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## ***Electrical Circuit Breakers***

This article is intended to supplement your knowledge beyond the immediate requirements of the NEC. It covers the types of circuit breakers that are found in various types of facilities today. The beginning lays a foundation (a review for many) and progress to introducing molded case, Insulated case, and drawout types with the series ending with the most advanced of all, microprocessor based circuit protective devices that are becoming more common. The following topics are covered in this the first part of the article:

- Circuit Breakers Defined
- Circuit Breakers As Switches
- Current Levels To Be Broken
- Over-Currents
- Current and Temperature
- Circuit Breakers As High Temperature Limit Switches
- Ampacities Of Electrical Conductors
- Short Circuits
- Shorts To Ground
- Arcing Faults
- Bolted Faults
- Safety First, Always First
- NEC requirements For Circuit Breakers

Let us begin by defining circuit breakers then we will delve into some of the "nice to know" details about the relationships of current, temperature, and ampacities of conductors. The subject of faults and the various types of faults will then be covered. The topic of safety while next to last is highlighted as being of first order importance. The final topic for this part is a brief listing of some of the general NEC requirements relating to circuit breakers.

## ***Circuit Breakers Defined***

The American National Standards Institute (ANSI) defines a circuit breaker as: "*A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions. Also capable of making and carrying for a specified time and breaking currents under specified abnormal circuit conditions, such as those of a short circuit.*" The NEC defines a circuit breaker as "*a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within it's rating.*" While the ANSI and the NEC definitions describe the same family of devices, they do have some differences. The same is true with the actual circuit breakers themselves. They are much the same in general terms; however, there are a number of significant differences between the many types of electrical circuit breakers installed in various types of facilities today.

## ***Circuit Breakers As Switches***

Both the ANSI and the NEC definitions acknowledge the potential for the legitimate use of circuit breakers as switches. Switches (pass, but do not consume electrical energy) are considered as being control devices, thus one may also say that a breaker is a control device, or a controller. A circuit breaker can control and protect an electrical circuit and people operating the utilization equipment. An electrical relay is an example of an operating control; it opens and closes the circuit. Circuit breakers are not designed as replacements for operating controls such as relays, contactors, or motor starters.

There is as you may intuitively have anticipated an exception. Some circuit breakers are manufactured for use in a specific type of application. When a circuit breaker is designed to also be routinely used as an on-off switch to control 120 or 277volt florescent luminaires they are marked SWD, for switch duty. This does not mean that a switch duty breaker can be used to manually control a traffic signal light where it will be cycled on and off 1,000 or more times per day. The point is; the listing for switch duty (SWD) does not mean a circuit breaker can be used as a high frequency cycling operating control, such as a relay that has a life span rated in tens, if not hundreds of thousands of duty cycles.

While circuit breakers can be legitimately and safely used as switches, the frequency and duration of such use is limited. Routinely circuit breakers are manually operated for service-maintenance, and repair type activities. With the preceding enhancing our understanding, we can say that circuit breakers can legitimately be used as switches,

though generally they are not intended for prolonged repetitive manual breaking and making type control of electrical energy utilization equipment.

### ***Current Levels To Be Broken***

For general consideration, and our immediate purposes; the amounts of current circuit breakers are required to open, can be divided into the following three broad current amplitude groups.

The first and lowest being *rated load or less*. For example: a 60 amp low voltage molded case thermal-magnetic breaker must be able to open or close 48 amps (80% of its rating) or less.

Next up in current quantity, this same breaker must be able to open *Overload level currents*. Overloads, for our purposes, can be understood by reference to the NEC requirements for overload protection for motors. Thermal overloads are commonly sized for some 115% of the motor's nameplate full load amps. A motor with a service factor of one, having a rated load of 10 amps would be overloaded when pulling 11.5 amps or more. Overload currents can for our immediate purposes be considered to be percentages increases above rated normal load current.

The third and highest current level grouping is *Short Circuit Currents*. Short circuit (fault) currents can be considered as being fifteen (15) or more times normal rated load currents.

In summation, circuit breakers may be called upon to open or close a circuit within a range of from no current flow, to as much as fifteen (15) times or more its rated current. For a 100 amp breaker that could 1,500 amps or more.

As will be covered later, this high value of short circuit current is routinely exceeded by circuit breakers today. This should not be considered as implying that circuit breakers can open unlimited amounts of current, as will be covered later on, they can not.

### ***Over-Currents***

The National Electrical Code (NEC) defines overcurrent as "**any current in excess of the rated current of the equipment or the ampacity of a conductor.**"

Overcurrent (or excessive current) conditions are caused by defective conductor insulation, equipment, or an excessive workload burden placed upon the utilization equipment and its electrical circuit. Fuses and circuit breakers provide a level of

safety against overcurrent conditions in electrical circuits. We therefore routinely say that fuses and circuit breakers are overcurrent protective devices (OCPD). That is they protect the circuit's components from too much current.

Gazing into the fog that is the future, perhaps we will begin to see these types of electrical devices taking on additional roles, thus becoming a more general intelligent circuit protective device. To minimize the length of this paper, only automatic circuit breaker type overcurrent protective devices will be covered. Restated, this paper does not cover fuses, and motor starter type overload relays.

A circuit breaker's primary functions are to provide overcurrent protection, and isolation from energized circuit components and un-energized circuit components. Breakers must perform these functions when properly applied without fail in all circumstances completely and safely, while protecting the electrical circuit against overcurrent induced damage between normal rated current and the breaking capacity of the breaker called its Ampere Interrupting Capacity (AIC). Now that is a big job and an important job.

Modern breakers routinely do their job day in and day out with very little maintenance. Like all things that are made by man, they do have limits and they do fail. Hopefully this paper will help you better understand and appreciate the task performed by those little black boxes.  
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## ***Current and Temperature***

The movement of electrons (electricity) in a conductor produces a rise in the temperature of the conductor's material and it's electrical insulation. Excessive temperature rise (caused by an excessive amount of electron collisions with base material atoms) can result in the melting of the wires material (assumed to be copper by the NEC), if it is allowed to rise as high as 1,980 degrees F. For a point of reference, the NEC limits the operating temperature of XHHW type conductor insulation to no more than 194 degrees F. Thus it can be understood that long before the copper wire will begin to melt, the wires insulation material will have melted, and perhaps to have even burned up.

Our first priority therefore is the temperature of the conductor's electrical insulating materials. Different types of insulating materials have different maximum design operating temperatures.

## ***Circuit Breakers As High Temperature Limit Switches***

Electrical energy is transported throughout an electrical circuit by the conductive path provided by electrically insulated wires. The material that performs the insulation function in the circuit has a high temperature limit far below that of the copper wire. Circuit breakers are routinely sized to limit thermal energy related damage to the electrical insulation material and not the copper wire. This being the case we can say that a circuit breaker limits the temperature of the connected-protected wire's insulation materials.

## ***Ampacities Of Electrical Conductors***

Just how hot an electrically insulated wire can get before its insulation melts, suffers damage or a decrease in electrical dielectric strength (the ability to perform as an electrical insulator) are well-known facts. The various types of materials used as electrical insulation have been tested and the results listed in what are called ampacity tables in the NEC in article 310.16.

How long an installed conductor's electrical insulation material will last without overload, is yet another question. Research is underway to determine the life of an installed insulated conductor. No doubt when completed, it will point to many factors that have a negative impact upon the inservice life of an insulated conductor. For now we can book a safe bet that voltage spikes, vibration, environmental factors such as temperature, dust (both electrically and thermally conductive and non-conductive types), UV light, aggressive vapors and fluids, and relative humidity will all be proven to shorten, to some degree, the life of modern plastic type electrical insulation materials.

I suspect that many of these same factors also have a negative impact upon circuit breakers. I do not know of any research, in the past or currently, that defines the service life of circuit breakers. Considering the importance of the safety provided to people and property that circuit breakers provide, it is a bit puzzling as to why such research has not already been undertaken.

For many years various types of materials have been used as electrical insulators. Today conductors are made using material for outer jacketing, and for filling in the gaps (indices) between bundled round conductors. These materials may or may not be considered to be electrical insulators. Some medium and high voltage cables are made using materials that are considered to be conductive, or semi-conductive.

## ***Short Circuits***

A short circuit is an unintended path through which current can flow. Any time current flows in a path that is not the normal path, we say that the circuit is shorted. Shorts are further defined by the nature of the shorted connection. A direct short is commonly a phase-to-phase short; which is when two hot (un-grounded) wires make unintended contact with each other; thus a phase-to-phase short circuit has been created.

A circuit breaker must be able to respond to a short circuit, which can present a large current flow in a short period of time. A short circuit unlike an overload (typically a percentage increase, and not multiples of rated load current) presents its self in a very short period of time and will typically be multiples of the load's normal operating current.

Breakers are tested to determine their ability to clear a short circuit without damage to them self's. With a phase-to-phase short, the breaker will be required to open the circuit at the circuit's rated phase-to-phase voltage. This would be the case independent of the system being grounded or un-grounded, that is either wye or delta solidly grounded or un-grounded or resistance (impedance) grounded.

## ***Shorts To Ground***

When an insulated hot wire, (un-grounded) unintentionally makes electrical contact with an electrically conductive-grounded object, a ground fault is created. The words ground fault means that there is a defect in the wire's electrical insulation; and the faulted wire has shorted to ground. Many times a phase-to-phase short will develop into a ground fault, and the other way around. Either a phase-to-phase short can produce a ground fault, or a ground fault can produce a phase-to-phase short. The fault can be in one, two or three wire's insulation materials.

Ground fault type circuit breakers (GFCI) will not be covered in this paper. The short circuit, overload current limiting nature of these types of breakers however will be covered. It is only the ground fault or residual current feature of GFCI type breakers that is not covered in this paper. A ground fault can present a current flow that is limited only by the impedance of the circuit and the capacity of the energy source supplying the faulted circuit. Ground faults can occur rapidly and can be either a low impedance type, developing a significant amount of electrical energy or as an arcing type fault with little total energy consumed. The common breaker is not designed or calibrated to respond to arcing type shorts to ground.

Circuit breakers typically will respond to a short to ground that is of the low impedance type as current levels are typically multiples of load currents to which the circuit breaker has been manufactured to sense and then respond to.

When installed in a grounded system, such as a center grounded wye system, only about one half of the system's phase-to-phase voltage will be broken by the breaker on a ground type fault. With an un-grounded type system a ground fault on the first phase to ground connection does not result in any current flow as the system is not referenced to ground. Yet should a second ground fault develop, the breaker will be required to break phase to phase system rated voltage.

With resistance grounded systems, the impedance of the supply system's ground and the circuit's ground fault combine to determine the amount of current drawn. Further, more detailed pursuit of understanding of the various electrical system grounding (earthing) methods used in America is beyond the limiting scope of this paper. I suggest that you read more on grounding, as it is a subject that seems to always open up disagreements. Mr. Holt's book titled *Grounding and Bonding, NEC 250* (product # O2NCT2) is just out and it covers this topic much better than I have done.

### ***Arcing Faults***

When a loose connection (a gap is present) is made in the faulted circuit, so loose that the current flow is non-continuous, it is called an arcing or arc fault. This type of circuit defect is much like a welder using a welding electrode to produce an electric arc. Arcing type faults are the most difficult to locate (due to conductor concealment in conduit or inside of walls and their non-continuous nature) and can be the cause of fires. This type of defect is the opposite of a bolted fault, the circuit impedance is higher and the connection is very irregular (high frequency). The current flows for only a fraction of a second and then cools down and may not flow current, or heat up again and produce an arc across the gap between the two conducting surfaces.

During the A-C cycle there are two times that the supply circuit voltage goes to zero volts; there are two times when the circuit's electromotive pressure is zero and an arc cannot be produced. This zero volts time helps to increase the faulted circuit's impedance. This higher impedance makes it more difficult for the arc to re-establish it's self again. These types of faults produce heat in a very small area thus they can start a fire and not trip a common thermal-magnetic circuit breaker and their energy level is so low and they last for such a short time, that they typically are not responded to by a common circuit breaker.

In response to this unique type of circuit defect, a new family of circuit protectors called arc fault circuit interrupter (AFCI) type circuit breakers has been under

development over for the last ten years. Because of the unique components (microcomputers) of these devices they will not be covered in this short paper. The common circuit breaker will not respond to the development of an arcing type fault due to the low total amount of thermal energy developed by the arc and the very high frequency of the arc. Perhaps one can think of an arcing fault as an embryonic electrical circuit defect, unlike the defect that has fully developed and matured into an adult electrical fault such as a bolted fault. Experience shows that on occasion a short circuit will clear its self before, or after the operation of the OCPD. That is it will develop into an open circuit.

### ***Bolted Faults***

Occasionally a shorted circuit will evolve that has such a firm connection (to either a grounded conductive object or another hot wire), that it is said to be a bolted fault. We are saying that it was not a loose connection, it was not wiggling around. A bolted fault offers less impedance to the flow of current than does an arcing type fault.

A loose connection type of fault may produce enough heat to melt or plasticize the conductor's conductive material and having cooled enough to then produce a joint so firm and secure as to be comparable to a welded joint. Then we would call it a bolted fault. Circuit breakers are typically calibrated to be capable of responding to a bolted type fault. This is because a bolted type fault produces sufficient current flow to cause either the thermal (after some intentional delay) or the magnetic (non-delay, but only if sufficient current flow is produced) trip elements to open the circuit.

### ***Safety First, Always First***

The exact nature of electricity, that is it can not be detected with the eyes, ears, or the nose, yet if it is touched, it can kill, must be remembered at all times. Circuit breakers are very reliable components of an electrical system, however they are man made; and are subject to becoming defective. *Proper lock-out-tag-out procedures must be followed when working on electrical circuits above 50 volts. Proper personnel protective equipment must be in serviceable condition and properly worn.* Safety is a requirement, not an option of every electrical task, large or small, be it routine or emergency in nature. Always use the three-step method when checking for voltage.

Take good care of your electrical test meters, having them *checked at least every three years for insulation strength and for calibration as listed in the instruction booklet, or once a year.* While a switch may visually indicate that the contacts have opened, a meter must be used to confirm that no voltage remains in the equipment to be worked on. Many times more than one source of power is provided to a

machine. Some electrical circuits contain motor starting/running or power factor correction capacitors that may still be charged even after power has been removed from the circuit.

When working with others do not assume that they know how to operate your meter, and do not assume that you know how to operate their meter. Take the time necessary to learn how to properly operate the test instruments that you will be required to use. I know that it is temporarily embarrassing to admit that we do not know something, but being found dead on the job, I believe to be permanently embarrassing. If you would like to learn more about the use of multi-meters and such, I suggest that you see if you can get your hands on a copy of the book titled "*Test Equipment*" published by Delmar. ISBN: 0-8273-4923-8.

## ***NEC Requirements For Circuit Breakers***

The National Electrical code has several requirements for circuit breakers (overcurrent protective devices). The following is a listing of some of them. Others can be found in the various specific articles, such as 430 covering motors.

- Main, feeder and branch circuit breakers must be installed in a readily accessible location.
- A working space as wide as the equipment, or at least 30 inches wide and three feet deep, or deep enough to allow any doors to be opened at a 90 degree angle be provided in front of the equipment housing a breaker.
- That when the operating handle is in the up position that it's center line be not more than 6 ft. 7 inches above the floor or working platform.
- That it be installed so that it is secure on its mounting surface.
- That when installed that the up position be on and that when the operating handle is moved down that this be the off position.
- That the breaker be clearly marked as to its off and on positions.
- That the breaker be clearly marked, such that after installation that the amperage rating is clearly visible. (There are some exceptions, see 240.83)
- That the operating handle be of a trip free design, that is it cannot be blocked or kept from tripping due to some type of obstruction keeping the operating handle from moving to the tripped position.
- When wires are connected to a breaker that they be properly torqued to the breaker's termination points.
- The NEC has specific requirements for both AFC and GFCI type circuit protectors that are mostly applicable based upon specific locations.

There are specific product type requirements for circuit breakers to be listed by a nationally recognized testing lab (NRTL) such as UL, that we will not be covering in this short paper. That means detailed information relating to engineering type testing

and things that the circuit breaker manufacture must know about are not covered. I am saying this to call your attention to the fact that this is not an everything your ever wanted to know about circuit breakers, type of encyclopedic article.

In this portion of the article; the following topics are covered:

- Functions
- Types
- Components
- Voltage Ratings
- Ampere Ratings
- Ampere Interrupting Capacity (AIC)
- Testing--Listing Of Circuit Breakers
- Not All "Breakers" Are Rated The Same
- The Electrical Arc
- Effects Of Current Flow
- Thermal Energy
- Thermal Trip Element
- Magnetic Trip Element
- Hydraulic-Magnetic Trip Elements

## ***Circuit Breaker Functions***

Later in this article we will cover several more specific features of some specialized types of circuit breakers; but for now let us begin by saying that a circuit breaker's main functions are:

- Sense the current flowing in the circuit
- Measure the current flowing in the circuit
- Compare the measured current level to its pre-set trip point
- Act within a predetermined time period by opening the circuit as quickly as possible to limit the amount of energy that is allowed to flow after the trip point has been reached.

## ***Circuit Breaker Types***

Medium and low voltage circuit breakers are commonly separated into the following groups based upon the type of material used to make the frames or cases out of:

- Molded case, (MCCB) the most common low voltage type
- Insulated case, (ICCB) the intermediate voltage and amperage sizes
- Metal clad, the higher in voltage (medium) and amperage rating

## ***Circuit Breaker Components***

The five basic components of a circuit breaker are:

- Frame, or case made of metal, or some type of electrical insulation
- Electrical contacts
- Arc extinguishing assembly
- Operating mechanism
- Trip unit, containing either a thermal element, or a magnetic element or both

## ***Circuit Breaker Voltage Ratings***

Low voltage (under 600 volts) circuit breakers are commonly rated for; 120 volts, 240 volt, 277 or 480 volts A-C. Some breakers are rated for used in DC circuits, while others are rated for use in either AC or DC circuits.

Single pole circuit breakers are rated for a voltage potential between the one hot wire and a grounded surface. Breakers that are intended to be part of a two or three phase circuit are rated for a voltage potential from opposite potential, to opposite potential, or phase-to-phase. You must not use two single pole a 240 volt breakers to control a 480 volt circuit, but two single pole breakers rated 277 volts could be used to control a 240 volt circuit.

When improperly applied out side of it's rating, a breaker may not be able to extinguish the arc when attempting to clear a fault. Some breakers have what is called a slash (/) rating such as 120/240 or 277/480. Breakers that are slash rated should not be used on un-grounded systems, as they have not been tested for safe operation on these types of systems. For a more detailed coverage of this topic review Mr. Holt's article "*Understanding Circuit Breaker Markings*" in the November 2001 issue of EC&M magazine. Cooper-Bussmann also has an article covering slash rated circuit breakers, if you would like to read still more.

## ***Circuit Breaker Ampere Ratings***

Circuit breakers have an ampere rating (typically marked on the end of the operating handle). This is the maximum continuous current that the breaker can carry without exceeding its rating. As a general rule the circuit breaker's ampere rating should be the same as the conductor's ampacity. In other words we would not want to put a 60 amp breaker on a 10 amp wire. Breakers are tested in open air, with a temperature of some 40 or 50 degrees C.

When a breaker is placed within an enclosure, cooling airflow is restricted; this reduces the ability of the breaker to carry a current to 80% of its ampere rating.

When they are installed in an electrical enclosure, breakers will trip when a current in the amount of their rating is placed upon them continuously. Breakers are designed to be able to safely carry a current in excess of their rating for very very short periods of time to allow some types of electrical equipment (called inductive loads) such as motors to start up.

While not as common, some breakers are rated for 100% continuous loads. These are typically called supplemental protectors (SP) and not circuit breakers.

### ***Ampere Interrupting Capacity (AIC)***

Circuit breakers are tested and then rated as to their ability to open the protected circuit with a specific amount of current flowing in the circuit. Circuit breakers typically have AIC ratings of between 5,000 and 200,000 AIC. The amount of fault current available must not exceed the breaker's ability to safely open the circuit. Not only must the breaker be rated for the applied voltage, and continuous amperage load; it must also have an AIC rating equal to or greater than the available current at the location in the circuit where it will be installed. Breakers that have been installed so that the available fault current exceeds its AIC rating may blow up, just like a bomb would explode, were it to attempt to clear a fault current above its rating. When opening a faulted circuit, it is possible for smoke and fire to be exhausted from a breaker. If you would like to see a breaker belch fire and smoke, see if you can locate and view the Cooper-Bussmann fuse company videotape titled " *Specification Grade Protection*". This tape will enhance your appreciation of the importance of an electrical device's AIC rating.

In your safety classes, you likely have received training in the *step to the side routine* before manually switching electrical circuits and this videotape will reinforce the value of this easy safety step. This is also a good reason why sheet metal covers called dead front trim should be re-installed on loadcenters, panelboards, and the like before operating switching devices.

Electrical engineers tell us that the two major factors that govern the amount of fault current that can be delivered in a system are the KVA rating of the transformer and the impedance of the transformer. The presence of connected electric motors in the circuit also adds to the amount of potential fault current. Considering 480 volt systems, combined transformer and motor fault currents can range from 14,400 amps for a 500-KVA transformer with an impedance of 5.0% to some 90,000 amps for a 3500 KVA transformer with 5.75% impedance. Selecting all circuit breakers for higher AIC ratings may be the safety first and cost last method.

An engineering level study of a facility's electrical system every five years (or before plant remodeling is undertaken) is a good idea. The study should include (among other things, like is every thing properly grounded) a review of the AIC of the plant's breakers and the fault current that the plant's electrical circuits can deliver to the line terminals of all major circuit breakers.

### ***Testing-Listing OF Circuit Breakers***

Molded case low voltage circuit breakers are typically tested to UL standard 489. UL uses the following test goals to determine if a breaker is considered to be safe, (incompliance with their safety standard):

- The breaker must interrupt the maximum short circuit current two times.
- The breaker must protect its self and the connected conductor and the equipment it is installed in.
- After having been tested the breaker must be fully functional and pass a thermal calibration trip test at 250% of its rated ampacity; and pass a dielectric withstand test at two times its rated voltage, (or a minimum of 900 volts).
- The tested breaker must also operate properly and have continuity in all of its poles.

UL-489 listed circuit breakers are tested with a four-foot length of wire. This is so they perform during the test as they would when installed in the real world, thus the wire is connected to make the test a bit more realistic. During the test the conductor's insulation must not be damaged. The connected wires must not be pulled loose from the breaker-conductor termination lug. The breaker case must not be damaged as a result of cable whip forces (caused by the poetically huge amount of magnetic force developed under short circuit conditions). The connected wire acts to some degree as a heat sink for the breaker. That is it helps to dissipate heat produced within the breaker. This is because the breakers' case acts as not only an electrical, but a thermal insulation as well, in that it tends to retard heat transfer. This is one reason why breakers have wire size ranges marked on them. Too small a wire attached to the breaker cannot adequately aid in cooling the breaker.

The temperature at the circuit breaker's terminals must not rise more than 50 degrees C. above the ambient air surrounding the breaker. The UL-489 test standard has been used to test many many circuit breakers over the years and has proven to be a pretty good standard by which the safety of circuit breakers can be determined.

### ***Not All "Breakers" Are Rated The Same***

A circuit breaker listed to UL-489 standard is not the same animal as a breaker looking thing listed to a UL standard as a supplemental circuit protector (SP). A circuit breaker listed to UL standard 489 will open the circuit under fault current conditions and is tested to a higher degree to do so than is a supplemental protector (commonly also tested to UL safety standards).

Supplemental protectors cannot be used as service equipment; that is without some device such as a UL-498 listed breaker or fuse in the circuit up-stream of them, they may or may not open the circuit under short circuit conditions. It may be difficult to determine the difference between a circuit breaker and a supplemental protector by simply looking at an installed device. The good folks with UL have pointed out that we need to pay close attention to what we are working with, as the testing procedures and listing requirements differ among all of these look-a-like black boxes.

I wish that I could pass on some sure fire just looking at it (without using a book or removing the device) method of determining if it was a circuit breaker, or a supplemental circuit protector, but at this moment regrettably I am unable to do so.

The same is somewhat true of magnetic trip (short circuit protection) only motor circuit protectors (MCP). With MCP's it helps that an amperage rating is not imprinted on the end of the operator handle. However that aid is of limited value, as the NEC allows the marking to be hidden by some type of covering trim, when a circuit breaker is rated over 100 amps. (See article 240.83 (A) and (B) for more details). Supplemental protectors are not required to have an AIC marked on them, but neither are circuit breakers that have an AIC of 5,000 amps. If you are a bit confused, so am I; and try as best they can, UL has not been able to communicate to me a hard and fast rule of how I can physically tell the difference in the field without removing the device, or finding part numbers and looking them up in a parts book (that plant maintenance folks do not typically have readily accessible). You can obtain additional information about the listing of Supplemental protectors by obtaining a copy of UL's listing guide number: QVNU2 and circuit breakers number: DIVQ.

## ***The Electrical Arc***

As soon as two energized electrical contacts separate, one contact (called the cathode) transmits electrons and the other (called the anode) receives them, an electrical arc is created. If you were to ask a layman to tell you what electricity looks like, he would likely describe an electrical arc, which it is not. We frequently see a wide range of arcs; the Godzilla of electrical arcs, the lightning strike, and the micron sized static electrical discharge occasionally experienced after walking across a carpeted floor.

The electrical arc is a naturally occurring event; a part of doing business with electricity so to speak. The visible arc (ionized air) is not electricity but an effect of electricity, just as heating of conductors when current flows in a circuit. An Electrical arc produces an intense amount of heat that can reach temperatures of 4,000 C and higher. If not extinguished quickly, an arc can pit (a transfer of metal from one surface to another), or even destroy the electrical contacts and insulating material such as the breaker's casing.

Circuit breakers are designed to minimize, if not eliminate damage caused by electrical arcs in the following ways:

- Submerge the contacts in oil
- Place the contacts in a vacuum tight enclosure
- Immerse the contacts with an inert gas such as SF-6
- Divert the arc away from the main contacts to secondary contacts or arc horns
- Divert the arc away from the contacts with a magnetic field (blowout coils)
- Deflect the arc off of the contacts by use of a differential pressure
- Extinguish the arc in arc chutes
- Making and separating contacts at high speed

Low and medium voltage circuit breaker manufactures have used combinations of the above methods. Methods such as oil, vacuum, and gases are less common on modern low and medium voltage breakers.

While it is correct to say that when the A-C sine wave reaches the zero voltage points, the arc will go out due to the lack of voltage. This is not the entire picture, for arcs are much more complicated. Quickly stated the arc has a voltage of its own, and if the air between the contacts is not cooled sufficiently, or the air gap is not wide enough, the arc may re-establish its self when the supply circuit voltage again increases.

A common method used in the above 200 amp or so size breaker is the use of arc extinguishing chutes. This method diverts and separates individual sections of the arc away from the contacts into thermally and electrically conductive chutes where the arc is stretched and cooled sufficiently to extinguish it. The use of contact surface coating material such as silver is used to harden contact surfaces and reduce pitting damage. Spring powered switching contacts are designed to increase contact movement speed, to reduce the life of an arc.

Copper only contacts are not used because heating causes a type of corrosion that increases the contact's impedance, which in turn increases the amount of heat generated.

An arc can travel across some types of insulated surfaces that have been heated so hot as to produce a carbon tract that provides a lower resistance path for future current flow. This means that external breaker insulation materials should be inspected from time to time for indications of overheating, dust, and for the possible formation of a fine carbon like material trail that can result in a short circuit.

### ***The Effects of Current Flow***

When current flows in a circuit two effects are produced, magnetic and thermal. Thermal energy is comparatively a much slower phenomenon to build up than a magnetic force. For example, under short circuit current conditions, the magnetic forces build up very quickly. Just as a magnetic can be used to move a metal object, so can magnetic forces torque or stress circuit components.

Under severe short circuit current conditions bus bars have been instantly ripped from their mountings, large cables have been whipped so violently as to have been pulled loose from their terminations. At the same time the slower thermal energy was melting sand in fuses into glass, while steel and copper metals were being heated so hot as to be turned into a superheated gas (the solid metal became a liquid and then a vapor).

We tend occasionally to focus our attention on the electrical insulation aspects, while potentially forgetting magnetic and thermal effects under short circuit current conditions. The practice of securing big cables in place, so that they stay in place under short circuit current conditions with thin plastic like twine should be reconsidered. So should the practice of tightening buss bar fasteners without the use of a torque wrench.

### ***Thermal Energy***

Excessive current flowing in a circuit can result in heat related damage to electrical equipment. That is because a rise in current results in an increase in thermal energy. Mathematically speaking, a current increase results in a squared value increase in the amount of heat, that is,  $I^2 T$  means that the higher the current the much greater the amount of heat that will be developed. Many years ago it was established that, an increase of only twenty degrees C. above the maximum rated temperature of an electrical insulator (motor windings) can reduce its life by as much as 50%. Electrical insulation can withstand only a limited amount of repeated overheating (much the same as structural stress cycles are cumulative) before it fails.

### ***Thermal Trip Element***

When the circuit is required to be provided with a protective device for overload type conditions, a thermal time delay element is typically provided. The thermal element provides a time delay function called Inverse. That is to say, as the current flow in the circuit increases, heat begins to build up in a BI-metal element, (that is made from two thin strips of different metal) and it begins to bow and cause the contacts of the breaker to open. These two metals are selected for their different rates of thermal expansion (heating) and contraction (cooling). Having been fused together by the manufacture, changes in their temperature results in them expanding and contracting in an arc, and not in a straight line. This movement allows them to be used as the source of the force needed to open the breaker's contacts.

Thermal elements require some of the heat to be dissipated before they can be reset after having tripped. This means that when a breaker trips on thermal element (due to a running overload) it may need a few minutes to cool off before it can be reset.

### ***Magnetic Trip Element***

The trip unit is the brain of the breaker. It consists of the components necessary to automatically open the circuit when an overcurrent is sensed. Generally a magnetic sensing element, or both a magnetic and a thermal sensing element will be included in the trip unit.

When a breaker has only a magnetic sensing element, it is a non-delay instantaneous trip type. With this type of circuit breaker, no delay has been intentionally designed into its operation. These devices have a magnetic coil that surrounds a moveable plunger, which is held in place by a spring. The circuit current flows through the magnetic coil and when it produces a pull on the plunger greater than the retaining spring, it will move the plunger, which results in the device's contacts opening.

When an OCPD has only a magnetic sensing element it will provide protection only from short circuit level currents and not from overload level currents. These types of devices are called motor circuit protectors (MCP). They are used when running overload protection is provided by a device such as a three phase motor starter with thermal overload relay-heater elements. When a circuit breaker has tripped on the magnetic element, they can be immediately reset. One should not reset a breaker more than twice without correcting the cause of the fault. To do so may result in serious personal injury.

### ***Hydraulic-Magnetic Trip Elements***

Some brands of circuit breakers use a hydraulic fluid (silicone) type of current sensing element. With this type of sensor, a wire is coiled around an oil filled cylinder

containing a piston, which is connected on one end to the breaker's trip unit. This forms a magnetic coil through which load current flows. The piston is held in a position by a spring. When current flows in the coil, a magnetic field is created that pulls the piston deeper and deeper into the coil. As the current in the circuit increases, so does the coil's magnetic field strength, the spring is compressed, drawing the piston deeper into the coil, increasing the coil's magnetic field, as plunger movement progresses, the fluid tends to oppose rapid movement of the piston in the cylinder.

By varying the fluid's viscosity the manufacture can, alter the amount of opposing-retarding force; this in turn allows the amount of time delay to be varied. By changing the size of the coil wire and number of wraps of the wire in the coil; the amount of force (MMF) created by the magnetic field can be changed (changing either or both the quantity of amps, or the number of turns of the wire changes the amount of pull produced by a electro-magnetic coil).

Manufactures using this type of element design can offer the protection of a quick responding magnetic element and the time delay of a thermal element in their breakers with out using a bi-metal element.

In this portion of the article; the following topics are covered:

- Methods Of Mounting Circuit Breakers
- Fixed Mounted Circuit Breakers
- Removable Mounted Circuit Breakers
- Drawout Mounted Circuit Breakers
- Methods Of Securing Circuit Breakers
- Stab Lock Type Circuit Breakers
- Bolted Type Circuit Breakers
- Din Rail Mounted Circuit Breakers

## ***Methods Of Mounting Circuit Breakers***

For our study purposes we will divide the methods used to mount circuit breakers into three general groups, those being: Fixed, Removable, and Drawout. A review of these mounting methods follows.

### ***Fixed Mounted Circuit Breakers***

A circuit breaker that is bolted in its enclosure and wired to the load frame, we can call a fixed mounted circuit breaker. These units are typically rated 600 volts or less and are front mountable. Power is provided to the breaker typically by wires or sectional type bus bars. Power feeding the circuit breaker must be turned off in order to physically remove the fixed mounted breaker.

## ***Removable Mounted Circuit Breakers***

A removable circuit breaker has two parts, a base, which is bolted to and wired to the frame, and the actual breaker, which has insulated parts that electrically mate with the base. This means of mounting allows the unit to be replaced without re-wiring the unit on the line side of the breaker. This type of mounting is typically used for breakers rated 600 volts or less.

## ***Drawout Mounted Circuit Breakers***

A drawout circuit breaker also has two parts, the base, which is bolted and wired to the frame and the actual breaker, which slides into and electrically mates with the base. This allows the unit to be replaced without having to turn off the power feeding the breaker. The load must be turned off in order to test, remove or replace the unit.

As a safety feature these units are interlocked to automatically turn the power off just before removal of the breaker begins. By design, only the circuit breaker's load must be turned off to remove the breaker. This method of mounting allows for a single breaker to be disconnected from the power supply. That is to say that it does not require that all of the power be disconnected from all of the breakers installed in the larger enclosure such as a motor control center.

There are various designs used to facilitate the *"racking-in"(installation)* and *"racking out"(withdrawal)* of the drawout type circuit breaker. Commonly some form of jacking screw is used to initially move and thus electrically disengage the breaker, then a traveling trolley type of hoist (somewhat like a small boat winch) supports the breaker during removal and re-installation. A transient supporting device is necessary as these sizes of breakers are too heavy and too bulky to be safely moved into and out of position by one person.

## ***Methods Of Securing Circuit Breakers***

Circuit breakers are typically secured in place by one of the following methods:

- Through bolts
- Stab locked to the bus or some type of receptacle connection
- Bolted to the bus
- Din rail mounted

## ***Stab Lock Type Breakers***

This type of breaker employs a male-female type of plug & receptacle connection to a metal bus bar on one end. The opposite end of the breaker is mated to the enclosure housing and does not make electrical contact with the bus bar. These types of breakers are found in homes and light commercial applications installed in loadcenters. With this method of mounting some movement of the breaker is normal. This small amount of breaker case movement is typically 1/8 of an inch or less on the bus bar end. The circuit conductor termination lug may also exhibit some minor movement of the termination lug; again normally this movement is less than about 1/8 of an inch.

## ***Bolted Type Breakers***

When a longer service life breaker is wanted, a bolted type is typically used. These types have a metal tab (one for each phase) sticking out from one end that is bolted to the bus bar with a machine screw (bolt type fine threads and not sheet metal screw type steep pitch threads). When replacing these types of breakers, the retaining bolts or machine screws will have power on them unless power to the entire panelboard has been removed.

It is not un-common for some individuals to initially determine that it is necessary to replace these types of breakers with power still applied to the bus bars. I am not a big fan of working any thing above 12 volts hot, for I have witnessed too many good folks get hurt doing what was initially anticipated as being a quick and simple task. When this type of breaker must be replaced with power still applied to the bus bars, it should be done only under strict safety procedures; using proper personnel protective equipment and double insulated tools (every day plastic handle screwdrivers must not be used). A detailed job safety analysis should be conducted before any hot work is undertaken. On more than one occasion I have witnessed some truly professionals conducting rehearsals of this type of activity several times until each safety step was done correctly. Take the time you need to be safe.

## ***Din Rail Mounted Breakers***

With this method, a mounting rail is secured to the enclosure and the breaker is snapped onto the mounting rail. This allows for replacement to be made quickly as the device can be un-clipped and a new one clipped on to the DIN rail. Conductors for the supply and load are typically secured to the breaker using pressure connectors that are tightened by some type of threaded fastener. While not as easy to replace as

say a stab-lock type breaker, it does allow for some saving of time, both during panel building and individual breaker replacement later on.

The letters DIN stand for German Industry Standards. Din rails are available in more than one physical size. The DIN rail mounting method is increasingly replacing thru-bolt, foot, and plate mounting methods once more commonly used.

In this portion of the article, the following topics are covered:

- Time Current Curves
- Available Fault Current
- Series Rated Devices
- Selective Coordination
- Line and Load Terminal Connections
- Ambient Compensated Circuit Breakers

### ***Time Current Curves***

The proper design of an electrical system involves many-detailed task, such as selection of the circuit breakers that will protect the conductors, equipment and people who operate the equipment. Proper selection, and coordination of breakers for a specific installed system is facilitated by the use of time current curves. Reading these curves is quite technical and will not be covered in adequate detail to allow someone to properly select OCPD's; my intention is to provide only a brief overview in this short paper.

Time current curves are plots of the amount of current (vertical scale) flowing in the circuit to the time (horizontal scale) required for the breaker to clear the fault current. Curves are listed by some manufactures as being instantaneous, ultra-short, short, medium and long.

Current limiting fuses have no moving parts, so no inertial forces need to be overcome for the fuse to open the circuit. Breakers on the other hand have parts that must be moved from one position to the other to open the circuit. Generally speaking fuses can open a circuit faster than can circuit breakers. Some solid-state components can be damaged beyond repair in less time than a breaker may be able to open the circuit. For this and other reasons, some types of electrical components are best protected by fuses and not breakers. Restated, you cannot always replace a fuse with a circuit breaker of the same voltage, and amperage values.

The time a circuit protective device operates can be divided into the following time segments: *sensing time*; magnetic elements are quicker than thermal elements (which intentionally add delay). *opening time*, fuses are quicker than breakers as

they have no parts to move, and *arcing time*, the time during which an arc is present. Both fuses and breakers have to extinguish the resultant arc, and *arc extinguishing time*, the time the protective device takes to extinguish the faults arc, varies with the type of device, amperage rating, AIC rating, voltage, and the amount of short circuit or overload current developed.

## ***Available Fault Current***

When selecting circuit breakers it is important to know both the maximum continuous amperage and the available fault current. The NEC in article 110.9 provides the following guidance, ***“ Equipment intended to interrupt current at fault levels, shall have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment. ”*** There are two methods commonly used to comply with this NE code requirement.

The most conservative method is to select all OCPD's based upon the fault current available at the electrical service (or source of supply). For example if 50,000 amps of fault current could be supplied to a building at the service, even the most distant (from the service) branch circuit breaker would be selected to have the ability to safely open the circuit with 50,000 amps of fault current, even though that amount of current would not be available to the line terminals of the most distant circuit protective device. Depending upon the specific nature (such as arcing, or a bolted low impedance type fault) of the fault, the total amount of fault current available may or may not be developed during operation of the nearest upstream protective device.

## ***Series Rated Devices***

The second method of breaker selection, which is more realistic and more economical, is to select the device based upon the level of fault current that engineering level calculations determine can be potentially available at the device's line terminals.

One may question why spend the extra money purchasing breakers that have a higher AIC than the system can deliver? When it is reasonable to anticipate that the power supply's capacity will be increased, the initially more costly selection may be justified based upon anticipated system capacity growth.

## ***Selective Coordination***

Selective coordination is the selection and application of circuit protective devices in series such that under overload or fault current conditions, only the device just upstream from the overload, or fault will open to clear the fault. The remainder of the

circuit's protective devices will remain closed passing power to their individual loads. Selectivity can be based upon time or current levels. This method of selection allows two devices to be connected in series with each other, and seeing the same current level to respond in differing times, the one closest to the fault, with the shortest operating time would open the circuit. The device up stream from it while having the same current level trip point, would have a longer trip delay time, allowing the closer device to react first to open the protected circuit.

If not properly coordinated, the device closest to the fault could have the longer time of response (both having the same current level trip values), and the next protective device up stream could open the circuit, resulting in a potentially more wide spread circuit outage to be experienced by the facility. When the breaker nearest the circuit's faulted point does not trip, yet the one above it does, a review of the degree of coordination should be undertaken.

### ***Line and Load Terminal Connections***

The terminals (when installed in a vertical position) at the top of a breaker are for connection to the source of supply and are referred to as the line connections (NEMA markings L-1, L-2, L-3, or IEC markings 11, 21, 31). The terminals at the bottom of the breaker are for connection to the load (NEMA markings T-1, T-2, T-3, or IEC markings 12, 22, 32). Most breakers must be installed with the source of supply connecting to the top terminals.

Some breakers are listed such that they may be connected to the source of supply either at the top (line) or the bottom (load). These breakers can then be used in a back-fed type of application; that is power can be connected to the bottom (load) of the breaker and the breaker can be used to supply power via its line (top) connections to a bus bar. When a breaker is marked line or load, it must be installed in that manner only. That is line to the source of power and load terminations connected to the utilization equipment. The NEC requires that back-fed type breakers be so installed that it takes more than a pull on the breaker to remove it. See article 408.16 (F) of the 2002 edition.

### ***Ambient Compensated Circuit Breakers***

There are some common installations where the electrical load to be protected will be located in an area that is subject to a different range of environmental conditions, particularly ambient temperature. An extreme example of this type would be where a fan motor is located in say a minus 40 degree ice cream freezer and its protective circuit breaker is located in a poorly ventilated motor control center room where the air temperature routinely exceeds 100 degrees F. during hot summer months. This

could result in the breaker's thermal element trip point being reduced due to its hotter ambient.

Were a motor to be placed in a hot environment (say a boiler room) and its circuit breaker be placed in an air conditioned space, the breaker may experience nuisance type tripping. To avoid temperature related offsets breakers are available with an ambient compensation feature. This allows the breaker to open the circuit, without deviation caused by changes in the ambient air temperature within a listed ambient temperature range.

In this portion of the article, the following topics are covered:

- Insulated Case Circuit Breakers
- Accessories
- Shunt Trip
- Auxiliary-Remote Alarm Switch
- Ground Fault Sensor
- Under Voltage Trip
- Lock-Out-Tag-Out Provisions
- Remote Operator Handle
- Stored Energy Breaker Operator

### ***Insulated Case Circuit BREAKERS (ICCB)***

This type of circuit breaker is assembled on a metal frame contained within an insulated case and is provided with air break contacts. Its intended use is as a component of larger installations such as switchboards and MCC type switchgear. Its components are larger and heavier for severe duty applications.

The insulated case circuit breaker typically has a high short time withstand and high interrupting ratings. They are available today with both a local and a remote means of communication for setting of the various values, and facilitate such task as remote monitoring of electrical energy consumption and troubleshooting. The insulated case circuit breaker can be purchased today with any of a growing list of accessories, several of which are briefly reviewed in the following paragraphs.

### ***Accessories***

The following is a brief survey of the accessories that are commonly available for the ICCB and for microcomputer-equipped circuit breakers today. Only those specific accessories listed for a specific breaker should be attached to a breaker. To do otherwise may potentially compromise safety.

## ***Shunt Trip***

Some times it is advantageous to turn a breaker off from a remote location. To facilitate this task, an accessory called a shunt trip feature is installed by the manufacture inside of the breaker. This device consists of an electro-magnetic trip coil that is connected in series with an external field wired switch. When the switches contacts are closed, power is passed to the shunt trip coil causing the breaker's mechanical latch to cause the breaker to move to the open position. Re-closing the breaker is done by physically going to the breaker and manually moving the operating handle to the on-closed position.

When opened by use of the shunt trip coil, the breaker's operating handle moves to the off (maximum handle travel) and not the tripped (short of full handle travel) position. Knowing this can help when you are trying to determine if the breaker tripped off due to a fault or overload, or was remotely turned off.

## ***Auxiliary-Remote Alarm Switch***

Occasionally it is advantageous that an indication be provided that a breaker is open at a remote location. To facilitate remote indication, some manufactures provide a built-in form C (SPDT) contact set. The contact set may receive power from the breaker's power source by internal connection, or it may be a set of dry contacts, that require a foreign power source. By "foreign power source", I intend to communicate that the form C-contact set is not powered from the same source of supply of current going to the breaker's line terminals.

## ***Ground Fault Sensor***

Some manufactures offer an external ground fault sensor accessory. These devices open the circuit within a pre-established time period when the current flow to ground exceeds a pre-determined value. This occurs by detecting a current difference between two or more load leads that have been routed through an air core current transformer. The trip current set point values are higher for these types of devices than are found on common MCCB type GFCI (5 to 6 Ma class A) units. This is because these types of sensors are primarily intended to provide protection for equipment and not people. You should be aware that some circuit breakers are provided with a ground fault trip unit, while others are provided with an alarm only function for use with emergency systems as required by the NEC in sections 700-7(D) and 700-26.

## ***Under Voltage Trip***

The undervoltage trip feature will operate the circuit breaker when the supply voltage drops below a preset value. Typically the adjustable range provided is from 35 to 70% of nominal line voltage. This device incorporates a feature that prevents the breaker from being re-set until the supply voltage returns to a minimum of 85% of its normal level.

## ***Lock-Out-Tag-Out Provisions***

With this factory-installed accessory the task of performing OSHA required Lock-out-Tag-out of the breaker is made easier and safer. With the device properly installed, and locked, the breaker operator handle cannot be moved to the closed position from the open position.

## ***Remote Operator Handle***

Occasionally a breaker will be installed in a type of enclosure that does not allow ready access to the breaker's operator handle with the door closed. Many manufactures offer a flexible cable (or rod) that is connected directly to the breaker's operator handle at one end and an externally mounted manual switch at the other end. The remote operator handle is typically installed on a flange type section of the enclosure and performs the opening and closing of the breaker without the need to open the enclosure's door. This feature helps to reduce the risk associated with arc related flash burns. The risk of flash burns has increased as our nation's electrical generating, transmission, and distribution capacity has increased over the years. The 2002 edition of the NEC has introduced specific requirements intended to reduce the risk of injury to personnel from electrical arc flash burns.

## ***Stored Energy Breaker Operator***

The two step stored energy mechanism is used when a lot of energy is required to operate the circuit breaker and when it needs to be closed or opened rapidly to minimize arcing related damage. The two-step stored energy process is to charge (compress) the closing spring and then release the energy to close the breaker. This method uses separate opening and closing springs. This design permits the closing spring to be charged independently of the opening process. This allows for an open-close-open duty cycle. The closing spring can be charged manually via a charging handle or an internally mounted DC electric motor about the size of a 3/8 inch drill motor. The motor can be operated remotely, allowing for increased Operator safety.

Once the closing spring is charged, it sits compressed ready to rapidly re-close the breaker. Safety is enhanced with this type of operating mechanism by providing remote (motor operated) charging of the spring and then allowing the breaker to be remotely closed. Should it become necessary provisions are provided for spring charging may also be accomplished manually.

In this portion of the article, the following topics are covered:

- Molded Case Circuit Breakers
- Molded Case Circuit Breaker Maintenance

### ***Molded Case Circuit Breaker (MCCB)***

The most common type of re-settable overcurrent protective device is the molded case circuit breaker. The case functions as both an outer wrapper and to retain in proper position the breaker's internal components. These cases are made from various types of electrical insulating and fire retardant plastic. Cases are typically not hermetically sealed; this allows them to be subject to corrosion from environmental factors. They are limited to 600 volts and less. They are typically available in either single, two, or three pole models. This type of circuit breaker is now available as, AFCI, GFCI, and magnetic, hydraulic-magnetic and thermal-magnetic types.

The book titled "Overcurrents and Undercurrents" by Mr. E.W. Roberts, P.E. ISBN: 0967432316 covers GFCI type devices. The book is well written, and is the only text (that I am aware of) that covers AFCI's as well.

### ***Molded Case Circuit Breaker Maintenance (MCCB)***

MCCB have many years of life built into them, allowing for very little maintenance type attention be paid to them. This should not be taken as an indication that periodic maintenance is not required. NETA (InterNational Electrical Testing Association Inc.) has developed and published a book titled "Maintenance Testing Specifications (NETA-MTS-01) that provides some guidance as to how various types of electrical equipment, including MCCB, and ICCBs should be tested. Again you may have anticipated my next statement. I recommend that you obtain a copy for your reference. I know that books cost money, but not knowing how, or what to do cost a lot more money, so try and talk the boss into purchasing it for you. In the interim, the following is a quick overview of some MCCB maintenance task. It is recommended that at least once a year a qualified electrician, properly trained and equipped perform the following maintenance task:

- Visually inspect the case to determine if any portion indicates overheating, replace the breaker if overheating indications are found.

- Check connections for indications of overheating.
- Cycle the breaker five times manually.
- Check and record the voltage drop across the breaker using a calibrated digital voltmeter (capable of reading three places to the right of the decimal point).
- The load should be operated at full load for three hours, or until the breaker reaches normal load temperature, scan the breaker with an IR type non-contact thermometer, record the readings.
- Record voltages, and note any voltage imbalance from phase to phase.
- Current readings should be taken with a true RMS type meter due to the increasing harmonic content in many electrical systems in commercial/industrial facilities today.
- Current readings on equipment grounding conductors (where required) for specific machines should be noted. Clamp on type ground-rod circuit resistance reading meters should be used for this task as they can detect both the impedance and the level of current on the conductor (if any is present, as other clamp on type amp-meters will not indicate Ma levels).

While breaker test sets are commercially available, they are for use on the larger frame size breakers. Generally molded case breakers 250 amps and under cannot be tested to confirm operation on their original time-current curves. Testing of the larger frame power type breakers is a very specialized area, requiring special training and test equipment and should be conducted only by competent personnel.

In this portion of the article, the following topics are covered:

- Microcomputer Circuit Breakers
- Field Selectable Rating Circuit Breakers
- Operation Overview
- Current Sensing
- Continuous Amps
- Long Time Delay
- Short Time Pick-up
- Short Time Delay
- Instantaneous Current Pick-up Trip
- Ground Fault Current
- Ground Fault Pick-up
- Ground Fault Delay
- Visual Annunciation-indication Lamps
- Power Consumption Monitoring
- Internal Test Functions

## ***Microcomputer Circuit Breakers***

For breakers in sizes above about 500 amps, the need to tailor the breaker's response increases to the point that a microcomputer based circuit breaker becomes economical. Load profiles in many commercial/industrial facilities tend to change over time and the ability to tailor a breaker's specific performance aids in improving the level and types of protection provided for both people and electrical equipment. The following overview will present a brief introduction to some of the more common features available in microcomputer-based breakers that are available today.

The adjustment of any circuit breaker should not to be undertaken too lightly. Almost any one can turn a knob, or enter a new value into a computer program. It takes a fair amount of training to be able to setup one of these computerized circuit breakers properly. Unless you have received the specific training needed to correctly adjust one of these units, I suggest that you do not attempt to do so. Just where maintenance task ends and electrical engineering begins should be determined before any adjustments are undertaken. Recall that circuit breakers provide not only protection for equipment, but people as well.

## ***Field Selectable Rating Circuit Breakers***

Some manufactures offer a line of breakers in the 500 to 5,000 amp range that have a replaceable rating plug. These rating plugs allow for example a 400 amp frame size breaker to be selected from 200, 225, 250, 300, 350 or 400 amps by the selection of matching rating plugs. This selectable feature would allow a facility that was anticipating a major increase in load in a few years to initially select a 400 amp frame size breaker with a 225 amp rating plug to be installed. When the load increased in the future, the breaker could have its amperage rating increased by the quick replacement of the rating plug. Various selectable values for these types of breakers are based upon either percentages or multiples of the basic continuous current rating of the installed rating plug.

## ***Operation Overview***

Current data is obtained for each phase from current transformers (CT) mounted within the breaker. The CT signals are converted to digital values and sent to a microcomputer. The microprocessor monitors each phase individually at a very high sampling rate. This is a key improvement in identifying current and voltage waveforms. The microcomputer will then determine when the circuit breaker should trip due to an over current condition. An electro-magnetic latch unit in the breaker causes the breaker to trip upon receipt of a trip signal from the microcomputer. This

allows the shape of the breaker's time current curve to be manipulated electronically, and to be tailored to fit the desired performance profile in most every detail.

The ability to field program the microprocessor to accomplish the desired response to various values of time and current and voltage offers a level of circuit protection never before possible. With the addition of an external communications link (LAN or Ethernet type gateway) individual breakers can be communicated with, monitored, re-programmed, controlled, and coordinated from any compatible connected location, be it locally or from a distant central control room.

Many of these breakers have the ability to record past events such as, the cause of the individual trip events, date and time of past trips, voltage and current values or waveforms on all three phases and the neutral.

### ***Current Sensing***

The use of microcomputers has allowed for many improvements to be made in circuit protective devices. One area is in the sensing of current. Some breakers sense an average of the current, while others sense only the peak currents generated in a sine wave. This is fine, if the circuit's current waveform is that of a true sine wave, which few are.

The increased use of ultra fast power switching devices has resulted in harmonic distortions becoming more and more common. With microcomputer-equipped breakers, the true RMS value can be determined even with harmonic distortions. The microcomputer is able to take many samples of the current's waveform per second. The microcomputer then uses these samples to calculate the true RMS value of the load current. This allows the breaker to perform faster, and with greater accuracy than ever before.

The AFCI feature of molded case low voltage circuit breakers has been made possible by advances in current transformers capable of responding to very high frequency currents; in turn the microcomputer has allowed the data to be analyzed, classified, plotted, stored and when so required to displayed for further analysis.

### ***Continuous Amps***

Continuous ampere is a percentage of the circuit breaker's normal current rating. Continuous amps can be adjusted typically from 20 to 100 % of the breaker's nominal rating (in this example the plug unit selected is 1,000 amps, so 100 % would be 1,000 amps. A setting of 80% would result in decreasing the continuous load amps to some 800 amps.

## ***Long Time Delay***

The long time delay causes the breaker to wait a certain amount of time to allow for temporary inrush currents to subside, such as those caused from motor starting locked rotor currents without the breaker tripping. The long time delay function setting is the length of time the breaker will hold an overload (running overcurrent) before causing the breaker to open.

## ***Short Time Pick-up***

This function's setting will determine the amount of current the breaker will carry for a short time period, allowing down stream circuit protective devices to open the circuit and clear the fault without tripping the up stream breaker. This allows for fine-tuning of the selective clearing function of the breaker.

This function is typically adjustable from one and one half to ten times the trip unit ampere setting. For example a 1,000 ampere frame can be adjusted to trip anywhere from 1,500 to 10,000 amps. This is the amount of current the breaker must see in order for it to respond.

## ***Short Time Delay***

The short time delay is used in conjunction with the short time pickup, and controls the amount of time involved in postponing a short time pickup operation. This is the amount of time that must elapse before causing the breaker to open the circuit. This feature allows better coordination with downstream circuit breakers and fuses.

## ***Instantaneous Current Pickup***

This feature's setting is used to trip the circuit breaker with no intentional delay at any current typically between two and forty times the breaker's continuous ampere setting. In this example the instantaneous pickup has been set to ten times the continuous amp setting or 10,000 amps (10 x 1,000) with a continuous amp setting of 1,000 amps. In this case a higher setting would trip at 10,000 amps due to a fixed instantaneous override of 10,000 amps, which automatically trips the circuit breaker regardless of the instantaneous pickup setting. If the continuous amp setting had been 300 amps, the instantaneous pickup setting at ten would make the instantaneous setting equal to 3,000 amps, well below the fixed instantaneous override. This function is much the same as the magnetic trip unit's instantaneous pick-up only programmable for the specific needs of the unique installation.

## ***Ground Fault Current***

Typically an LED type of display provides a reading of the number of amps flowing across the equipment ground conductor. The ground fault monitor can be utilized with a display module or a relay that has a set of contacts for a ground fault alarm. When used with a shunt trip equipped breaker; a ground fault monitor can be used for ground fault sensing operation of the breaker equipped with a shunt trip feature.

## ***Ground Fault Pickup***

This adjustment controls the amount of ground fault current that will cause the breaker to open. These adjustments typically range from 20 to 70% of the maximum breaker rating in compliance with article 230.95 (A) of the NEC, that no pickup setting exceeds 1200 amps. Ground fault pickup is sometimes divided into sections that allow various time delay values to be added to the breaker's trip point when a ground fault occurs. This feature is useful for improving circuit breaker coordination with both up and down stream protective devices.

## ***Ground Fault Delay***

This is the time period that must pass before the breaker trips. This feature's setting is typically one of two types, an inverse time or a constant amount of time delay. The inverse time method shortens the amount of delay as the amount of ground fault current increases. Please recall that the longer a fault exist, and the higher the current flowing in the fault, the more potential danger and damage there will be. The constant amount of time delay method maintains the time delay period the same no matter what the amplitude of the fault current may be.

## ***Visual Annunciation-Indication Lamps***

Depending upon the brand and model various lights give the user a means for visually determining what type of fault caused the breaker to open. Typically indicator lamps are provided for indication of Long time fault, Short time fault, Instantaneous fault, and Ground fault events.

## ***Power Consumption Monitoring***

Some models come equipped with features to assist in monitoring electrical energy consumption. Data displays are the common seven segment LEDs. Adjustable alarm set points may also be provided on some models. Various communication protocols are used by individual manufactures. With increasing concerns about power quality,

this feature is being expanded to include factors relating to power quality and not just power quantity.

### ***Internal Test Functions***

This feature enables the user to test the microcomputer's trip circuit's electronics, the electro-magnetic latch and power contact set opening mechanism. The purpose of this test function is to provide the user with an easy means to conduct a quick- go no-go type of test before bringing the circuit breaker on-line to protect and pass power to the connected loads.

Some manufactures provide for some degree of automatic testing each time the system is powered up. With others individual test are carried out manually following predetermined steps. The testing of many of these complex breakers cannot be done until all of the field selectable and variable values have been entered, or default values (where provided) have been selected. Many of these internal test functions are covered under the label of a "watchdog timer" that monitors the processor's health for indications of non-performance (within specified times). The concept of intelligent electrical devices has long been out of the research lab and has been broadly integrated into the "plant floor".

If we could give Mr. Edison one of these modern replacements for his lead wire fuse; I wonder what he would do with it? My bet is just what manufactures are doing today, try and make them better.

This concludes this article covering circuit breakers. I hope that you will continue your study of circuit and overcurrent protective devices. If you have any questions or comments, please send me an E-mail.

Remember Work Smarter, Not Harder

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