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Power System Protection

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1

Transformer Protection

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1.1 Types of Transformer Faults

Any number of conditions have been the reason for an electrical transformer failure. Statistics show that winding failures most frequently cause transformer faults (ANSI/IEEE, 1985). Insulation deterioration, often the result of moisture, overheating, vibration, voltage surges, and mechanical stress created during transformer through faults, is the major reason for winding failure.

Voltage regulating load tap changers, when supplied, rank as the second most likely cause of a transformer fault. Tap changer failures can be caused by a malfunction of the mechanical switching mechanism, high resistance load contacts, insulation tracking, overheating, or contamination of the insulating oil.

Transformer bushings are the third most likely cause of failure. General aging, contamination, cracking, internal moisture, and loss of oil can all cause a bushing to fail. Two other possible reasons are vandalism and animals that externally flash over the bushing.

Transformer core problems have been attributed to core insulation failure, an open ground strap, or shorted laminations.

Other miscellaneous failures have been caused by current transformers, oil leakage due to inadequate tank welds, oil contamination from metal particles, overloads, and overvoltage.

1.2 Types of Transformer Protection

1.2.1 Electrical

Fuse: Power fuses have been used for many years to provide transformer fault protection. Generally it is recommended that transformers sized larger than 10 MVA be protected with more sensitive devices such as the differential relay discussed later in this section. Fuses provide a low maintenance, economical solution for protection. Protection and control devices, circuit breakers, and station batteries are not required.

There are some drawbacks. Fuses provide limited protection for some internal transformer faults. A fuse is also a single phase device. Certain system faults may only operate one fuse. This will result in single phase service to connected three phase customers.

Fuse selection criteria include: adequate interrupting capability, calculating load currents during peak and emergency conditions, performing coordination studies that include source and low side protection equipment, and expected transformer size and winding configuration (ANSI/IEEE, 1985).

Overcurrent Protection: Overcurrent relays generally provide the same level of protection as power fuses. Higher sensitivity and fault clearing times can be achieved in some instances by using an overcurrent relay connected to measure residual current. This application allows pick up settings to be lower than expected maximum load current. It is also possible to apply an instantaneous overcurrent relay set to respond only to faults within the first 75% of the transformer. This solution, for which careful fault current calculations are needed, does not require coordination with low side protective devices.

Overcurrent relays do not have the same maintenance and cost advantages found with power fuses. Protection and control devices, circuit breakers, and station batteries are required. The overcurrent relays are a small part of the total cost and when this alternative is chosen, differential relays are generally added to enhance transformer protection. In this instance, the overcurrent relays will provide backup protection for the differentials.

Differential: The most widely accepted device for transformer protection is called a restrained differential relay. This relay compares current values flowing into and out of the transformer windings. To assure protection under varying conditions, the main protection element has a multislope restrained characteristic. The initial slope ensures sensitivity for internal faults while allowing for up to 15% mismatch when the power transformer is at the limit of its tap range (if supplied with a load tap changer). At currents above rated transformer capacity, extra errors may be gradually introduced as a result of CT saturation.

However, misoperation of the differential element is possible during transformer energization. High inrush currents may occur, depending on the point on wave of switching as well as the magnetic state of the transformer core. Since the inrush current flows only in the energized winding, differential current results. The use of traditional second harmonic restraint to block the relay during inrush conditions may result in a significant slowing of the relay during heavy internal faults due to the possible presence of second harmonics as a result of saturation of the line current transformers. To overcome this, some relays use a waveform recognition technique to detect the inrush condition. The differential current waveform associated with magnetizing inrush is characterized by a period of each cycle where its magnitude is very small, as shown in Fig. 1.1. By measuring the time of this period of low current, an inrush condition can be identified. The detection of inrush current in the differential current is used to inhibit that phase of the low set restrained differential algorithm. Another high-speed method commonly used to detect high-magnitude faults in the unrestrained instantaneous unit is described later in this section.

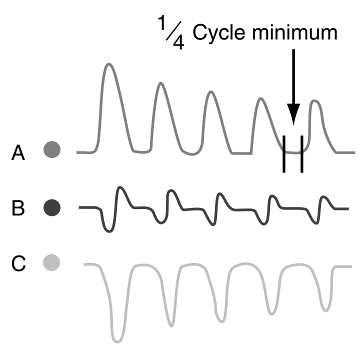

FIGURE 1.1 Transformer inrush current waveforms.

When a load is suddenly disconnected from a power transformer, the voltage at the input terminals of the transformer may rise by 10–20% of the rated value causing an appreciable increase in transformer steady state excitation current. The resulting excitation current flows in one winding only and hence appears as differential current that may rise to a value high enough to operate the differential protection. A waveform of this type is characterized by the presence of fifth harmonic. A Fourier technique is used to measure the level of fifth harmonic in the differential current. The ratio of fifth harmonic to fundamental is used to detect excitation and inhibits the restrained differential protection function. Detection of overflux conditions in any phase blocks that particular phase of the low set differential function.

Transformer faults of a different nature may result in fault currents within a very wide range of magnitudes. Internal faults with very high fault currents require fast fault clearing to reduce the effect of current transformer saturation and the damage to the protected transformer. An unrestrained instantaneous high set differential element ensures rapid clearance of such faults. Such an element essentially measures the peak value of the input current to ensure fast operation for internal faults with saturated CTs. Restrained units generally calculate an rms current value using more waveform samples. The high set differential function is not blocked under magnetizing inrush or over excitation conditions, hence the setting must be set such that it will not operate for the largest inrush currents expected.

At the other end of the fault spectrum are low current winding faults. Such faults are not cleared by the conventional differential function. Restricted ground fault protection gives greater sensitivity for ground faults and hence protects more of the winding. A separate element based on the high impedance circulating current principle is provided for each winding.

Transformers have many possible winding configurations that may create a voltage and current phase shift between the different windings. To compensate for any phase shift between two windings of a transformer, it is necessary to provide phase correction for the differential relay (see section on Special Considerations).

In addition to compensating for the phase shift of the protected transformer, it is also necessary to consider the distribution of primary zero sequence current in the protection scheme. The necessary filtering of zero sequence current has also been traditionally provided by appropriate connection of auxiliary current transformers or by delta connection of primary CT secondary windings. In microprocessor transformer protection relays, zero sequence current filtering is implemented in software when a delta CT connection would otherwise be required. In situations where a transformer winding can produce zero sequence current caused by an external ground fault, it is essential that some form of zero sequence current filtering is employed. This ensures that ground faults out of the zone of protection will not cause the differential relay to operate in error. As an example, an external ground fault on the wye side of a delta/wye connected power transformer will result in zero sequence current flowing in the current transformers associated with the wye winding but, due to the effect of the delta winding, there will be no corresponding zero sequence current in the current transformers associated with the delta winding, i.e., differential current flow will cause the relay to operate. When the virtual zero sequence current filter is applied within the relay, this undesired trip will not occur.

Some of the most typical substation configurations, especially at the transmission level, are breaker-and-a-half or ring-bus. Not that common, but still used are two-breaker schemes. When a power transformer is connected to a substation using one of these breaker configurations, the transformer protection is connected to three or more sets of current transformers. If it is a three winding transformer or an auto transformer with a tertiary connected to a lower voltage sub transmission system, four or more sets of CTs may be available.

It is highly recommended that separate relay input connections be used for each set used to protect the transformer. Failure to follow this practice may result in incorrect differential relay response. Appropriate testing of a protective relay for such configuration is another challenging task for the relay engineer.

Overexcitation: Overexcitation can also be caused by an increase in system voltage or a reduction in frequency. It follows, therefore, that transformers can withstand an increase in voltage with a corresponding increase in frequency but not an increase in voltage with a decrease in frequency. Operation cannot be sustained when the ratio of voltage to frequency exceeds more than a small amount.

Protection against overflux conditions does not require high-speed tripping. In fact, instantaneous tripping is undesirable, as it would cause tripping for transient system disturbances, which are not damaging to the transformer.

An alarm is triggered at a lower level than the trip setting and is used to initiate corrective action. The alarm has a definite time delay, while the trip characteristic generally has a choice of definite time delay or inverse time characteristic.

1.2.2 Mechanical

There are two generally accepted methods used to detect transformer faults using mechanical methods. These detection methods provide sensitive fault detection and compliment protection provided by differential or overcurrent relays.

Accumulated Gases: The first method accumulates gases created as a by product of insulating oil decomposition created from excessive heating within the transformer. The source of heat comes from either the electrical arcing or a hot area in the core steel. This relay is designed for conservator tank transformers and will capture gas as it rises in the oil. The relay, sometimes referred to as a Buchholz relay, is sensitive enough to detect very small faults.

Pressure Relays: The second method relies on the transformer internal pressure rise that results from a fault. One design is applicable to gas-cushioned transformers and is located in the gas space above the oil. The other design is mounted well below minimum liquid level and responds to changes in oil pressure. Both designs employ an equalizing system that compensates for pressure changes due to temperature (ANSI/IEEE, 1985).

1.2.3 Thermal

Hot Spot-Temperature: In any transformer design, there is a location in the winding that the designer believes to be the *hottest* spot within that transformer (ANSI/IEEE, 1995). The significance of the "hot-spot temperature" measured at this location is an assumed relationship between the temperature level and the rate-of-degradation of the cellulose insulation. An instantaneous alarm or trip setting is often used, set at a judicious level above the full load rated hot-spot temperature (110°C for 65°C rise transformers). [Note that "65°C rise" refers to the full load rated *average* winding temperature rise.] Also, a relay or monitoring system can mathematically integrate the rate-of-degradation, i.e., rate-of-loss-of-life of the insulation for overload assessment purposes.

Heating Due to Overexcitation: Transformer core flux density (B), induced voltage (V), and frequency (f) are related by the following formula.

$$B = k_1 \cdot \frac{V}{f} \tag{1.1}$$

where K_1 is a constant for a particular transformer design. As B rises above about 110% of normal, that is, when saturation starts, significant heating occurs due to stray flux eddy-currents in the nonlaminated structural metal parts, including the tank. Since it is the voltage/hertz quotient in Eq. (1.1) that defines the level of B, a relay sensing this quotient is sometimes called a "volts-per-hertz" relay. The expressions "overexcitation" and "overfluxing" refer to this same condition. Since temperature rise is proportional to the integral of power with respect to time (neglecting cooling processes) it follows that an inverse-time characteristic is useful, that is, *volts-per-hertz* versus *time*. Another approach is to use definite-time-delayed alarm or trip at specific per unit flux levels.

Heating Due to Current Harmonic Content (ANSI/IEEE, 1993): One effect of nonsinusoidal currents is to cause current rms magnitude (I_{RMS}) to be incorrect if the method of measurement is not "true-rms."

$$I_{RMS}^2 = \sum_{n=1}^{N} I_n^2 \tag{1.2}$$

where n is the harmonic order, N is the highest harmonic of significant magnitude, and I_n is the harmonic current rms magnitude. If an overload relay determines the I^2R heating effect using the fundamental component of the current only [I_1], then it will underestimate the heating effect. Bear in mind that "true-rms" is only as good as the pass-band of the antialiasing filters and sampling rate, for numerical relays.

A second effect is heating due to high-frequency eddy-current loss in the copper or aluminum of the windings. The winding eddy-current loss due to each harmonic is proportional to the square of the harmonic amplitude and the square of its frequency as well. Mathematically,

$$P_{EC} = P_{EC-RATED} \cdot \sum_{n=1}^{N} I_n^2 n^2 \tag{1.3}$$

where P_{EC} is the winding eddy-current loss and $P_{EC\text{-}RATED}$ is the rated winding eddy-current loss (pure 60 Hz), and I_n is the n^{th} harmonic current in per-unit based on the fundamental. Notice the fundamental difference between the effect of harmonics in Eq. (1.2) and their effect in Eq. (1.3). In the latter, higher harmonics have a proportionately greater effect because of the n^2 factor. IEEE Standard C57.110-1986 (R1992), *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents* gives two empirically-based methods for calculating the derating factor for a transformer under these conditions.

Heating Due to Solar Induced Currents: Solar magnetic disturbances cause geomagnetically induced currents (GIC) in the earth's surface (EPRI, 1993). These DC currents can be of the order of tens of amperes for tens of minutes, and flow into the neutrals of grounded transformers, biasing the core magnetization. The effect is worst in single-phase units and negligible in three-phase core-type units. The core saturation causes second-harmonic content in the current, resulting in increased *security* in second-harmonic-restrained transformer differential relays, but decreased *sensitivity.* Sudden gas pressure relays could provide the necessary alternative internal fault tripping. Another effect is increased stray heating in the transformer, protection for which can be accomplished using gas accumulation relays for transformers with conservator oil systems. Hot-spot tripping is not sufficient because the commonly used hot-spot simulation model does not account for GIC.

Load Tap-changer Overheating: Damaged current carrying contacts within an underload tap-changer enclosure can create excessive heating. Using this heating symptom, a way of detecting excessive wear is to install magnetically mounted temperature sensors on the tap-changer enclosure and on the main tank. Even though the method does not accurately measure the internal temperature at each location, the *difference* is relatively accurate, since the error is the same for each. Thus, excessive wear is indicated if a relay/monitor detects that the temperature difference has changed significantly over time.

1.3 Special Considerations

1.3.1 Current Transformers

Current transformer ratio selection and performance require special attention when applying transformer protection. Unique factors associated with transformers, including its winding ratios, magnetizing inrush current, and the presence of winding taps or load tap changers, are sources of difficulties in engineering a dependable and secure protection scheme for the transformer. Errors resulting from CT saturation and load-tap-changers are particularly critical for differential protection schemes where the currents from more than one set of CTs are compared. To compensate for the saturation/mismatch errors, overcurrent relays must be set to operate above these errors.

CT Current Mismatch: Under normal, non-fault conditions, a transformer differential relay should ideally have identical currents in the secondaries of all current transformers connected to the relay so that no current would flow in its operating coil. It is difficult, however, to match current transformer ratios exactly to the transformer winding ratios. This task becomes impossible with the presence of transformer off-load and on-load taps or load tap changers that change the voltage ratios of the transformer windings depending on system voltage and transformer loading.

The highest secondary current mismatch between all current transformers connected in the differential scheme must be calculated when selecting the relay operating setting. If time delayed overcurrent protection is used, the time delay setting must also be based on the same consideration. The mismatch calculation should be performed for maximum load and through-fault conditions.

CT Saturation: CT saturation could have a negative impact on the ability of the transformer protection to operate for internal faults (dependability) and not to operate for external faults (security).

For internal faults, dependability of the harmonic restraint type relays could be negatively affected if current harmonics generated in the CT secondary circuit due to CT saturation are high enough to restrain the relay. With a saturated CT, 2^{nd} and 3^{rd} harmonics predominate initially, but the even harmonics gradually disappear with the decay of the DC component of the fault current. The relay may then operate eventually when the restraining harmonic component is reduced. These relays usually include an instantaneous overcurrent element that is not restrained by harmonics, but is set very high (typically 20 times transformer rating). This element may operate on severe internal faults.

For external faults, security of the differentially connected transformer protection may be jeopardized if the current transformers' unequal saturation is severe enough to produce error current above the relay setting. Relays equipped with restraint windings in each current transformer circuit would be more secure. The security problem is particularly critical when the current transformers are connected to bus breakers rather than the transformer itself. External faults in this case could be of very high magnitude as they are not limited by the transformer impedance.

1.3.2 Magnetizing Inrush (Initial, Recovery, Sympathetic)

Initial: When a transformer is energized after being de-energized, a transient magnetizing or exciting current that may reach instantaneous peaks of up to 30 times full load current may flow. This can cause operation of overcurrent or differential relays protecting the transformer. The magnetizing current flows in only one winding, thus it will appear to a differentially connected relay as an internal fault.

Techniques used to prevent differential relays from operating on inrush include detection of current harmonics and zero current periods, both being characteristics of the magnetizing inrush current. The former takes advantage of the presence of harmonics, especially the second harmonic, in the magnetizing inrush current to restrain the relay from operation. The latter differentiates between the fault and inrush currents by measuring the zero current periods, which will be much longer for the inrush than for the fault current.

Recovery Inrush: A magnetizing inrush current can also flow if a voltage dip is followed by recovery to normal voltage. Typically, this occurs upon removal of an external fault. The magnetizing inrush is usually less severe in this case than in initial energization as the transformer was not totally de-energized prior to voltage recovery.

Sympathetic Inrush: A magnetizing inrush current can flow in an energized transformer when a nearby transformer is energized. The offset inrush current of the bank being energized will find a parallel path in the energized bank. Again, the magnitude is usually less than the case of initial inrush.

Both the recovery and sympathetic inrush phenomena suggest that restraining the transformer protection on magnetizing inrush current is required at all times, not only when switching the transformer in service after a period of de-energization.

1.3.3 Primary-Secondary Phase-Shift

For transformers with standard delta-wye connections, the currents on the delta and wye sides will have a 30° phase shift relative to each other. Current transformers used for traditional differential relays must be connected in wye-delta (opposite of the transformer winding connections) to compensate for the transformer phase shift.

Phase correction is often internally provided in microprocessor transformer protection relays via software virtual interposing CTs for each transformer winding and, as with the ratio correction, will depend upon the selected configuration for the restrained inputs. This allows the primary current transformers to all be connected in wye.

1.3.4 Turn-to-Turn Faults

Fault currents resulting from a turn-to-turn fault have low magnitudes and are hard to detect. Typically, the fault will have to evolve and affect a good portion of the winding or arc over to other parts of the transformer before being detected by overcurrent or differential protection relays.

For early detection, reliance is usually made on devices that can measure the resulting accumulation of gas or changes in pressure inside the transformer tank.

1.3.5 Through Faults

Through faults could have an impact on both the transformer and its protection scheme. Depending on their severity, frequency, and duration, through fault currents can cause mechanical transformer damage, even though the fault is somewhat limited by the transformer impedance.

For transformer differential protection, current transformer mismatch and saturation could produce operating currents on through faults. This must be taken into consideration when selecting the scheme, current transformer ratio, relay sensitivity, and operating time. Differential protection schemes equipped with restraining windings offer better security for these through faults.

1.3.6 Backup Protection

Backup protection, typically overcurrent or impedance relays applied to one or both sides of the transformer, perform two functions. One function is to backup the primary protection, most likely a differential relay, and operate in event of its failure to trip.

The second function is protection for thermal or mechanical damage to the transformer. Protection that can detect these external faults and operate in time to prevent transformer damage should be considered. The protection must be set to operate before the through-fault withstand capability of the transformer is reached. If, because of its large size or importance, only differential protection is applied to a transformer, clearing of external faults before transformer damage can occur by other protective devices must be ensured.

1.4 Special Applications

1.4.1 Shunt Reactors

Shunt reactor protection will vary depending on the type of reactor, size, and system application. Protective relay application will be similar to that used for transformers.

Differential relays are perhaps the most common protection method (Blackburn, 1987). Relays with separate phase inputs will provide protection for three single phase reactors connected together or for a single three phase unit. Current transformers must be available on the phase and neutral end of each winding in the three phase unit.

Phase and ground overcurrent relays can be used to back up the differential relays. In some instances, where the reactor is small and cost is a factor, it may be appropriate to use overcurrent relays as the only protection. The ground overcurrent relay would not be applied on systems where zero sequence current is negligible.

As with transformers, turn-to-turn faults are most difficult to detect since there is little change in current at the reactor terminals. If the reactor is oil filled, a sudden pressure relay will provide good protection. If the reactor is an ungrounded dry type, an overvoltage relay (device 59) applied between the reactor neutral and a set of broken delta connected voltage transformers can be used (ABB, 1994).

Negative sequence and impedance relays have also been used for reactor protection but their application should be carefully researched (ABB, 1994).

1.4.2 Zig-Zag Transformers

The most common protection for zig-zag (or grounding) transformers is three overcurrent relays that are connected to current transformers located on the primary phase bushings. These current transformers must be connected in delta to filter out unwanted zero sequence currents (ANSI/IEEE, 1985).

It is also possible to apply a conventional differential relay for fault protection. Current transformers in the primary phase bushings are paralleled and connected to one input. A neutral CT is used for the other input (Blackburn, 1987).

An overcurrent relay located in the neutral will provide backup ground protection for either of these schemes. It must be coordinated with other ground relays on the system.

Sudden pressure relays provide good protection for turn-to-turn faults.

1.4.3 Phase Angle Regulators and Voltage Regulators

Protection of phase angle and voltage regulators varies with the construction of the unit. Protection should be worked out with the manufacturer at the time of order to insure that current transformers are installed inside the unit in the appropriate locations to support planned protection schemes. Differential, overcurrent, and sudden pressure relays can be used in conjunction to provide adequate protection for faults (Blackburn, 1987; ABB, 1994).

1.4.4 Unit Systems

A unit system consists of a generator and associated step-up transformer. The generator winding is connected in wye with the neutral connected to ground through a high impedance grounding system. The step-up transformer low side winding on the generator side is connected delta to isolate the generator from system contributions to faults involving ground. The transformer high side winding is connected in wye and solidly grounded. Generally there is no breaker installed between the generator and transformer.

It is common practice to protect the transformer and generator with an overall transformer differential that includes both pieces of equipment. It may be appropriate to install an additional differential to protect only the transformer. In this case, the overall differential acts as secondary or backup protection for the transformer differential. There will most likely be another differential relay applied specifically to protect the generator.

A volts-per-hertz relay, whose pickup is a function of the ratio of voltage to frequency, is often recommended for overexcitation protection. The unit transformer may be subjected to overexcitation during generator startup and shutdown when it is operating at reduced frequencies or when there is major loss of load that may cause both overvoltage and overspeed (ANSI/IEEE, 1985).

As with other applications, sudden pressure relays provide sensitive protection for turn-to-turn faults that are typically not initially detected by differential relays.

Backup protection for phase faults can be provided by applying either impedance or voltage controlled overcurrent relays to the generator side of the unit transformer. The impedance relays must be connected to respond to faults located in the transformer (Blackburn, 1987).

1.4.5 Single Phase Transformers

Single phase transformers are sometimes used to make up three phase banks. Standard protection methods described earlier in this section are appropriate for single phase transformer banks as well. If one or both sides of the bank is connected in delta and current transformers located on the transformer bushings are to be used for protection, the standard differential connection cannot be used. To provide proper ground fault protection, current transformers from each of the bushings must be utilized (Blackburn, 1987).

1.4.6 Sustained Voltage Unbalance

During sustained unbalanced voltage conditions, wye-connected core type transformers without a delta-connected tertiary winding may produce damaging heat. In this situation, the transformer case may produce damaging heat from sustained circulating current. It is possible to detect this situation by using either a thermal relay designed to monitor tank temperature or applying an overcurrent relay connected to sense "effective" tertiary current (ANSI/IEEE, 1985).

1.5 Restoration

Power transformers have varying degrees of importance to an electrical system depending on their size, cost, and application, which could range from generator step-up to a position in the transmission/distribution system, or perhaps as an auxiliary unit.

When protective relays trip and isolate a transformer from the electric system, there is often an immediate urgency to restore it to service. There should be a procedure in place to gather system data at the time of trip as well as historical information on the individual transformer, so an informed decision can be made concerning the transformer's status. No one should re-energize a transformer when there is evidence of electrical failure.

It is always possible that a transformer could be incorrectly tripped by a defective protective relay or protection scheme, system backup relays, or by an abnormal system condition that had not been considered. Often system operators may try to restore a transformer without gathering sufficient evidence to determine the exact cause of the trip. An operation should always be considered as legitimate until proven otherwise.

The more vital a transformer is to the system, the more sophisticated the protection and monitoring equipment should be. This will facilitate the accumulation of evidence concerning the outage.

History—Daily operation records of individual transformer maintenance, service problems, and relayed outages should be kept to establish a comprehensive history. Information on relayed operations should include information on system conditions prior to the trip out. When no explanation for a trip is found, it is important to note all areas that were investigated. When there is no damage determined, there should still be a conclusion as to whether the operation was correct or incorrect. Periodic gas analysis provides a record of the normal combustible gas value.

Oscillographs, Event Recorder, Gas Monitors—System monitoring equipment that initiates and produces records at the time of the transformer trip usually provide information necessary to determine if there was an electrical short-circuit involving the transformer or if it was a "through-fault" condition.

Date of Manufacture—Transformers manufactured before 1980 were likely not designed or constructed to meet the severe through-fault conditions outlined in ANSI/IEEE C57.109, *IEEE Guide for Transformer Through-Fault Current Duration* (1985). Maximum through-fault values should be calculated and compared to short-circuit values determined for the trip out. Manufacturers should be contacted to obtain documentation for individual transformers in conformance with ANSI/IEEE C57.109.

Magnetizing Inrush—Differential relays with harmonic restraint units are typically used to prevent trip operations upon transformer energizing. However, there are nonharmonic restraint differential relays in service that use time delay and/or percentage restraint to prevent trip on magnetizing inrush. Transformers so protected may have a history of falsely tripping on energizing inrush which may lead system operators to attempt restoration without analysis, inspection, or testing. There is always the possibility that an electrical fault can occur upon energizing which is masked by historical data.

Relay harmonic restraint circuits are either factory set at a threshold percentage of harmonic inrush or the manufacturer provides predetermined settings that should prevent an unwanted operation upon transformer energization. Some transformers have been manufactured in recent years using a grain-oriented steel and a design that results in very low percentages of the restraint harmonics in the inrush current. These values are, in some cases, less than the minimum manufacture recommended threshold settings.

Relay Operations—Transformer protective devices not only trip but prevent reclosing of all sources energizing the transformer. This is generally accomplished using an auxiliary "lockout" relay. The lockout relay requires manual resetting before the transformer can be energized. This circuit encourages manual inspection and testing of the transformer before reenergization decisions are made.

Incorrect trip operations can occur due to relay failure, incorrect settings, or coordination failure. New installations that are in the process of testing and wire-checking are most vulnerable. Backup relays, by design, can cause tripping for upstream or downstream system faults that do not otherwise clear properly.

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Warrington, A.R. van C., *Protective Relays, Their Theory and Practice*, Vol. 1, Wiley, New York, 1963, Vol. 2, Chapman and Hall Ltd., London, 1969.

3 12 Power System Protection Part â€“ 1 Dr.Prof.Mohammed Tawfeeq Elements of a Protection System 1 4 2 ï® Circuit breakers isolate the fault by interrupting the current. 3 ï® Tripping power, as well as power 1 4 required by the relays, is usually provided by the station battery because is safer 2.1 than the ac faulted system. 2 A D 5 2.2 2.4 ïP... Electrical Protection Systems. Electrical power system operates at various voltage levels from 415 V to 400 kV or even more. Electrical apparatus used may be enclosed (e.g. motors) or placed in open (e.g. transmission lines). All such equipment undergo abnormalities in their life time due to various reasons. Power System Protection Practices // ABB. For example, a worn out bearing may cause overloading of a motor. A tree falling or touching an overhead line may cause a fault. Power System Protection Disclaimer. This document does not claim any originality and cannot be used as a substitute for prescribed textbooks. The information presented here is merely a collection by the committee faculty members for their respective teaching assignments as an additional tool for the teaching-learning process.Â The committee faculty members make no representations or warranties with respect to the accuracy or completeness of the contents of this document and specifically disclaim any... Power system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the disconnection of faulted parts from the rest of the electrical network. The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation. Thus, protection schemes must apply a very pragmatic and pessimistic approach to... Objective of Power System Protection. The objective of power system protection is to isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severe damage due to fault current.Â The protective relays must operate at the required speed. There must be a correct coordination provided in various power system protection relays in such a way that for fault at one portion of the system should not disturb other healthy portion.