples employed in this article). The test record on the right is for a 15 A breaker that fails the 135% test, eventually tripping at 22.07 A (147% of its rating).

breakers now tested include a mix of new and used breakers (the “used” breakers were previously installed in buildings).

Each and every defective breaker in the sample set is labeled (by its manufacturer) as being listed by a recognized NRTL and meeting the applicable standard, which is UL489 for Brand 10 and Brand 11, and CSA 22.2 No. 5-09 for Brand 15. The three brands, with high defect levels, are each listed by a different NRTL.

III. EXPERIMENTAL METHOD

Each of the 100 sample breakers is first tested at 135% of rating per UL489, then at 200% of rating per UL489, and, finally, at 300% of rating per NEMA AB-4. The three tests are performed on the breaker in that sequence, with a cooling period between tests. There is no change in the physical setup (mounting and wiring) during the test sequence for a given breaker.

A low-voltage 100 A dc power supply is used in the constant-current mode. The output current is programmed using a data acquisition and process control adapter mounted in and controlled by the computer. A precision shunt and digital voltmeter provide capability for independent verification of test current and for calibration of the data acquisition system. Fig. 3 is a block diagram of the test setup.

The history of each test is recorded as a screenshot of the computer display window taken after the breaker trips to open the circuit. The screenshot record has a chart of current versus time along with digital meter displays of time-to-trip and maximum current during the test run. Fig. 4 shows representative

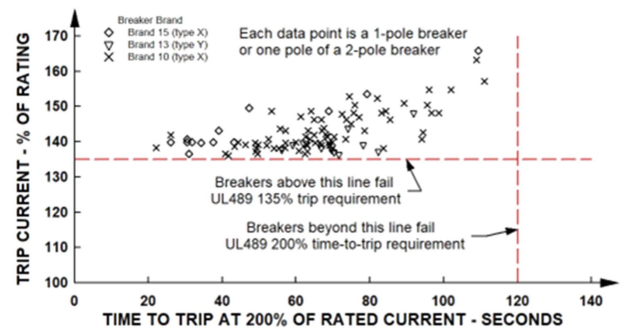


FIGURE 5. UL489 calibration test results for 100 defective breakers. They all fail the standard’s 135% calibration test, but pass the standard’s 200% calibration test.

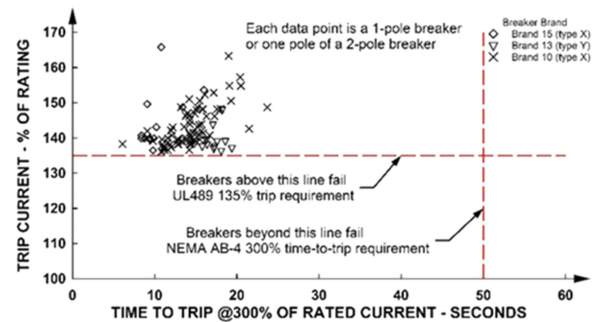


FIGURE 6. NEMA AB-4 calibration test results for the same 100 defective breaker shown above in Fig. 5. They all have failed the UL489 135% calibration requirement but pass the NEMA AB-4300% time-to-trip calibration test.

calibration test records for two 15 A breakers, one that passes and one that fails the UL135% calibration test. The breaker has tripped when the current drops to zero.

For breakers rated 15 A, as are those of Fig. 4, the applied test current for the 135% test is 20.25 A. If the breaker has not tripped by the end of one hour at 20.25 A, it has failed the 135% calibration requirement of UL489. The applied current is then slowly ramped up in 0.1 A increments until the breaker trips. That applied current is the minimum current that will cause the breaker to trip under the standard test conditions. For the defective breaker of Fig. 4 (test record on the right), its minimum trip current is 22.07 A, which is 147% of its 15 A rating.

The breaker on test is then allowed to cool prior to performing the 200% and 300% calibration tests in sequence, per UL489 and NEMA AB-4, respectively, again allowing the breaker to cool between tests. Current for these tests is applied as a step function and held constant until the breaker trips. The test record for those tests is similar to the left-hand record of Fig. 4, but with higher current and shorter time to trip.

IV. TEST RESULTS

After confirming that they are defective, because they do not trip at 135% of rated current, all of the breakers passed both the UL489 200% calibration test and the NEMA AB-4300% calibration tests by a substantial margin. None of the 100 defective breakers was rejected by the higher-current tests. The error rate for both the UL489 200% calibration test and

the NEMA AB-4300% calibration tests is 100% in regard to assuring that the tested breakers will trip as required at 135% of current rating.

Figs. 5 and 6 show the test results for the 100 defective breakers. The breakers were specifically selected for retest because they had previously failed to meet the UL135% calibration test. All 100 of them again failed to trip within one hour at 135% of rating. Their actual calibration, the minimum trip current, ranged from 137% to 165% of rating. Their data points therefore are all above the horizontal dashed line depicting the allowable 135% maximum allowed by UL489. They are all improperly calibrated.

The data shown in Figs. 5. and 6 is for the same specimens and the same 135% test results. The difference is the current applied to generate the time-to-trip data, namely 200% of rating for the UL489 calibration test of Fig. 5 and 300% of rating for the NEMA AB-4 calibration test of Fig. 6. Each data point in these figures shows the results of two tests on the same breaker, one to determine its minimum trip current and the other to determine the time to trip at the specified current level. The vertical dashed lines show the allowable time to trip, which is 120 s for the UL489 test at 200% and 50s for the NEMA AB-4 test at 300% of rating. None of the 100 defective breakers were rejected by either of the high-current tests.

V. DISCUSSION

A. FIRE SAFETY PROBLEM

Residential branch-circuit breakers are not tested for proper calibration once they leave the factory. They remain installed for an indefinite length of time, during which they are never tested for their ability to actually trip as required at 135% of rated current. The result is a sustained elevated risk of fire and injury for the occupants of buildings in which defective circuit breakers are installed.

The fire risk stems mainly from long-term cumulative degradation of electrical insulation at elevated temperature caused by excessive current. By design, in a code-conforming installation with a properly calibrated circuit breaker, it is impossible to sustain a current overload considered to be unsafe. The breaker trips to prevent that from happening.

But, if the breaker is not properly calibrated and its circuit is subjected to periods of higher than rated current, the safe life of the electrical insulators in the circuit (hours of operation when carrying current) is substantially shortened. Insulation deterioration can result in arc faults, which are reported to be a major cause of electrical fires [17], [18].

The temperature rise of the current-carrying conductors and components in a circuit is proportional to the current squared, and the useful safe service life of most electrical insulating materials is highly sensitive to temperature. The commonly-accepted rule-of-thumb relationship, based on the Arrhenius equation, is that the safe service life of an insulator is halved for every 10 °C increase in temperature rise [19]. The result is that it does not take very much overcurrent, in terms of percentage of circuit (and circuit breaker) rating, to deteriorate

an insulating material enough to create a potential fire hazard sometime within the lifespan of a building.

An example demonstrating the sensitivity of insulation life to breaker calibration (minimum trip current) for a nonmetallic (NM) cable is provided in [13]. NM cable, also known as “Romex,” is the most common type used for wiring branch circuits in houses in the USA. For that particular example, at the maximum sustained current for a breaker that is calibrated to trip just under 135% of its rated current, the expected life of the PVC insulation of the vertical NM cable situated in a thermally insulated wall is 20% of its expected safe life at 100% of rated current. If a breaker allows current to be sustained at 165% of rating, as would the worst-case defective breaker of those tested in this present investigation, as seen in Figs. 5 and 6, then the safe life of that cable will be reduced to about 4% of its expected life at rated current.

The flow of improperly-calibrated branch circuit breakers into the distribution chain has persisted for at least 60 years. In some instances, defective breakers were shipped as a result of deliberate improper actions. Without documentation to the contrary, however, it can be assumed that most of the defective breakers have slipped through the safety net due to long-standing acceptance and use of ineffective test procedures that are rigorously performed by well-meaning employees of the manufacturers and NRTLs. That would explain, at least partially, why the calibration defect problem of some brands has been around for so many decades without being noticed and corrected.

The calibration defect problem extends to commercial trade in used circuit breakers. This is a substantial and useful business activity that provides obsolete types of breakers when needed as replacements or for adding circuits in existing panels. The calibration test recommended in NEMA AB-4, at 300% of rated current, is commonly employed by sellers of “recertified” used breakers. It has now been clearly established that this test does not screen out improperly calibrated breakers.

B. CORRECTIVE ACTIONS AT THE FACTORIES

It is up to the errant manufacturers to take appropriate action to halt production of substandard breakers.

This is a straightforward manufacturing engineering exercise. No new concepts are required. Given allowable high (135% of rating) and low (100% of rating) limits for a breaker’s trip current, determine what the particular factory has to do to assure that every breaker shipped to the market will reliably trip between those limits. This is not an impossible task, as demonstrated by the fact that about half of the manufacturers appear to have been doing it correctly [12], [13]. It must be recognized that existing high current test procedures at 200% or 300% of rating do not in any way assure that breakers will trip properly at or below 135% as required.

C. CORRECTIVE ACTION BY THE NRTLs

In the eyes of the people most at risk, namely the occupants of the homes in which the defective breakers are installed,

the NRTLs are the gatekeepers acting in the interest of public safety. They have the obligation to detect calibration deficiencies and the authority and responsibility to act decisively to halt the production and shipment of defective breakers.

Detecting calibration deficiencies requires effective independent testing by the NRTLs on a statistically significant number of random samples taken from both the production lines and the distribution chain. The testing must include breaker calibration at 135% of its current rating. That test is effective, while testing at higher currents and assuming correlation is not effective.

D. RECALL AND REPLACEMENT

Halting production of defective breakers would not alleviate the safety exposure posed by defective breakers that are already installed. Ideally, a recall and replacement program should be implemented. At the minimum, property owners and others should be informed as to the defect levels and advised to have them replaced.

VI. CONCLUSION

The unique experimental results presented in this article help explain why the flow of improperly calibrated branch circuit breakers from some factories has persisted undetected and uncorrected for decades. It is most likely due to the following factors:

- 1) Defective breakers are produced when manufacturers calibrate their breakers to trip close to the maximum allowable current limit without providing an adequate safety factor to allow for product variability.
- 2) These manufacturers and their respective NRTLs are not testing for proper tripping at 135% of rated current. If they were performing tests at that current, it would have been statistically impossible for the double-digit calibration defect problem to go unnoticed for so many years. This is undeniable, since calibration testing at 135%, by definition, is certain to detect and reject the defective breakers – those that fail to trip at 135%.
- 3) The errant manufacturers and their associated NRTLs are most likely relying on time-to-trip testing at higher current for checking calibration. The experimental results presented above prove that testing at 200% or 300% of rated current (per UL489 or NEMA AB-4 respectively) does not identify breakers that will fail to meet the standard requirement to trip at 135% of rated current.

This present work unveils an underlying cause of a long-standing breach of residential electrical fire safety protection. Considering that double-digit calibration defect rates have been demonstrated for no less than three currently-marketed residential branch circuit breaker brands, each overseen by a different NRTL, our present system of NRTL oversight of this important safety device must be viewed as a failed experiment. Electrical fire safety in millions of structures has been compromised as a result. It is a life-safety issue worthy of prompt and effective corrective action by industry and/or government.

REFERENCES

- [1] *Standard for Molded-Case Circuit Breakers and Circuit Breaker Enclosures*, Underwriters Laboratories Standard UL489, 2016 and prior editions.
- [2] *Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures*, Canadian Standards Association Standard CSA 22.2 No. 5-16, 2016 and prior editions.
- [3] Final Judgement, Underwriters Laboratories, Inc. vs. Federal Pacific Electric Company, Superior Court of New Jersey, Chancery Division, Essex County, Docket C 46956, 1956.
- [4] R. Madison, *Statistical Evaluation of Circuit Breaker Failures*, memo to E. W. Krawiec, U.S. Consumer Product Safety Commission, Bethesda MD, Aug. 12, 1978.
- [5] J. Palmer, *Report on First Meeting of Circuit Breaker Follow Up Program Ad Hoc Committee – June 21 & 22 1979*, GTE Sylvania, Jackson MS, Jun. 27, 1979.
- [6] “Exxon buys a scandal along with a company,” *Business Week*, vol. 2646, Jun. 21, 1980.
- [7] Calibration and Condition Tests of Molded Case Circuit Breakers, Final Report: Contract CPSC C 81 1429, Wright Malta Corporation, Ballston Spa, NY, Dec. 30, 1982.
- [8] *Commission Closes Investigation of FPE Circuit Breakers and Provides Safety Information for Consumers*, Press release, U.S. Consumer Product Safety Commission, originally issued, 1983. Revised: Feb. 18, 2011 [Online]. Available: <https://www.cpsc.gov/Newsroom/News-Releases/1983/Commission-Closes-Investigation-Of-FPE-Circuit-Breakers-And-Provides-Safety-Information-For-Consumers>
- [9] R. W. Eckert, “Molded case circuit breakers – Oldies but goodies,” *Elect. Construction Maintenance*, vol. 81, no. #4, pp. 70–74, 1982.
- [10] J. Aronstein, *Hazardous FPE Circuit Breakers and Panels*, J. Aronstein, Consulting Engineer, Schenectady, NY, Mar. 29, 2024. [Online]. Available: www.fpeinfo.org/hazardous_fpe_240329.pdf
- [11] J. Aronstein and R. Lowry, “Estimating fire losses associated with circuit breaker malfunction,” *IEEE Trans. Ind. Appl.*, vol. 48, no. 1, pp. 45–51, Jan./Feb. 2012.
- [12] J. Aronstein and D. W. Carrier, “Molded case circuit breakers—Some holes in the electrical safety net,” *IEEE Access*, vol. 6, pp. 10062–10068, 2018.
- [13] J. Aronstein, “Faulty residential circuit breakers—A persistent fire safety problem,” *IEEE Open J. Ind. Appl.*, vol. 4, pp. 75–86, 2023.
- [14] *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*, Standard Practice NEMA AB 4, National Electrical Manufacturers’ Association, Arlington VA, 2017, and prior editions.
- [15] Deposition of R. A. Weckstein, Spencer v. Worcester Electric et al, Massachusetts Superior Court Department of the Trial Court, Worcester, MA, Jul. 15, 1993, p. 62.
- [16] D. Shapiro, “Disturbing news - how reliable are residential breakers?,” *Elect. Contractor*, vol. 47, no. 5, May 2018, p. 68.
- [17] L. Smith and D. McCoscrie, Residential Electrical Distribution System Fires, U.S. Consumer Product Safety Commission. [Online]. Available: <https://www.cpsc.gov/s3fspublic/reselecfire.pdf>
- [18] D. A. Lee, A. M. Trotta, and W. H. King, Jr., *New Technology for Preventing Residential Electrical Fires: Arc-Fault Circuit Interrupters (AFCIs)*, U.S. Consumer Product Safety Commission, [Online]. Available: https://www.cpsc.gov/s3fs-public/AFCIFireTechnology_0.pdf
- [19] T. W. Dakin, “Electrical insulation deterioration treated as a chemical rate phenomenon,” *Trans. Amer. Inst. Elect. Eng.*, vol. 67, no. 1, pp. 113–122, Jan. 1948.

JESSE ARONSTEIN (Life Senior Member, IEEE) received the bachelor’s degree in mechanical engineering from The City College of New York, New York, NY, USA, in 1957, and the master’s degree in mechanical engineering and the Ph.D. degree in materials science from Rensselaer Polytechnic Institute, Troy, NY, USA, in 1962 and 1970, respectively.

His industrial experience includes engineering positions with General Electric Co., from 1957 to 1961, and both engineering and management positions with IBM Corporation, from 1961 to 1974, and Wright-Malta Corp., from 1974 to 1984. He is currently a Consulting Engineer, primarily involved with electrical equipment failure and safety analysis. He has been involved in performance and safety testing of residential electrical components and appliances, since the late 1970s. He is a licensed Professional Engineer in New York State. He has 15 patents in his name and received several invention and achievement awards for his work with IBM. He has authored more than 30 technical papers, primarily related to electrical contact and connection technology.