

PROPER APPLICATION & MAINTENANCE OF MOLDED CASE BREAKERS TO ASSURE SAFE AND RELIABLE OPERATION

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Abstract - This paper will discuss the importance of reliable and repeatable performance of molded case circuit breakers in today's power distribution systems. The paper will review existing standards for maintenance of molded case breakers including procedures outlined in NEMA AB4 and IEEE1458. Common misconceptions and system application issues regarding these devices will be discussed. Several examples of on-line infrared scans of circuit breakers over the course of a five year period will be presented and reviewed. Experiences at an integrated paper mill located in Longview, Washington USA explains documented cases where infrared thermography has been used as a predictive maintenance tool in determining potential problems with breakers while in service. Follow-up analysis by the circuit breaker manufacturer has generally validated mill maintenance decisions to remove a breaker from service and replace it, based on infrared scan results. Periodic infrared scanning used as a tool in identifying potential problems with sealed molded case circuit breakers will be discussed. This and other breaker off-line testing methods used at this site will be reviewed. Finally, overall reliability improvement and impact on the results of the existing mill-wide safety compliance programs will be summarized.

Index Terms – Risk Management, Electrical Safety Program, Infrared Thermography, Molded Case Circuit Breakers, Predictive Maintenance, NFPA70E Standard.

I. INTRODUCTION

A number of presentations from past Institute of Electrical and Electronics Engineers (IEEE) Conferences and Electrical Safety Workshops have focused on the reliability and maintainability of molded case circuit breakers as a factor in developing a credible facility safety program. Most certainly, proper maintenance of any electrical product is necessary to assure reliable operation. However, past assertions such as "Several studies have revealed that circuit breakers that were not maintained within a period of five years have a 50% probability of failure" [1] and "If a breaker has not been operated within as little as 6 months, it should be removed from service and manually exercised" [2] and "Maintenance of molded case circuit breakers is limited to proper mechanical mounting, electrical connections and periodic manual operation" [3] tend to be misleading. In actual practice, circuit

breakers subjected to interruption of high level faults, harsh environments and lack of maintenance will certainly need to be replaced before their performance is compromised. The question is how does one know when these breakers should be replaced?

Over the past several years an integrated paper mill in Longview WA has used innovative preventive maintenance diagnostic methods to confirm the integrity of molded case circuit breakers (MCCBs). Facility maintenance processes and testing methods have resulted in sound decisions to remove breakers from service during rotational outages based upon thermal imaging from routine infrared (IR) scans.

II. FRAMING THE ISSUES

Today's modern MCCBs are applied throughout most, if not all industries, offering a safe and economic means of connecting and disconnecting loads from the electrical source and providing both overload and short-circuit overcurrent protection. Although there are many types of molded case circuit breakers, all are comprised of five major components including the molded case or frame, an operating mechanism, arc extinguishers, contacts and trip components. A cutaway view of a typical MCCB is shown in Fig. 1 below.

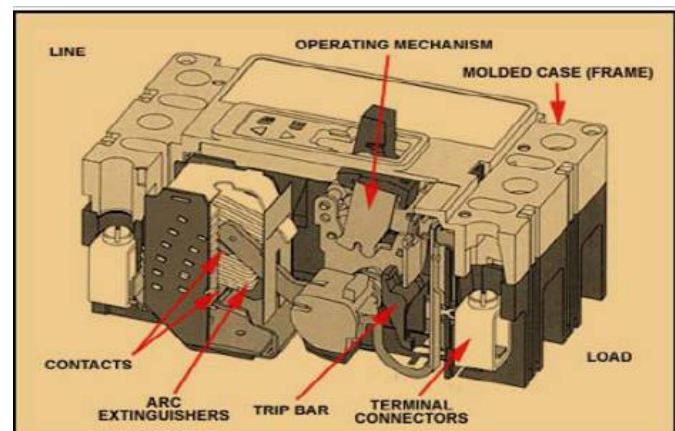


Fig. 1: Cutaway view of a molded case circuit breaker identifying the main components.

Unique issues exist in identifying when a MCCB should be considered as a candidate to be replaced. By nature of the component itself, manufacturers of these products assemble, calibrate, test and then many times seal the molded cases of

these devices. There are typically no internal serviceable parts and breaking the factory seal generally results in jeopardizing the manufacturer's warranty. Because of issues inherent to the product design, historically the maintenance of MCCBs by the end user has been limited to mechanical mounting, electrical wiring and manual operation of the mechanism.

Determining when MCCBs have been compromised and should be removed from service has been problematic to the traditional end user, even to users with skilled maintenance forces. When a MCCB interrupts a high level fault at or near the device interrupting rating, there is no easy way of knowing after the fault has been cleared that the breaker can be reset and is suitable for continued service. Internal damage that occurs during repeated high level fault current interruption could affect the breaker's ability to interrupt a future fault, thereby potentially compromising its performance. If potential problems were known in advance, the user might elect to remove the breaker from service, replacing it with a new one.

In addition to the complexities in determining the possible end of life for a MCCB, electrical safe workplace standards such as the National Fire Protection Association's NFPA-70E [4] place a new emphasis on a circuit breaker interrupting a fault as designed and also clearing the fault in a repeatable fashion, within a prescribed clearing time. The IEEE companion document Standard IEEE1584 [5] includes methods to calculate downstream electrical arc flash energy based on breaker time-current curves published by the manufacturers of these products. If a MCCB has been in service for a long period of time and has not been properly maintained, or if the device has repeatedly interrupted high level faults near the device's interrupting rating in the past, it's difficult to know with some measure of confidence that the breaker is capable of interrupting a future fault.

Certainly, maintaining MCCBs in today's industrial plants presents some challenges, both historic and emerging. The authors will address these issues by first identifying the testing standards these devices are designed to comply with before leaving the factory, and then discussing the installation, testing and maintenance standards that exist in industry today. Finally, some common misconceptions regarding MCCB application and data collected from MCCBs installed at the paper mill referenced will be reviewed and analyzed.

III. MCCB CODES AND STANDARDS

There are a number of existing codes and standards for MCCBs that offer valuable information surrounding testing, installation and maintenance of these devices.

A. UL489

Molded Case Circuit Breakers are evaluated to the Tri-National Standard across North America *Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures*. In the US, this standard is UL 489 [6], in Canada CSA C22.2 No. 5 [7] and in Mexico NMX-J-266-ANCE [8]. This standard requires that all designs of MCCBs be subjected to many thousands of endurance test operations at 100% rated current. Fig. 2 shows a sample of the required endurance testing included in the standard.

The MCCB test standard also requires that the devices be able to operate under multiple overload operations. An

overload for this test is defined as 600% of rated current. Fig. 3 shows a sample of the required overload testing included in this standard.

Maximum frame size in amperes	Number of cycles of operation			
	Per minute ^a	With current	Without current	Total
100	6	6,000	4,000	10,000
150	5	4,000 ^b	4,000	8,000 ^b
225	5	4,000	4,000	8,000
600	4	1,000	5,000	6,000
800	1	500	3,000	3,500
1200	1	500	2,000	2,500
2500	1	500	2,000	2,500
6000	1 ^c	400	1,100	1,500

^a For circuit breakers rated more than 800 A, the endurance test may, at the option of the manufacturer, be conducted in groups of 100 load operations. No-load operations may be conducted between groups of load operations at the option of the manufacturer.

^b Where tests are required on samples having ratings of 100 A or less, 250 V or less, the number of operations is to be the same as for the 100 A frame.

^c Rate of operation: 1 cycle per minute for first 10 operations; thereafter in groups of 5, at 1 cycle per minute, with an interval between groups that is agreeable to the submitter and the testing agency.

Fig. 2: MCCB Endurance Tests - Table 7.1.5.1 from the UL489 Standard. A 225 ampere frame breaker is cycled for 4000 operations no-load current and 4000 operations at rated load current, 8000 operations total.

Frame size in Amperes	Number of operations			Number of cycles of operation per minute
	Circuit breakers		Switches	
	Close and open manually ^{a,b,c,d}	Close manually, open automatically		
50	35	15	50	6
100	35	15	50	6
125	50 ^e	- ^f	50	5
150	50 ^e	- ^f	50	5
200	50	-	50	5
225	50	-	50	5
400	50	-	50	4 ^g
600	50	-	50	4 ^g
800	50	-	50	1 ^h
1200	50	-	50	1 ^h
1600	50	-	50	1 ^h
2000	25	-	25	1 ^h
2500	25	-	25	1 ^h
3000	28 ⁱ	-	28 ⁱ	1 ^h
4000	28 ⁱ	-	28 ⁱ	1 ^h
5000	28 ⁱ	-	28 ⁱ	1 ^h
6000	28 ⁱ	-	28 ⁱ	1 ^h

^a The operations may be performed by a machine simulating manual operation.

^b If the test sample trips during manual operation, it is still considered as a manual operation.

^c At the option of the manufacturer, the adjustable instantaneous response of a circuit breaker rated 400 A or more may be adjusted to less than the maximum position.

^d The minimum closed time shall be one cycle, unless the sample trips.

^e In the case of a multipole breaker without a common trip, and rated at more than 100 A, 35 cycles of operation shall be made manually and 15 automatically as specified in 7.1.3.14.

^f Operation may be conducted in groups of 5, with 15 minutes maximum between groups.

^g Three operations at 600 percent of rating at the rate of 1 cycle per minute, followed by 25 operations at 200 percent of rating at the rate of 1 cycle per minute (may be conducted in groups of 5 with 15 minutes maximum between groups).

Fig. 3: MCCB Overload Tests - Table 7.1.3.1 from the UL489 Standard. A 225 ampere frame breaker is cycled manually for 50 operations at 600% rated load current.

MCCBs are also subjected to two interruption tests at “limited” fault current as defined by the UL489 Standard. The word limited is defined as 10 kilo-amperes (kA) for 101-800 ampere breakers, 14kA for 801-1200 ampere breakers, 20kA for 1201-1600 ampere breakers, 25kA for 1601-2000amp breakers and 60kA for 4001-5000amp breakers.

Finally, MCCBs are subjected to two interruption tests in accordance with UL489, at maximum rated short-circuit current. For a device rated at 100kA interrupting current, this means the breaker would be required to clear this rated current twice. Clause 7.1.11.3.1.15 of the UL489 Standard requires both that the test circuit be closed on the circuit breaker and also that the circuit breaker be closed into the maximum fault, both times safely interrupting the fault.

B. NEMA Standard AB4

In an effort to better frame the ongoing maintenance recommendations for MCCBs after they have been installed and are operational, the National Electrical Manufacturers Association (NEMA) first published the AB-4 Standard [9] in 1991. This document is available as a free download at <http://www.nema.org/>. The document focuses on inspection, preventive maintenance, and test procedures for breakers that are in service. One area of maintenance focus in this document is a recommendation to mechanically cycle MCCBs periodically. In addition, when the breaker includes a push-to-trip actuator, the tripping mechanism can also be tested. This test exercises the trip mechanism components called upon to function during the interruption of a fault. In most MCCB designs, initiating a test-to-trip results in the breaker handle toggling to the center position. In order to reset the trip, the MCCB handle must be moved to the off position before the breaker can be re-energized.

C. IEEE Standard 1458

The IEEE has also published a standard for maintenance of MCCBs titled *Recommended Practice for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications* [10]. The work was originally sponsored by members of the IEEE Petroleum and Chemical Industry Committee after the group discovered a need to raise the general level of understanding for specifiers and users of UL 489 molded case circuit breakers. Included in this newer 2005 standard is an important section titled ‘Procedures for field testing and determining the remaining life of molded case circuit breakers’. The standard establishes specific methods to ascertain when a MCCB should be removed from service, including photos of MCCBs with visible wear or damage to the molded case frame as shown in Fig. 4. There is also an article in the standard addressing methods for an exposed face and lug temperature check using an infrared non-contact temperature measuring instrument. In this section, temperatures detected above 54.4°C (130°F) on the exposed insulated face of the breaker, or the adjacent surrounding dead front surfaces of the enclosure, warns that a reason for the elevated temperature must be found before returning the MCCB to service. An explanation suggests that the most likely cause of elevated temperature is a loose connection. A host of additional field tests such as Individual Pole Resistance Test and Instantaneous Overcurrent Trip Test are clearly defined with step-by-step procedures. Most tests require



If a circuit breaker with a cracked case or burn marks is found, take the circuit breaker out of service and replace it as soon as safely possible

Fig. 4: Photo from IEEE Standard 1458 showing visible external damage to a breaker case, a stated reason to remove the breaker from service.

removal of the MCCB from service before field testing can be conducted.

IV. MCCB APPLICATION MYTHS VS FACTS

Over the course of the past 30 years, the authors have been challenged to refute a number of claims regarding the application of MCCBs. This seems to be especially prevalent when the discussion is focused on their merits versus other overcurrent protective device technologies. Without digressing to a “mine is better than yours” debate, it is important at this point to at least correct some common misconceptions regarding application of MCCBs in today’s power distribution systems.

A. Is It Necessary To Always Derate The MCCB Interrupting Rating?

No! Many users have elected to derate the nameplate interrupting rating of MCCBs, in part because the battery of tests MCCB designs are subjected to as a part of the UL489 test standard are typically not well known or understood. This decision is driven by the notion that the device may be capable of interrupting the maximum nameplate rating one time, but it would then be unusable and incapable of interrupting the next fault. In actual practice, these devices are subjected to tests to prove them safely capable of interrupting multiple fault currents. The UL489 test standard requires MCCBs to interrupt the maximum nameplate fault current twice. Industry standard ampere interrupting capacity (AIC) ratings have been established to simplify breaker selection and application among the multiple manufacturers. It should be noted that derating of MCCB interrupting ratings should be considered on the rare occasion that these devices are applied on a corner grounded delta connected system.

B. Do Breakers Have A History Of Inherent Nuisance Tripping Problems In Motor Circuits?

Most nuisance tripping problems of the past can be traced back to changes in motor designs and requirements in the National Electrical Code [11]. One of the application issues that has emerged in the past 5 years is the use of MCCBs in motor protection circuits feeding high-efficiency motors. Common practice in applying circuit breakers to motor circuits

has been the use of magnetic-only MCCBs, designed to protect the circuit from faults just above the motor starting inrush current. The overload relay that is a component of the motor starter is designed to protect for overloads in motor running currents up to the motor inrush current. Article 430.51 of the National Electrical Code (NEC) has historically recognized the application of magnetic-only MCCBs in motor circuits, but has limited the maximum magnetic setting of these breakers to 13 times the motor rated full load current. As new high-efficiency motors have emerged in recent years, the industry has experienced some issues with these designs and higher inrush currents. Newer motors essentially rendered the NEC article obsolete. To resolve this issue, the 2005 edition of the NEC was the first edition to allow breaker magnetic trip setting to be as high as 17 times the full load motor current for Design B energy-efficient motors. Since this code revision, nuisance tripping problems have been greatly reduced.

C. Don't Circuit Breakers Take Longer To Clear A Fault Than Other Types Of Overcurrent Protective Devices?

In many cases, no! Most real world faults are lower level, single phase arcing faults. In these situations, MCCBs will often clear the fault faster than other types of overcurrent protective devices. When operating in their instantaneous overcurrent range, the majority of today's MCCBs will clear a fault in less than one cycle. Larger low-voltage power circuit breakers and medium-voltage vacuum circuit breakers, can take as long as 5 cycles to clear a fault. Fig. 5 shows a typical time-current curve for a 100A molded case breaker. Note that this device clears a fault in the instantaneous region of the curve within 0.007 seconds – for 60 hertz systems a fault would be cleared in less than one-half cycle.

The instantaneous clearing time for any overcurrent protective device is critically important. In calculating let-through energy and establishing an effective electrical safe workplace, time, distance and energy are three variables available to the system designer in the quest to reduce arc-flash energy. Some industry standards, including the NFPA-70E [4] and IEEE1584 [5] mentioned previously, are not necessarily up to date regarding MCCB clearing time performance. NFPA-70E Table 130.7 (C)(9) suggests that MCCBs applied in low-voltage MCCs should be evaluated based on a 0.03 second, 2 cycle clearing time. IEEE1584 uses a "simple" method based on the worst-case time-current curves for four breaker manufacturers, or an "alternate" method based on the published time-current curve of the breaker being evaluated. In actual practice, all of these methods are very conservative. Even using manufacturer's data and the specific time-current curve of the breaker under evaluation often yields erroneous results in the instantaneous region of the curve. Remember, this data was originally published by manufacturers for selective coordination evaluation and intended to define the maximum clearing time. In this application, a conservative approach is desired. Engineers completing system arc flash evaluation often try to use time-current curve published by breaker manufacturers as "let through" curves, which they were never intended to be. Finally, manufacturer's published time-current curves do not take into account the inherent dynamic impedance of the device as the contacts are parting. These issues are addressed in further detail in [12].

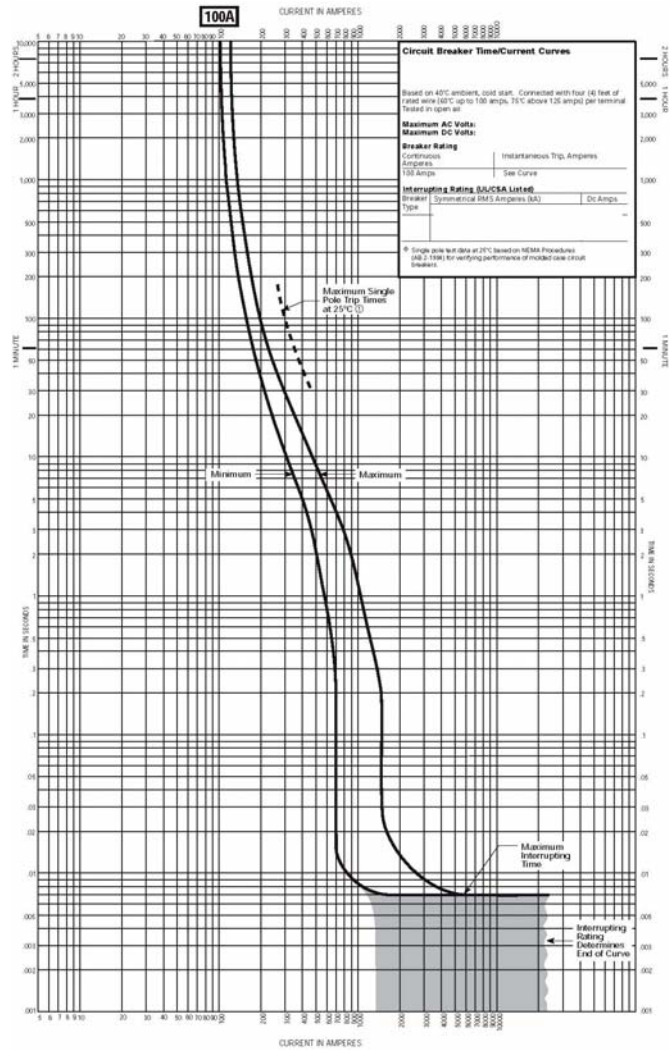


Fig. 5: Typical MCCB time-current curve.

D. Only More Sophisticated Current Limiting Design Breakers Limit Let-Through Current During A Fault Interruption.

Not true. For several years, breaker manufacturers have assembled breakers with designs based upon contact configuration in a reverse current loop, with current flow of the stationary and moving contacts traveling in opposite directions. The result is superior performance, especially for interruption of high-magnitude fault currents. The opposing current flow enables electromagnetic forces present during the fault to effectively drive the contacts apart faster. This effect is likened to bringing two positive or two negative poles of a magnet together. With a higher fault current, the resulting magnetic force is stronger, and thus the contact parting time is faster. The result is that an arc is developed across the contacts earlier during interruption of a higher level fault. The arc plays an important role in limiting the let-through current. Effectively, the geometry of the contact configuration in many of today's breakers enables these devices to be inherently current-limiting.

Published time-current curves from breaker manufacturers do not take into account their current-limiting benefits. Again, historic application of these curves has been for short-circuit and coordination studies, which has driven manufacturers toward a more conservative approach. To determine the actual impact of the current limiting affects of MCCBs, specific testing will need to be completed. Some early work [12] has recently been conducted with results that look to be very encouraging. More testing is needed. The IEEE and the NFPA are coordinating the \$6.5 million dollar Arc Flash Collaborative Research Project to help fund study and research on how to prevent and better understand the arc flash phenomena. The goal of this collaborative project is to improve electrical safety standards, predict the hazards associated with arcing faults and accompanying arc blasts, and provide practical safeguards for employees in the workplace. Additional testing of breakers and other overcurrent protective devices will be completed in the early phases of this project.

E. Don't Single Pole Interrupting Capabilities Restrict Applications Where MCCBs Can Be Safely Applied?

Rarely! There has been much written on the limitation of a single pole (of a three pole breaker) in its ability to successfully clear a fault. The genesis of this debate can be traced back to the UL489 Standard that essentially requires single pole testing of all MCCBs manufactured to this standard of 10,000 AIC. The magnitude of this interrupting current is typically well below the available fault current in most industrial applications. Added concern surfaced when the 2002 version of the National Electrical Code added a fine print note in article 430.52(c)(6) emphasizing the issue of MCCB single pole rating limitations on corner grounded delta-connected systems.

The individual poles of a 3-phase MCCB are effectively tested at the full current value of the interrupting rating and at phase voltage when they interrupt the 3-phase short circuit in the high available fault test of UL 489. So when MCCBs are applied in solidly grounded wye systems, there would be no condition where a MCCB would fail to interrupt any fault up to and including its interrupting rating.

Single pole interrupting concerns regarding breakers applied in ungrounded delta and resistance grounded systems wye or delta, have been generally proven to be unfounded. In high resistance grounded (HRG) systems, so long as two simultaneous faults occur downstream from the breaker, under no conditions will a single pole of a breaker be required to interrupt full phase to phase voltage. The only time a single pole of a breaker would be required to interrupt full phase to phase voltage, would be if a second simultaneous fault occurred on another phase and on the line side of the breaker with the first fault. Even if this condition were to exist, there would be added impedance in the ground path from each fault, thus greatly lowering the fault current. Similar to the explanation regarding derating, MCCB single pole ratings should be considered on the rare occasion that these devices are applied on a corner grounded delta connected system. This is the only known system connection where a MCCB single pole rating comes into play, all other system connections are not impacted by this issue. There have been several excellent papers offering details on this topic including [13] and [14].

V. FIELD EXPERIENCE AT THE PAPER MILL

The paper company referenced previously operates an integrated newsprint paper mill in Longview, Washington USA. The mill was first built in 1979 and today operates three paper machines. The mill has over 2000 motors in operation at a utilization voltage of 600 VAC, most of which are fed from low-voltage motor control centers.

Like many manufacturing facilities in the process industries, the mill continuously looks for new technologies to improve process reliability, while reducing operating costs. Because major electrical distribution equipment in the mill typically is maintained during rotational outages every three years, predictive maintenance (PdM) techniques are frequently used as a means of identifying potential failure points that could be addressed during scheduled outages. One PdM tool used very extensively in the facility is infrared thermography. For the past 10 years the mill has retained a full-time in-house technician that "sweeps" the entire facility every 6 months, checking for thermal signatures that may require attention. Thermal imaging has proven a very effective tool across a wide array of applications including areas such as measuring the impact of corrosion, detecting liquid levels in process tanks, final product conformity and of course, electrical.

Thermal imaging of MCCBs is primarily conducted within motor control centers for breakers feeding motor control circuits. IR scans are conducted while the circuit is energized, with the breaker closed. This is accomplished by defeating the mechanical interlock included in the motor control center (MCC) handle mechanism. Fig. 6 below shows a photo of a thermographer conducting a survey within a MCC unit. In this photo, the individual is standing outside of the flash protection boundary as defined by the NFPA70E Standard, so the appropriate personal protective equipment (PPE) is worn during the survey (hand protection was temporarily removed for dexterity in IR camera operation).



Fig. 6: Paper mill Thermographer conducting thermal scan survey of low-voltage MCC compartment.

A. Early Results Of Molded Case Breaker Thermal Scans

In August 2002, mill maintenance surveyed nearly 400 breakers and removed three MCCBs from service in the Paper Machine No. 3 and Deink area of the mill. The No. 3

machine was originally commissioned in 1990 as opposed to the other two paper machines, No. 1 and No. 2 that were commissioned in 1978 and 1980 respectively. Because the older section of the mill was built in an era when circuit breaker interrupting ratings were typically much lower, the No. 1 and No. 2 machine areas included thermal-magnetic circuit breakers with integral current-limiters for each motor circuit. The current-limiters were required due to the mill system available fault current exceeding the vintage MCCBs capability as a stand-alone overcurrent protective device. The three breakers in the Machine No. 3 area were removed from service during a scheduled rotational outage, based on what looked to be elevated temperature readings from thermal scans during an earlier periodic survey. All breakers removed from low-voltage MCC's were serving motor loads and were of the magnetic-only design. The breakers were returned to the manufacturer's Product Integrity Center (PIC) in Pittsburgh, Pennsylvania. There they were carefully inspected and then subjected to a battery of tests, similar to the testing required for new circuit breakers as defined by the UL489 test standard. By observing the manufacturer's date codes on the returned breakers, the three units were found to be manufactured in July and October of 1990 and in January 1996. The factory test results of the breakers returned to the PIC yielded some interesting results as outlined in Table I.

- Remove dust, dirt, soot grease or moisture with clean dry cloth.
- While de-energized, operate breaker mechanism several times to check mechanical linkages.
- If possible, operate breaker under load to clear contact debris/oxidation.
- During cold outages, use the push-to-trip button. Trip and reset the breaker from the mechanism to assure proper mechanical operation.
- Check for case cracks or discoloration.
- Refer to NEMA AB4 for specific field testing.

B. Follow-up Results Of Thermal Scans And PIC Testing

Drawing upon the lessons learned from returning a small sample of breakers that were voluntarily removed from service following thermal image surveys, mill engineers elected to collect a larger sample of breakers for return to the manufacturer's PIC for analysis. In August of 2008, a group of 11 more breakers that had been removed from service during rotational outages based on routine thermal imaging of over 500 breakers. These 11 were also returned for evaluation.

During this effort, each breaker was carefully marked so the thermal image could be matched to the testing results collected at the manufacturer's PIC. Although all 11 breakers were tested, specific information on each MCCB test is not included in this text due to the extensive amount of data gathered. Instead, a few items of special interest are reported here, with IR scans, photos and test results. The complete PIC test results for all breakers are included in Appendix A.

1) *Test Case 1:* The first breaker to be reviewed is a 150 ampere magnetic-only MCCB located in MCC designation D304D-3C. This breaker is identified as Breaker ID 4919-2 (see Appendix A). The MCCB was originally manufactured in 1995, so it had been in service for nearly 13 years. Fig. 7 shows the results from IR scans conducted at the mill site in January 2008. Thermal inspection for this breaker suggested a hot spot temperature of 149.4°F, a temperature above the 130°F threshold temperature identified in the IEEE 1458 Standard (as discussed previously in Section III.C of this text). Note from this thermal image that the observed elevated temperatures resided near the line terminals at the top of the breaker and down the left side. The line terminal connections were checked for tightness, but the temperature issue persisted. Although it was difficult to determine the source of elevated temperatures for the image, with known good terminations the test technician elected to remove this breaker from service and replace it during a scheduled outage.

This breaker was then returned to the manufacturer's PIC for analysis. At the PIC, the breaker cover was removed, and each arc-chute assembly was removed from the molded casing. Photos of the breaker external case as well as the inside of the breaker cover, contact area and arc-chute components were taken as shown in Fig. 8. Although there was no visible external damage, some internal components appeared visibly discolored. This evidence suggests that this breaker had interrupted multiple fault currents of a fairly high magnitude. The mill recorded IR thermal hot spot at the upper section of the breaker. This may be significant in that this is in proximity of the MCCB main contacts, suggesting a higher contact resistance, perhaps caused by erosion of the contact surface following interruption of a high-level fault.

TABLE I - NORPAC BREAKER EVALUATION			
10/23/2002			
BKR TYPE	MAG-ONLY	MAG-ONLY	MAG-ONLY
DATE CODE	10/9/1990	1/25/1996	7/20/1990
AS-FOUND	VISIBLE ARCING ON CONTACTS AND ARC CHUTES	CONTACTS DIRTY. A PHASE SUBJECTED TO EXCESSIVE HEAT	BREAKER DAMAGED. MECHANISM WILL NOT OPERATE
TEST RESULTS	SEAL BROKEN. BREAKER NOT TESTED. SIGNIFICANT HIGH FAULT INTERRUPTIONS	TEMP RISE TEST FOLLOWED BY CYCLE AND CLEAN. TEMP REDUCED TO SPECIFICATION. BREAKER OK	NOT TESTED. DEBRIS THROUGHOUT BREAKER CONSISTENT WITH SEVERAL SHORT CIRCUIT INTERRUPTIONS

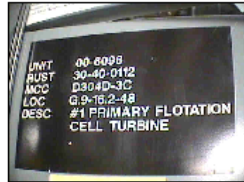
Of the nearly 400 breakers surveyed, three breakers were returned to the factory for analysis, and two were judged to not be suitable for continued service. One encouraging result from this effort was that the thermal imaging program at the mill had effectively discovered potential problems with these MCCBs while they were in service. IR scanning was validated as an effective PdM tool for the mill site. As a follow-up of this effort, the breaker manufacturer's field organization conducted a training session for electrical maintenance personnel in January 2003, sharing the results of these findings and offering an update on ways to improve maintenance of MCCBs in the mill. The mill was offered the following list:

Breaker Maintenance Hot Buttons

- Check terminal connections for proper tightness (many conditions of elevated temperature are traceable back to terminal connection issues)

ELECTRICAL INSPECTION

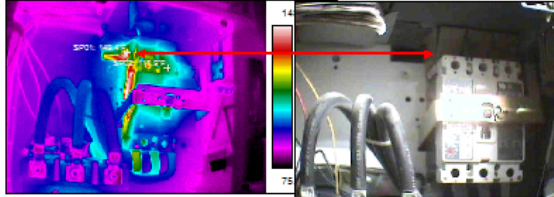
LOCATION	D-1
EQUIPMENT	
TIME OF IMAGE	11:09:24 AM
DATE OF IMAGE	1/22/2008
DATE OF REPORT	1/22/2008
THERMOGRAPHER	RODGER LEAK



THERMAL IMAGE

F:\D-1

VISUAL IMAGE



HOT SPOT	149.4°F
REFERENCE TEMP.	117.9°F
DELTA-T	31.5
MAX RATED AMP LOAD	
ACTUAL AMP LOAD	
COMMENTS	CHECK CONNECTION A-PHASE TOP OF BREAKER
REPAIR / DATE	
REPAIRED BY	
COMMENTS	

Fig. 7: Infrared inspection of 150 ampere Breaker 4919-2 located in LV MCC D304D-3C.

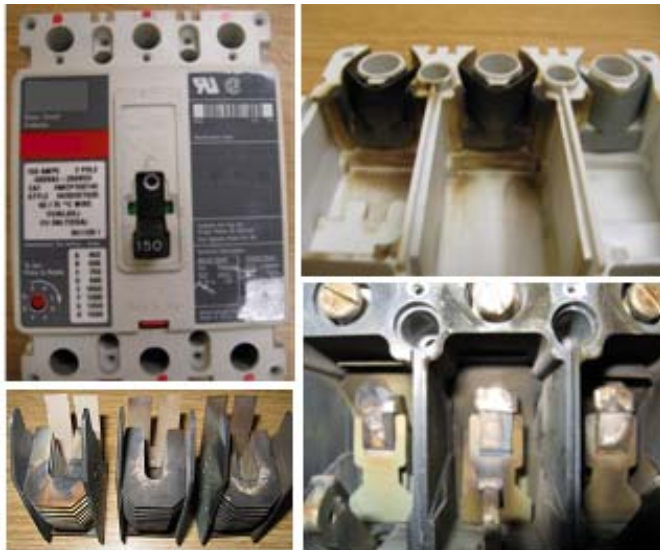


Fig. 8: Photos of Breaker 4919-2 clockwise from upper right; external breaker case, line-side of breaker cover, main moving and stationary contacts, arc-chute assemblies.

Following disassembly and observation of the internal breaker components, the MCCB was re-assembled and tested under load at the manufacturer's PIC lab. Complete thermal tests were conducted on this and the other ten MCCBs. A summary of all test results are included in

Appendix A. The PIC test procedure involved line and load cable connections to the breaker, with thermocouple temperature probes connected at each pole of the three-pole breaker. The MCCB was then subjected to three-phase rated load current and temperature readings were recorded at each of six thermocouples on five-minute intervals. Temperatures were recorded until all measured values stabilized. The ambient temperature was also recorded during the load test so the temperature rise (the difference between measured and ambient temperature) could be calculated for each recorded value. An MCCB design test is considered a "pass" when the measured temperature rise at all terminals does not exceed 50°C. Note that this 50°C rise threshold is the design performance test for a new breaker. Variability in the field due to issues such as unbalanced loads, loose terminations, vibration, moisture, dirt, dust and contact wear will impact the thermal performance. Tests for Breaker 4919-2 at the PIC lab resulted in stable temperature values in 2 hours, 35 minutes. Line and load terminal temperature rise for phase A, B and C were recorded as shown in Table II. From the test results, four out of six of these values, which are highlighted in Table II, exceed the thermal design threshold of 50°C. In this case, the lab test delivered results consistent with IR scans conducted in the field.

	LINES:			LOADS:		
	A	B	C	a	b	c
TIME	°C	°C	°C	°C	°C	°C
2:25	61.15	54.37	42.70	57.44	51.99	46.64
2:30	61.27	54.44	42.78	57.65	52.07	46.68
2:35	61.38	54.44	42.78	57.57	51.99	46.62

2) *Test Case 2:* The second breaker to be reviewed was also a 150 ampere magnetic-only MCCB located in low-voltage MCC designated D304D-4H. This breaker is identified as Breaker ID 4919-4 with PIC recorded test data shown in Appendix A. Fig. 9 shows the results from IR scans conducted at the mill site in January 2008. Thermal inspection of this breaker suggested a hot spot temperature of 130.8°F. This temperature is just above the 130°F threshold identified in the IEEE 1458 Standard. Once again, from the thermal image the thermal hot spot temperatures appear to be at or near the line terminals of the MCCB. After cable terminations were checked for tightness, this breaker was also removed from service during a rotational outage, again suspected of possible internal damage. This breaker was returned to the manufacturer's PIC, then disassembled and photographs were again taken as shown in Fig. 10. In contrast to the photos for breaker 4919-2 shown in Fig. 8, the photos of this breaker appear to show very little visible wear or burning, evidence of interruption of higher-level faults. The contact surfaces appear only slightly discolored, particularly for phase B and C poles. The arc-chute assemblies look nearly new, although once again, this breaker had a service life of nearly 13 years, with a manufacturing date of November 1995.

The PIC lab thermal test stabilized in 3 hours, 10 minutes when the test was considered complete. Table III shows results from this test. In this case, five out of six of these tested values highlighted in Table III exceed the thermal design threshold of 50°C, with line terminals B and C

demonstrating the highest measured temperatures, a result verified by field based IR scans. Overall, the lab test once again delivered results consistent with IR scans from the field.

Interestingly, there was a significant disparity between phase terminal temperatures, but with less visible discoloration from the photographs in Fig. 10.

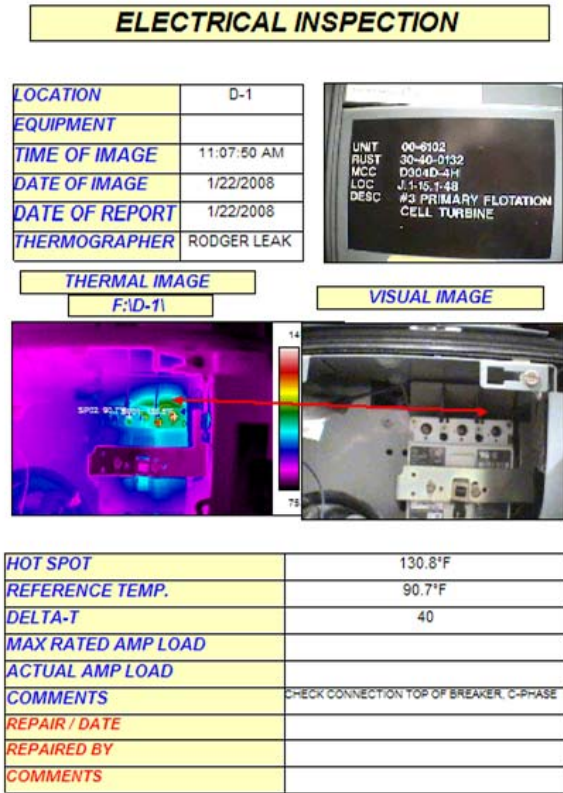


Fig. 9: Infrared inspection of 150 ampere Breaker 4919-4 located in LV MCC D304D-4H. Note elevated temperature at line side of MCCB poles B and C.



Fig. 10: Photos of Breaker 4919-4 clockwise from upper right; external breaker case, arc-chute assemblies, main moving and stationary contacts with evidence of elevated heat primarily on Phases B and C, close-up of Phase C moving contact.

TABLE III - PIC TEMERAURE RISE TEST MCCB 4919-4

TIME	LINES:			LOADS:		
	A °C	B °C	C °C	a °C	b °C	c °C
3:00	34.91	56.36	66.41	49.78	55.04	56.55
3:05	34.48	56.45	66.89	50.01	55.29	56.88
3:10	34.69	56.60	67.46	50.23	55.53	57.33

3) Test Case 3: The third breaker to be reviewed is also a 150 ampere magnetic-only MCCB; this one located in low-voltage MCC designated D302D-4H. This breaker is identified as Breaker ID 4919-1 with PIC recorded test data shown in Appendix A. Fig. 11 shows the results from IR scans conducted at the mill site in January 2008. Thermal inspection for this breaker suggested a hot spot temperature of 171.8°F. This temperature is well above the 130°F IEEE 1458 Standard threshold. Once again, from the thermal image the hot spot temperatures appear to be at or near the line terminals of the MCCB. After cable terminations were checked for tightness, this breaker was also removed from service during a rotational outage.

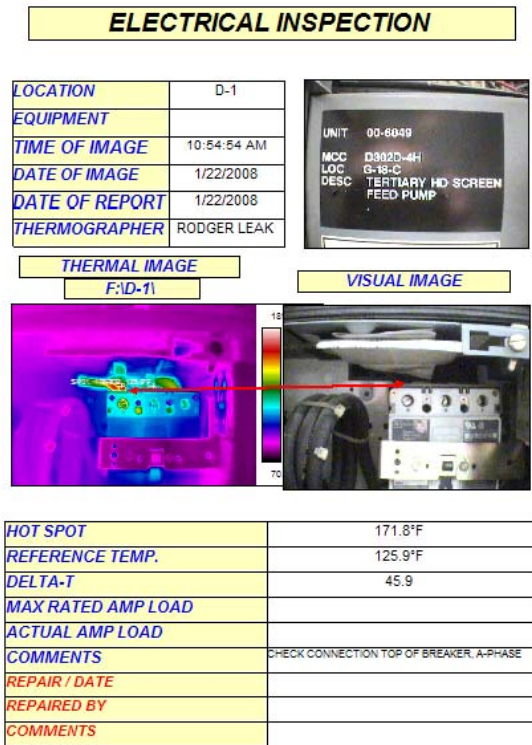


Fig. 11: Infrared inspection of 150 ampere Breaker 4919-1 located in LV MCC D302D-4H. Note elevated temperature at line side of MCCB with hot spot temperature of 171.8°F.

This breaker was also returned to the manufacturer's PIC where it was disassembled. Photographs are shown in Fig. 12. Similar to the previous example of Breaker 4919-4, the internal components of this MCCB appear to show very little visible wear or burning. The contact surfaces appear only slightly discolored, particularly for the Phase A breaker pole. This breaker was manufactured in December 1999, so the MCCB was in service for just over 8 years.



Fig. 12: Photos of Breaker 4919-1 clockwise from upper right; external breaker case, main moving and stationary contacts, arc-chute assemblies.

The PIC lab thermal test stabilized in 4 hours, 35 minutes. In this case line terminal temperature rise for line and load terminals is shown in Table IV. From the test results, none of the six stabilized temperatures exceed the thermal design threshold of 50°C. In this case, the lab test delivered results that were inconsistent with the IR scans conducted in the field. So, based on the aforementioned 50°C temperature rise threshold, it appears likely that this MCCB was removed from service unnecessarily.

TABLE IV - PIC TEMERAURE RISE TEST MCCB 4919-1						
	LINES:			LOADS:		
	A	B	C	a	b	c
TIME	°C	°C	°C	°C	°C	°C
4:25	38.50	43.37	42.47	44.52	46.24	45.84
4:30	38.50	43.37	42.49	44.45	46.15	45.75
4:35	38.40	42.85	41.99	44.33	45.57	45.40

It's instructional here to note that the thermal test lab at the PIC also included a thermal image test using thermography similar to the field based IR scans. Fig. 13 shows the test lab thermal image for Breaker 4919-1. Comparing this image to the field IR scan shown in Fig. 11, the hot spot temperature was recorded at 142.3°F, a value much lower than the 171.8°F hot spot temperature measured by the mill. This suggests that perhaps some variable in the field such as an unbalanced load or a line terminal that in fact was improperly tightened, caused an overall higher hot spot temperature. It is also interesting to compare the field and test lab overall thermal images of this breaker. Note that the thermal profile of the lab test appears more consistent throughout the MCCB

frame, whereas the field IR scan shows a more isolated area of elevated temperature. Remember that the IR camera is recording surface temperature. IR is not measuring the actual heat generated by the conducting components of the breaker, but instead the camera measures the deflected and absorbed temperature of the conductors through the breaker frame. The lab test condition represents a balanced 3-phase 150 ampere current, while the field test condition presents infinitely more variables. So, some variability is to be expected.

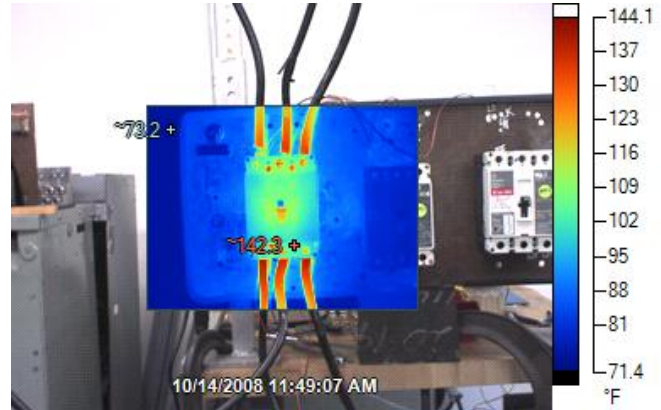


Fig. 13: PIC thermal scan of breaker 4919-1. Breaker tested at 150 ampere rated load for 4 hours, 35 minutes, 142.3°F hot spot.

C. Mill Thermal Scans Of Other Overcurrent Protective Devices

As mentioned previously, all of the MCCBs that were removed from service based on results from thermal imaging were removed from the Paper Machine No. 3 and Deink areas of the mill, an area where the equipment was newer than Machines No. 1 and 2. Remember that low-voltage MCCs in the older area of the mill included MCCBs with integral current-limiters. These were provided with the original equipment as the mill power system fault currents were at levels higher than circuit breaker designs of that period could interrupt. In these designs, interruption of higher magnitude fault currents was presumably accomplished by the current-limiter device. Thermal scans of breakers in this area of the facility at times yielded elevated temperatures in the area of the current limiter; one such case is shown in Fig. 14, with thermal hot spot temperature measured at 249.6°F! Further investigation revealed that the current limiting element partially failed, with three of four conducting elements melting, perhaps during an elevated fault current, and the fourth remaining intact. Fig. 15 shows the limiter element cut open, revealing portions of the element that melted while in operation. In this case, the elevated temperature detected during an IR scan resulted in a decision to remove the device from service and replace all three current-limiters serving this specific load. It appears that like MCCBs, current limiters that are typically applied in industrial systems can "age" over time based on environment and fault history.

The current limiter looks to be another good candidate for routine IR surveys as a means to attempt to determine when an overcurrent protective device may not be capable of interruption as designed, and therefore should be removed from service and replaced.

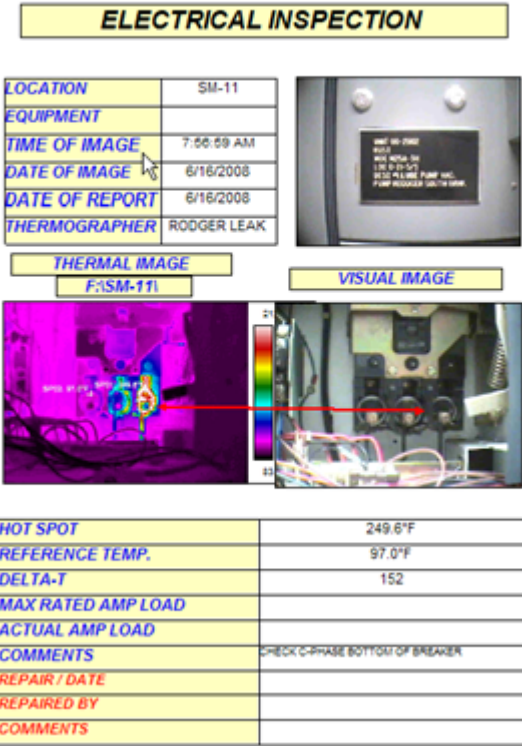


Fig. 14: Thermal scan of partially failed current-limiter installed in Paper machine #1 area. Elevated hot spot temperatures of nearly 250°F resulted in a decision to remove this device from service.



Fig. 15: Photo of current-limiter removed from service from Paper Machine #1 area. Cutaway view shows three elements melted while one remains intact.

D. Other Off-Line Breaker Testing Methods

In addition to a very comprehensive thermal imaging program to survey MCCBs and determine when a breaker should be removed from service, the mill also effectively employs other testing methods. Because this mill operates in a continuous process industry, it is nearly impossible to affect maintenance on MCCBs or other electrical system devices during operation. This facility schedules planned maintenance shutdowns on six-week intervals for isolated mill electrical systems. A significant portion of MCCBs in the respective operating area may be mechanically exercised and the trip system tested via the push-to-trip feature on the MCCBs as a part of the lockout and tagout procedure for equipment maintained during the period. General condition of each circuit breaker is noted, as external condition of the outer case may warrant immediate replacement or a subsequent spot thermographic inspection after the equipment is back in service.

A note regarding requirements for mechanical cycling of MCCBs: Standards including NEMA Standard AB4 and IEEE Standard 1458 discussed previously suggest mechanical operations and manual trip testing to assure the mechanism is operating freely. However, neither of these standards defines a set frequency for a mechanical test, because many factors such as ambient temperature, environment and loading cycle determine when mechanical cycling may be necessary. In this paper mill application, many of the MCCBs have not been mechanically cycled or tested over a period of multiple years. Subsequent test results presented here confirm that absence of mechanical cycling in this application has not impacted reliability. One possible contributing factor here is the use of more advanced Teflon based lubricants applied by manufacturers in most newer design MCCBs. NEMA AB4 and IEEE1458 offer many other step by step procedures for mechanical and electrical field testing of MCCBs both while installed in equipment and on a work bench.

VI. CIRCUIT BREAKER RELIABILITY RESULTS

Using the small sample of MCCBs removed from service at the paper mill facility as a result of this initiative, it's possible to calculate some measure of overall reliability of the MCCBs in this facility. Thermal imaging is conducted twice per year for each MCCB installed in the mill. Of 11 breakers removed from service in the Paper Machine #3 and Deink area during the course of one calendar year, only 5 that were returned and tested at the PIC exhibited temperature rise levels above the 50°C test standard. This represents 0.57% of the 876 total MCCBs installed and operational in this area of the mill. Speaking to the 6 breakers that passed design tests at the PIC but were removed from service by the mill, it's likely that supporting electrical systems for these breakers were the root cause of elevated temperature readings in the field. For instance, tightening a MCCB terminal that is corroded or has oxidized will have little affect in reducing elevated surface temperature readings following an IR scan. Also, review of the mill IR survey data shows that only 4 of the 11 breakers actually exhibited hot spot operating temperatures exceeding the 130°F threshold identified in the IEEE 1458 Standard. This

suggests it is also possible that some were removed from service unnecessarily.

Finally, it is important to note that none of the 11 breakers that were returned to the manufacturer's PIC for test actually failed. In fact, all were in sound mechanical condition and the tripping system functioned properly for all MCCBs tested. The reason these devices were removed from service was they were suspected of internal wear or perhaps damage based upon field based IR surveys showing elevated hot spot temperatures. Mill maintenance personnel elected to remove the suspected devices from service, given lack of any proof that the elevated temperatures were caused by loose connections or other variables identified previously. In the end, all breakers removed from service were replaced during a scheduled maintenance outage. This maintenance discipline offers a clear advantage of avoiding a problem that would have disrupted production, had it occurred during normal operation of the paper making process.

VII. CONCLUSIONS

Molded case circuit breakers operate reliably in countless industrial settings, and when properly applied these devices are designed to safely protect distribution systems for many years. In some cases, previous accounting of performance and reliability of MCCBs has been inaccurate, at times resulting in confusion for the engineer attempting to apply these devices properly.

Like any electrical component, ongoing maintenance of MCCBs is an important element in assuring these devices will perform as designed, protecting distribution systems when called upon to do so. Existing standards such as the NEMA Standards Publication AB4 and IEEE Standard 1458 serve as useful guides in identifying routine maintenance procedures that will prolong the life of these devices.

The paper mill in Longview, Washington has maintained a very effective predictive maintenance program via use of thermography to identify when a MCCB should be removed from service and replaced. In the aggregate, field decisions to remove a breaker from service are generally validated by factory testing after the device has been removed. Although there will be some error in making this choice strictly based upon a thermal survey, even a few wrong decisions have still resulted in very reliable overall performance of MCCBs within this facility.

VIII. ACKNOWLEDGEMENTS

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APPENDIX A
SUMMARY TEST RESULTS FROM CIRCUIT BREAKER TESTING AT PRODUCT INTEGRITY CENTER

BREAKER ID NUMBER	4919-01			4919-02			4919-03			4919-04		
BREAKER TYPE	MAG-ONLY			MAG-ONLY			MAG-ONLY			MAG-ONLY		
RATING	150A/600V			150A/600V			150A/600V			150A/600V		
MFG DATE CODE	15-Dec-99			28-Nov-95			3-Oct-90			27-Nov-95		
PIC TEST DATE	14-Oct-08			14-Oct-08			15-Oct-08			15-Oct-08		
TIME TO STABLE TEMP (HRS)	4:35			2:35			4:00			3:10		
BREAKER TERMINALS	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C
TEMP RISE °C	38.40	42.85	41.99	61.38	54.44	42.78	46.90	53.42	43.83	34.69	56.60	67.46
BREAKER TERMINALS	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C
TEMP RISE °C	44.33	45.57	45.40	57.57	51.99	46.62	46.56	49.32	46.37	50.23	55.53	57.33
AS-FOUND CONDITION	MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR			VISIBLE SIGNS ON HIGH TEMPERATURE ON COVER, ARC-CHUTES, CONTACTS, PHASES B & C			CASE DISCOLORATION. VISIBLE SIGNS ON HIGH TEMPERATURE ON ARC-CHUTES PHASES A & B			MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR		
TEST RESULTS	MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE ABOVE SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE ABOVE SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE ABOVE SPECIFICATION		

BREAKER ID NUMBER	4919-05			4919-06			4919-07			4919-08		
BREAKER TYPE	MAG-ONLY			MAG-ONLY			MAG-ONLY			MAG-ONLY		
RATING	150A/600V			100A/600V			15A/600V			150A/600V		
MFG DATE CODE	7-Feb-06			22-Oct-01			28-Apr-00			9-Oct-90		
PIC TEST DATE	16-Oct-08			22-Oct-08			3-Nov-08			24-Oct-08		
TIME TO STABLE TEMP (HRS)	4:35			4:00			2:40			3:35		
BREAKER TERMINALS	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C
TEMP RISE °C	49.28	39.25	48.75	90.04	58.28	49.75	8.62	9.39	9.85	49.28	39.25	48.75
BREAKER TERMINALS	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C
TEMP RISE °C	42.35	45.22	46.12	58.27	53.45	46.49	16.60	20.10	16.88	42.35	45.22	46.12
AS-FOUND CONDITION	MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR. SLIGHT PITTING ON PHASE C CONTACT			MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR			MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR			MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR. INST ADJUSTMENT KNOTCH STRIPPED		
TEST RESULTS	MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE ABOVE SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION		

BREAKER ID NUMBER	4919-09			4919-10			4919-11		
BREAKER TYPE	MAG-ONLY			THERMAL-MAG			MAG-ONLY		
RATING	100A/600V			100A/600V			100A/600V		
MFG DATE CODE	26-Oct-90			12-Sep-90			25-Jun-90		
PIC TEST DATE	24-Oct-08			28-Oct-08			29-Oct-08		
TIME TO STABLE TEMP (HRS)	1:20			3:55			4:20		
BREAKER TERMINALS	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C	LINE A	LINE B	LINE C
TEMP RISE °C	37.07	50.58	41.46	39.39	43.37	44.16	39.96	42.20	39.50
BREAKER TERMINALS	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C	LOAD A	LOAD B	LOAD C
TEMP RISE °C	41.00	49.33	44.41	44.77	45.15	45.99	43.87	45.58	43.33
AS-FOUND CONDITION	MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR			MINIMUM VISIBLE SIGNS OF DISCOLORATION OR WEAR			VISIBLE SIGNS ON HIGH TEMPERATURE ON COVER, ARC-CHUTES & CONTACTS OF PHASE A		
TEST RESULTS	MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE ABOVE SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION			MECHANICAL MECHANISM AND TRIPPING SYSTEM OK. HEAT RUN RESULTS ARE WITHIN SPECIFICATION		

HIGHLIGHTED TEMPERATURE RISE TEST DATA EXCEEDS 50°C THERMAL DESIGN TEST LIMIT