CIRCUIT BREAKER TESTING TECHNOLOGY

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This article will explore the technology of testing high current circuit breakers. It will touch upon various aspects of circuit protection, protective devices, and need for testing, but will focus upon the practical aspects of generating and measuring the high currents required in the testing of circuit breakers.

CIRCUIT PROTECTION

Circuit protection has been a factor in electrical systems since the beginning of the Electrical Age, and has matured over the years. Any system involving electricity has a source of power, conductors, and a device which uses the power. If any element fails, damage could occur, and protective devices may be used to limit its extent.

Of primary consideration is the maximum available power. Batteries and generators have maximum short circuit currents which are limited by their voltage and internal impedance, and severe overheating, mechanical stresses, and explosion may occur if excessive fault currents flow for more than a brief time.

The conductors carrying power to its destination are rated for a certain amount of continuous current, based on ambient temperature, insulation material, and type of conductor. Excessive currents cause a temperature rise over time that will eventually damage the insulation or even cause the conductor to melt.

In a power distribution system, where several users of power are connected to a main source, it is usually desirable that the failure of one section of the network should not disturb the operation of other sections. If protective devices are chosen properly, or coordinated, this effect may be achieved.

PROTECTIVE DEVICES

A protective device monitors one or more factor affecting safe operation of an electrical system, and produces an appropriate response in case of a fault condition. The factors include current, voltage, wattage, phase angle, frequency, temperature, and pressure. The appropriate response may be a visual, audible, or electrical signal, or a physical action which actually interrupts the current or otherwise eliminates the fault condition. Additionally, this response may be intentionally delayed by some period of time, which is often inversely proportional to the magnitude of the fault.

Fuses such as these provide inexpensive and reliable protection from catastrophic failures and extreme fault currents.

The devices covered by this article will be limited to those that monitor the amplitude of a current, and react by interrupting that current when it exceeds a predetermined value. The time delay from sensing the overcurrent to the actual interruption is assumed to be determined by the amount of overcurrent as well as other factors, such as ambient temperature and recent history of overcurrents.

The simplest device is the fuse or fusible link. This is basically a conductor which is designed to melt in a specified period of time at a given current, thereby breaking the circuit. Fuses are inherently the most reliable and least expensive protective device, because of their simplicity and immunity to environmental contamination. Fuses, however, are inconvenient if the circuit is subject to frequent fault conditions, since they must be physically replaced after each operation. In order to provide greater convenience and versatility, circuit breakers were developed, which could be reset after being tripped by a fault condition, and could be used to disconnect the circuit manually.

The simplest circuit breakers use the principle of electromagnetic trip with no intentional time delay. The current through a coil generates a magnetic field which exerts a force against a preset trip mechanism. When this force is large enough, the trip mechanism begins to operate, and after a period of time, determined by the amount of force, inertia, and other mechanical factors, the contacts open.

Since many electrical devices exhibit a considerable inrush current upon turn-on, or may produce temporary surges of current during normal operation, it is often necessary to provide a time delay. Circuit breakers that meet this requirement may use various combinations of heating coils and mechanical devices such as dashpots, or may employ electronic circuitry. The electronic type may have complex testing requirements, and will not be covered here.

This is a typical large draw-out air circuit breaker, removed from its cubicle.

A special type of time-delay circuit breaker is the motor overload relay. This type of device is used most often for the protection of electrical motors driving compressors, where a temporary locked rotor condition may occur. In this case, a thermal element trips the contacts after a moderate period of overcurrent, waits for a time, then resets itself, again applying power to the motor.

Sometimes there are other situations where fault conditions may be temporary, as in the case of lightning strokes or tree branches falling briefly across a power line. In such cases, the protective device may be in a remote area, and it would be inconvenient to require someone to reset it after such transient incidents. For this reason, devices known as reclosers were developed. When a fault occurs, the recloser trips, waits for a short period of time, and then resets itself. If the fault remains, it will cycle through a series of trips and recloses, during which the cause of the fault may be removed, or it eventually locks in a tripped condition. The testing of reclosers is similar to that for circuit breakers, but will not be covered in this article.

The last type of protective device to be discussed is the protective relay. This device consists of a circuit which monitors one or more factors affecting the electrical system, such as current, voltage, frequency, etc., and closes a circuit which trips one or more remotely located trip devices. The testing of protective relays has some commonality with circuit breaker testing, but will not be covered here.

THE NEED FOR TESTING

Almost all people have experienced the effects of protective devices operating properly. When an overload or a short circuit occurs in the home, the usual result is a blown fuse or a tripped circuit breaker. Fortunately, few have the misfortune to see the results of a defective device, which may include burned wiring, fires, explosions, and electrical shock.

These technicians are removing some large air drawout circuit breakers from their cubicles for testing and servicing. Regular maintenance should be scheduled and electrical testing should be performed to ensure reliability of the electrical protection system.

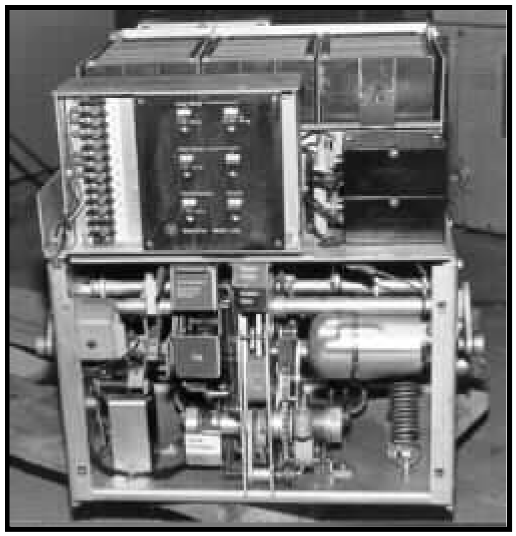
It is often assumed that the fuses and circuit breakers in the home or industry are infallible, and will operate safely when called upon to do so ten, twenty, or more years after their installation. In the case of fuses, this may be a safe assumption, because a defective fuse usually blows too quickly, causing premature opening of the circuit, and forcing replacement of the faulty component. Circuit breakers, however, are mechanical devices, which are subject to deterioration due to wear, corrosion, and environmental contamination, any of which could cause the device to remain closed during a fault condition. At the very least, the specified time delay may have shifted so much that proper protection is no longer afforded to devices on the circuit, or improper coordination causes a main circuit breaker or fuse to open in an inconvenient location.

TESTING METHODS

The manufacturers of circuit breakers must test their designs under actual operating conditions, which requires the application of fault currents at the rated voltage. Under such conditions, a circuit breaker will be subject to extreme mechanical and electrical stresses. At the maximum interrupting rating, it may actually be damaged or destroyed, but if the fault current is safely interrupted, the circuit breaker passes the test.

Naturally, it is impractical and unnecessary to test circuit breakers at full power in the field. It is generally accepted practice to apply fault currents to circuit breakers at low voltage, in order to test their time delay and instantaneous operating characteristics. AC or DC high voltage insulation tests, as well as visual inspection, normally suffice to determine if the breaker will function safely under actual fault conditions.

Some very high current circuit breakers employ current transformers, sense circuitry, and a trip signal to a set of main contacts, to perform the current interruption function. Although testing could be performed using the primary injection method, it may be very difficult and impractical. Therefore, a method called secondary injection is used, in which a current representative of the output of the CT's is applied to the sense circuitry, and the trip signal is monitored.



This view of a large draw-out air circuit breaker shows some of its complex electronic and mechanical components, all of which must work properly to provide reliable protection.

Crude functional tests are sometimes used in the field, but are not recommended. Soldering guns, which produce one or two volts at up to 200 Amperes, are sometimes applied to small breakers to see if they trip. However, the current is extremely variable, and there is no way to check the time/current characteristic. Another method is the application of DC current from an automotive storage battery, but this can produce currents large enough to damage the breaker, and can be very dangerous; moreover, the results are inconclusive.

CURRENT GENERATION REQUIREMENTS

In order to understand the requirements for generating current for the testing of circuit breakers, it is useful to examine the actual operation of a breaker under low voltage test conditions. When voltage is first applied to a device from a low impedance source, such as the output of a transformer, current will begin to flow according to the applied voltage and the overall impedance of the breaker, its connections, and the internal impedance of the test set. The current sensing apparatus will eventually operate a trip mechanism, causing the main contacts of the circuit breaker to open.

Some current will continue to flow as the contacts open, depending on resistance, source impedance, applied voltage, stored inductive energy, etc. For the purposes of low voltage testing, the duration of such additional current flow is normally minimal, but in some cases the change in impedance of the protective device may change sufficiently during operation so as to affect the amount of current flow, even to the point of inhibiting operation. This is not often encountered in simpler devices such as circuit breakers, but is very commonly seen in oil reclosers.

For the purposes of this discussion, the effects of using a low-voltage source for testing will be explored. Most test gear uses an arrangement of step-down transformers to generate a voltage which can be varied to produce currents in the device under test ranging from well under its nominal operating current to at least six times, and up to twenty times, this value. At any given test current, the combined impedance of the test set and the device under test interacts with the selected output voltage to produce that current. If any one of these factors vary, the test current will also vary.

The applied voltage may change due to variations in line voltage, which may be caused by changes in load, fluctuations in generator voltage, and heat generated variations in line resistance. Some of these effects are very slow and minimal in overall effect, while others may cause essentially instantaneous changes in voltage, and the resultant current. Line voltage may also exhibit some distortion (cyclic variations from true sinusoidal waveform), which may cause related distortion in the output current.

The test set impedance will generally remain fairly constant for a given setting of output voltage, but may vary considerably for various combinations of input voltage, input taps, output taps, and vernier settings. Heating effects often necessitate changes in these settings, resulting in impedance changes. Other factors, such as transformer design, wiring size, conductor routing, and connector resistance, will also produce greatly varying test set impedance for the same output current.

The impedance of the device itself will also affect overall current, and has the greatest likelihood of causing large, measurable changes in current during its operation. The operating coil of an interrupting device is largely inductive, and its impedance is directly related to its magnetic field. This field will change when any movement occurs in nearby ferrous objects, particularly its operating mechanism. Depending on its construction, this will cause various amounts of inductance change, which will have some effect on the test current. If this effect is great enough, and device is not fully committed to trip at this point, operation could actually be inhibited.

This is an EIL ORT-560 Recloser Test Set, with a typical recloser. The test set uses resistors to regulate the output current.

Some improvement may be made by increasing the impedance of the test current source enough to swamp out the effects of impedance change in the device under test. This is already being done in the some recloser test sets, because of the very large impedance changes of oil reclosers, which can be as great as 5 to 1. However, without an active source which electronically regulates the current, practical limitations dictate that some variation in test current must be tolerated. This fact indicates that the measurement technology must somehow compensate for unavoidable distortion, and still produce meaningful test results that correspond to the manufacturer's published time/current curves.

PRACTICAL CURRENT GENERATION

The generation of high currents for practical testing of circuit breakers is basically fairly simple. First, it is necessary to know the impedance of the circuit breakers to be tested, as well as the impedance of all connecting cables and buswork, to determine the voltage required to produce the test currents. Typically, this is in the order of one to 24 volts.

The 50,000 amp EIL BTS-500S was the top of the line for many years. It used a single E-I output transformer and tapped input autotransformer. Many are still in use today.

In order to minimize the power requirements, it is best to have a range of output taps on a transformer, to match the circuit breaker impedance as closely as possible. The power rating of the transformer should be chosen to provide just enough power for the expected range of circuit breakers to be tested, at a duty cycle representative of actual test requirements. It should be noted that a typical transformer capable of 1000 amperes continuous can produce 2000 amperes for ten minutes in a half-hour interval (33% duty cycle), and can produce a maximum of 10,000 to 20,000 amperes peak current into a short circuit, for several tenths of a second, enough to trip a circuit breaker instantaneously. Once a suitable output transformer rating is determined, the actual design of the transformer must be addressed.

The simplest design, used in many older test sets, uses a single E-I core, with a primary winding of 240 or 480 VAC. The secondary consists of heavy copper wire or buswork, with one common connection, and two or three taps for several ranges of output current and voltage. The disadvantages of this design are (1) the necessity of providing a continuously variable source from zero to maximum voltage at full current capacity, and (2) the inefficiency of having unused windings when operating at the highest current, lowest voltage tap. The driving source for the transformer is either a large, multi-deck variable autotransformer, or a multi-tap autotransformer with a boost transformer and vernier. The advantage of the multi-tap autotransformer is the capability of choosing among a range of input voltages.

Later designs, for larger test sets, employ an array of several E-I cores, with two identical series output windings, which could be connected in series or parallel for more efficient selection of output voltage/current rating. In some designs, one of the cores is made about half the size of the others, so that a buck/boost configuration with a smaller vernier can be used. Overall weight and size can be reduced substantially, since the primaries of the main elements are either shorted or connected directly to the input supply voltage. A disadvantage of this design is that only one input voltage may be used. Multi-tapped primaries and series/parallel connection of the vernier autotransformer could allow other voltages, but would be cumbersome to change

The EIL BTS-1000 used a multi-stage output transformer with series/parallel connections. It could produce over 100,000 amperes into a short circuit, and was capable of testing the largest circuit breakers in general use.

in the field.

A new variation on this design is now being developed, using an arrangement of toroidal transformer cores and buswork. The well-known advantages of toroids include greater efficiency, smaller size, lighter weight, and less acoustic and electrical noise. The configuration under development also allows selection of three output arrangements, for better matching of impedance to the device under test. A further advantage is modular construction, which permits flexible design and lower cost.

Another factor involved in generating test currents is distortion of the current waveform. Since circuit breakers are largely inductive, an applied voltage starting at a zero crossing will generate a high current transient, known as DC offset. This cannot be controlled with contactors, but newer test set designs use SCRs, which can be gated to turn on at or near the voltage peak, resulting in less DC offset and more repeatable readings.

CURRENT SENSING TECHNOLOGY

Circuit breaker testing requires the measurement of currents from less than one ampere to about 100,000 amperes. There are very few devices which can measure such a wide range of current to the required accuracy, which is in the order of 1%.

The most accurate current measurement device is probably the shunt, which is a precision resistor calibrated using DC, to accuracies of 0.1% or better. AC accuracy at line frequencies is likely to be nearly as good, but inductance may cause inaccuracies at higher frequencies. Shunts are readily available up to 10,000 amperes, and may be overloaded to ten or more times their rating for short periods of time as applicable to breaker testing. One limitation of the shunt is its low output voltage. A 10,000 ampere shunt will produce 100 millivolts at its rated current, but only one millivolt at 100 amperes. This means that a 1% error at 100 amperes represents only 10 microvolts, which may be very small in proportion to the several volts of common mode voltage, and hundreds of volts and thousands of amperes that are generated in the near vicinity of the measurement equipment. Another drawback to the shunt is its large power requirement, or burden. The 10,000 ampere shunt requires 1000 watts at its rated current, which is tolerable, but at 20,000 amperes this grows to 4000 watts, and at 100,000 amperes, 100,000 watts is consumed. Shunts are very useful for calibration purposes, but have limited use in practical AC high current test sets.

The traditional way to measure AC current at line frequencies is the iron core toroidal current transformer, or donut CT. This device has isolation, low burden, low cost, high output, and good accuracy. Its limitations are its limited useful range, and inability to measure DC components of the current waveform. Also, it is subject to saturation at high currents, with resultant waveform distortion, and non-linearity at lower currents due to required magnetization currents. A multi-tapped primary could be used for various current ranges, but this is unwieldy for a practical high current test set.

A popular alternative to iron-core CT's is the air-core CT, which may be configured as a toroid, a two-pronged fork, or other arrangement. A very simple CT of this type is an air-core inductor placed on or near the conductor of the current to be measured. The output of an air-core CT is a voltage, which is proportional to the differential (rate of change) of the current. This is relatively easily converted to read the actual current by performing an integration, which may be done with a resistor and a capacitor. A great advantage to the air-core CT is its wide operating range, demonstrated to be at least 1000 to 1, combined with its other qualities of low cost, low burden, wide frequency response, high isolation, and high output. Its chief limitation is its sensitivity to stray magnetic fields, making its placement around the conductor and within the test set critical.

CURRENT AND TIME MEASUREMENT REQUIREMENTS

Most overcurrent protective devices operate on the true-RMS value of the applied current. Electromagnetic breakers operate on the strength of a magnetic field, and are generally rated to work on DC as well as AC. Highfrequency components are integrated out due to inductance and physical mass of the operating mechanism. Time-delay devices usually use heaters or mechanical dashpots, which operate on the force-generating or heating effect of the current, which is the definition of true-RMS. Thus, if the measuring circuitry can read the true-RMS value of the applied current waveform, inaccuracies caused by distortion would be minimized.

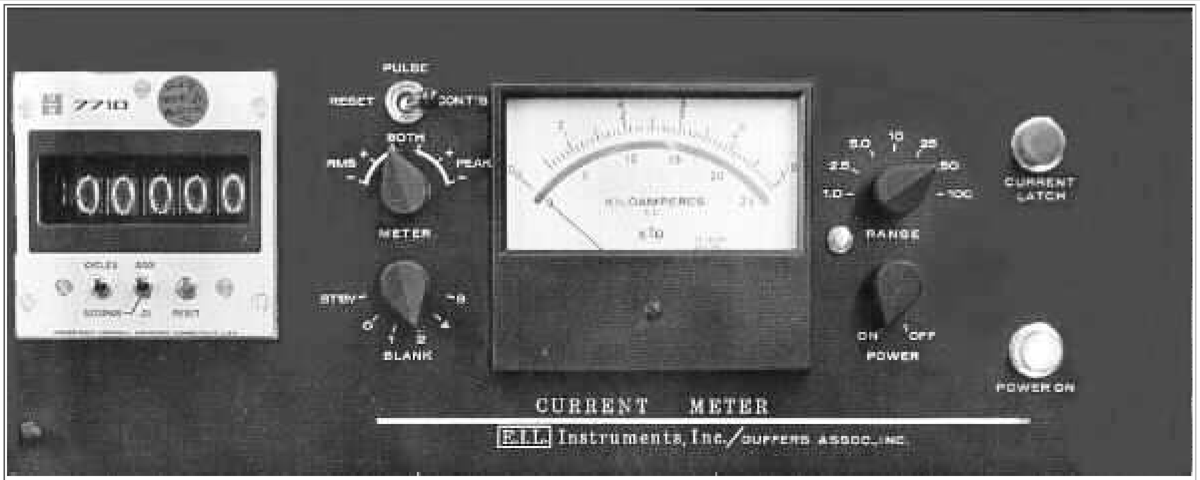
Circuit breakers are designed to conform to published time-current curves to an accuracy of about +/- 20%, which may apply to either current or time. In general, a circuit breaker is specified not to trip at its rated current value, and must trip at a current of perhaps 150% of its rating. This means that a 20 Ampere breaker may carry up to 29 Amperes forever, but must trip within several minutes at 30 Amperes. Time delay variations of 20% or more are usually reasonable, and are generally specified from about 200% to as much as 1200% of rating. At higher currents, breakers are expected to trip instantaneously, or with no intentional delay, which is typically no greater than 0.02 seconds, or about one cycle.

CURRENT MEASUREMENT TECHNOLOGY

The earliest high current measuring systems used iron vane analog meters in conjunction with iron core CT's. Pulse current of short duration was measured by using a pointer preset mechanism, which held the needle to the expected current. When the current pulse occurred, if the needle jumped, the preset amount of current was assumed to have been reached. Current measurement was very approximate, and timing was performed using electromechanical clocks, started at the time of initiation of output, and stopped when the breaker opened.

For reasons stated above, air-core CT's soon replaced the iron core transformers. The output of the CT first goes through a voltage divider, which selects an appropriate range. An integrator derives the true current signal, which is passed to a precision rectifier circuit. Its output is the absolute value of the input, and the RMS value is not changed. The average of this signal is then obtained by another integrator. Assuming a sinusoidal waveform, the RMS value may be calibrated as 1.1 times the average, but moderate distortion may cause errors of up to 10%.

This type of measurement is generally adequate for moderately distorted waveforms of sufficient duration to read a value visually, typically 1 second or longer. However, shorter duration pulses, even one cycle (0.0167 sec) or somewhat less, are encountered with some regularity in breaker testing.



The "Duffers" Memory Ammeter, used in many EIL circuit breaker test sets, incorporated peak reading circuitry, and used blanking to reduce error from DC offset. It was soon replaced by the Accu-Amp, which used a true-RMS converter IC in conjunction with a fast-attack, slow decay circuit.

One method of pulse measurement is a peak reading meter, which reads the peak absolute value of the waveform. For pure sine waves, this is accurate, since the RMS value is simply 0.707 of the peak value. However, distortion can produce errors of up to 30%. Another problem is that, depending on the phase angle of the initial portion of the waveform, a "DC offset" is produced, due to circuit inductance, and could have a peak value as much as twice normal. It is possible to "blank out" a number of measurement cycles, but this is impractical for very short pulses approaching one cycle.

An improved approach is a track-and-hold circuit, which may be adapted to the more accurate average-responding circuit. In this case, the integrated output of a precision rectifier is gated to a storage element, typically a capacitor, while the amplitude is above a preset value. A comparator is used to drive the gate while the actual signal remains above threshold. The problem here is that an integrator with a ripple (or error) of less than 1% also has a rise time much greater than one cycle, so either quick pulses are read as low, or random errors of greater than 1% are experienced.

One solution which has worked to some degree of success is a "fast attack, slow-decay filter", which is a modified peak-hold circuit with an intentional rate of decay. This eliminates some of the effects of DC offset at the beginning of a long pulse, but there are still necessary trade-offs in response time and accuracy, even for sine wave signals. Practical accuracies of 5% or somewhat better are obtainable for roughly sinusoidal signals of at least two or three cycles duration and minimal DC offset.

An improvement in true-RMS measurement technology has been made with the introduction of true-RMS to DC converter IC's, which perform a true-RMS conversion function using log and anti-log amplifiers, with an intermediate averaging function using a capacitor. With the proper components, a settling time of about 20 mSec with 1% accuracy is possible, but this is still insufficient for sub-cycle pulses. Combined with a fast-attack/slow-decay filter, accuracies approaching 2% on reasonably clean pulses of 2 cycles or more can be obtained.

TIMING MEASUREMENT TECHNOLOGY

The measurement of delay trip times of several seconds on three-phase breakers is no problem. Early technology employed electromechanical clocks, which started when the test current was applied to the breaker, and stopped when it tripped, as sensed by an auxiliary connection to an unused contact. The typical error of about a tenth of a second is acceptable for trip times of several seconds. This method cannot be used, however, for single pole breakers without unused or auxiliary contacts.

Such breakers required the use of a "current latch" circuit, which served the dual purpose of providing a signal which could maintain the test current through the breaker until it tripped, and operate the timer. A relatively simple circuit, consisting of a rectifier, filter, and threshold detector, can be used for the latch requirement.

Instantaneous trip time measurements, in the order of several cycles, present another challenge. Because of the turn-on delay of a contactor or SCR, and operating times of electromechanical relays, it is necessary to use current measurement techniques for such fast timing measurements. If the current waveform is observed on an oscilloscope, it is usually fairly easy to determine the start and stop points, even when there are discontinuities and other noise in the waveform. However, designing a circuit to do this is more difficult. If a simple comparator, set at 5% of maximum value, is used on the rectified waveform, a series of pulses of varying duty cycle is formed. This signal can be filtered and sampled by a second comparator, which should produce a step function which represents the time of the pulse. Using such circuitry produces accuracies of 5 to 10 milliseconds on most pulses.

DIGITAL ELECTRONICS AND MICROPROCESSORS

With analog-to-digital conversion and microprocessor-based signal analysis, greater accuracy has been made possible. Essentially, the signal is sampled by an A/D converter at several times the fundamental frequency, and the values stored in memory. Various algorithms, implemented in software, read the current, and determine starting and stopping points. A true-RMS calculation is performed on a selected part of the waveform, and the accuracy increases with the number of samples. Post-processing can also be used to adjust for amplitude effects, and the actual waveform may be saved to a disk, viewed on a screen, or plotted. The accuracy obtainable by using such methods should be in the order of 1% for amplitude, and 0.005 seconds for time.

The EIL PS-250 was one of the first breaker test sets to use a microprocessor, but it retained some of the original analog signal preprocessing. Its major advantages were programmable auto-jog and current hold, and data storage, retrieval, and report printing.

Several new systems were developed in the late 80s and early 90s. The ubiquitous and ever more economical IBM PC was used in several designs. A recloser test system was developed using a proprietary plug-in board for data acquisition and control. It was incorporated in a rack-mounted computer that was an integral part of the test set. The problem of determining the true-RMS value of the severely distorted waveforms was solved by performing a mathematical analysis of the stored A/D samples. The software also interfaced to a database program for data storage, test result verification, and report generation.

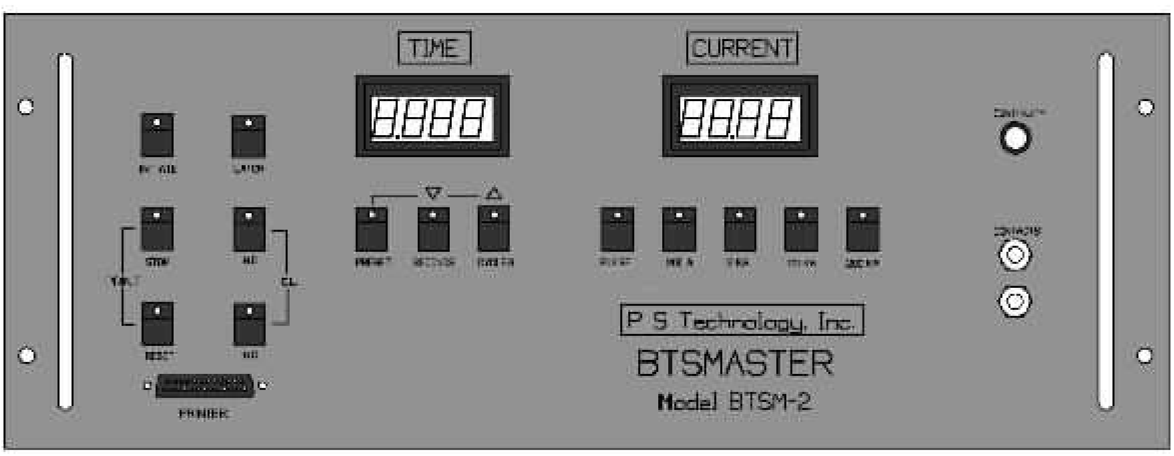
An early attempt to use the PC for circuit breaker testing used a passive backplane system with an off-the-shelf data processing board in conjunction with a proprietary interface to a keyboard and LCD display. This eliminated the awkward CRT display and standard PC keyboard, but added considerable cost, and eliminated certain useful functions, such as waveform display and custom reports. As the cost of portable PCs dropped, it soon became much more cost-efficient to use that platform, and the proprietary interface was never put into production.

One of the first practical systems using a laptop computer was developed in the early 90s, and was used in some new circuit breaker test sets as well as a retrofit system for older units. A database program was also developed for this design. However, it was difficult to install the A/D board and proprietary interface in the portable computer, and the interface was delicate and susceptible to electrical noise and mechanical damage. Nevertheless, it is still in use in some breaker test sets currently in production.

As the convenience and versatility of notebook style PCs became increasingly attractive and inexpensive, P S Technology pioneered the design of a parallel port interface that could be used for data acquisition and control. Its first application was for recloser testing, in the form of the ORTMASTER accessory, which was designed as a retrofit for existing test sets. It used an MSDOS program to display currents and trip times, and interfaced to a database program for immediate verification of results to manufacturer's curves.

The same basic hardware, with some modification and a different software program, was incorporated in a retrofit system for circuit breaker testing. It is marketed by P S Technology as the STABMASTER.

Although the PC-based system has many advantages, it was found to be too complex and fragile for many circuit breaker testing applications. In response to these concerns, P S Technology developed the BTSMASTER, which is a self-contained measurement and control package. It uses a Z-180 based microprocessor core, and is housed in a rugged rack-mountable enclosure that is mechanically and electrically compatible with the EIL Accu-Amp. This feature makes it ideal for retrofit applications. The pushbutton controls and dual LED readouts are designed for simplicity of operation and reliability, while the internal circuitry and firmware are optimized for accuracy.



The BTSMASTER, P S Technology's latest breaker testing instrument, incorporates an A/D converter and microprocessor for true-RMS reading of current, accurate reading of trip times, and a convenient programmable on time feature for auto-jog operation.

Future developments in circuit breaker testing will probably focus on simplicity, reliability, accuracy, and affordability. This will most likely be accomplished by a modular approach, with a simple, rugged main output unit, integral initiation and adjustment controls, a self-contained monitor and control unit, and interface capability to separate computer systems for enhanced operation.

PRACTICAL TEST SYSTEMS

Circuit breaker test sets should be designed according to requirements. For most purposes, it is sufficient to test circuit breakers at one or two representative points on the time-current delay curve, to a timing accuracy of +/- 0.1 seconds, and determine instantaneous trip current within about 5%. Very simple and inexpensive test sets may be built with these specifications.

With microprocessor technology being inexpensive and versatile, it is now possible to provide increased accuracy of testing, while also adding certain features to save time and reduce error. Test set automation may include an auto-jog feature to determine instantaneous trip current, as well as automatic adjustment of output current to a preset value for long-time testing. The addition of a computer can add additional benefits of automatic set-up of the test set for various tests on standard breaker types, and interface to a database of test results for subsequent analysis.

CONCLUSIONS

The most important idea that should be derived from this article is the need to perform regular testing on circuit breakers. We rely on their correct operation for protection from the extreme hazards that can be produced by electricity, but only with proper testing can we have true confidence.

If it is agreed that regular testing is necessary, it should also be apparent that reasonable accuracy must be guaranteed. This should be relatively easy to accomplish by means of proper design and construction of specialized test equipment. Older test sets should be carefully tested for accuracy and reliability, and if found to be deficient, they should be replaced or retrofitted with more modern measurement and control systems.

Finally, it is important to analyze the overall picture, on the basis of cost. If circuit breakers are tested regularly, the safety of the installation should be better, possibly resulting in lower insurance rates. If circuit breakers can be tested more quickly with a new, computer-based test system, less time spent in testing will result in monetary savings. Most important, if a comprehensive test program results in the saving of even one life, any effort or expenditure must be considered worthwhile.