

An American National Standard

IEEE Guide for Protective Relay Applications to Power Transformers

Sponsor
**Power System Relaying Committee
of the
IEEE Power Engineering Society**

Approved March 22, 1984
Reaffirmed December 6, 1990

IEEE Standards Board

Approved March 8, 1985
Reaffirmed May 20, 1991

American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.91-1985, IEEE Guide for Protective Relay Applications to Power Transformers.)

This revision of ANSI/IEEE C37.91 incorporates a number of changes since the original guide was issued in 1967. Some of the more significant changes were made in the sections dealing with differential and overcurrent protection. Other changes were made to bring this guide up-to-date and more in line with present-day requirements.

This guide was revised by the Transformer Protection Guide Revision Working Group of the Transformer and Bus Protection Subcommittee of the Power System Relaying Committee of the IEEE Power Engineering Society. The working group membership at the time of completion of this revision was as follows:

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Corrected Edition

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IEEE Guide for Protective Relay Applications to Power Transformers

1. Introduction

1.1 Purpose

The purpose of this guide is to aid in the effective application of relays and other devices for the protection of power transformers. Emphasis is placed on practical applications, the general philosophy and economic considerations involved in transformer protection are reviewed, the types of faults experienced are described, and technical problems with such protection, including current transformer behavior during fault conditions are discussed. Various types of electrical, mechanical, and thermal protective devices are also described and associated problems such as fault clearing and re-energizing considerations are discussed.

1.2 References

When the following American National Standards referred to in this standard are superseded by a revision approved by the American National Standards Institute, the revision shall apply:

- [1] ANSI/IEEE C37.2-1979, IEEE Standard Electrical Power System Device Function Numbers.¹
- [2] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.
- [3] ANSI/IEEE C57.91-1981, IEEE Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 55 °C or 65 °C Average Winding Rise.
- [4] ANSI/IEEE C57.92-1981, IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Up to and Including 100 MVA with 55 °C or 65 °C Winding Rise.
- [5] ANSI/IEEE C57.109-1985, IEEE Guide for Transformer through Fault-Current Duration.
- [6] IEEE Std 32-1972(R 1978), IEEE Standard Requirements Terminology and Test Procedure for Neutral Grounding Devices.
- [7] *Applied Protective Relaying Reference Book*, East Pittsburgh, PA: Westinghouse Electric Corporation, Relay Instrument Division, 1979.

¹ANSI documents are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

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2. Philosophy and Economic Considerations

Protective relaying is applied to components of a power system for several reasons:

- 1) To separate the faulted equipment from the remainder of the system so that the system can continue to function
- 2) To limit damage to the faulted equipment
- 3) Minimize the possibility of fire
- 4) Minimize hazards to personnel

In protecting some components, particularly high-voltage transmission lines, the limiting of damage becomes a by-product of the system protection function of the relay. However, since the cost of repairing faulty transformers may be great and since high speed, highly-sensitive protective devices can reduce damage and therefore repair cost, the equipment protective aspects of relays shall be considered when protecting transformers, particularly in the larger sizes.

Faults internal to the transformer quite often involve a magnitude of fault current which is low relative to the transformer rating. This indicates a need for high sensitivity, and high speed to obtain good protection.

Transformers with modern surge protection are generally reliable. However, if a possibility of failure exists, protection shall be provided. There is not one standard way to protect all transformers, or even identical transformers that are

applied differently. Most installations require individual engineering analysis to determine the best and most cost-effective scheme. Usually more than one scheme is technically feasible, and the alternatives offer varying degrees of sensitivity, speed, and selectivity. The plan selected shall balance the best combination of these factors against the overall economics of the situation while holding to a minimum:

- 1) Cost of repairing damage
- 2) Cost of lost production
- 3) Adverse effects on the balance of the system
- 4) The spread of damage to adjacent equipment
- 5) The period of unavailability of the damaged equipment

In protecting transformers, backup protection needs to be considered. The failure of a relay or breaker during a transformer fault may cause such extensive damage to the transformer that its repair would not be practical. When the fault spreads due to nonclearing by the transformer protection, remote line relays or other protective relaying may operate. Part of the evaluation of the type of protection applied to a transformer should include how the system integrity may be affected by such a failure. In this determination, since rare but costly failures are involved, a diversity of opinion on the degree of protection required by transformers might be expected among those familiar with power system relay engineering. The major economic consideration is not ordinarily the fault detection equipment but the isolation devices. Circuit breakers often cannot be justified on the basis of transformer protection alone. At least as much weight should be given to the service, requirements, the operating philosophy, and system design philosophy as to the protection of the transformer. Evaluations of the risks involved and the cost effectiveness of the protection are necessary to avoid going to extremes. Such considerations involve the art rather than the science of protective relaying. See [7],² [12], [16], and [19].

Table 1—Causes of Transformer Failures

1. Winding Failures a. Turn-to-turn insulation failure b. Surges due to lightning, switching, etc. c. Moisture d. External faults (producing insulation failure) e. Overheating f. Open winding g. Deterioration h. Improper blocking of turns i. Grounds j. Phase-to-phase failures k. Mechanical Failures	4. Terminal Board Failures a. Loose connections b. Leads (opened) c. Links d. Moisture e. Insufficient insulation f. Tracking g. Short Circuit
2. Tap Changer Failures a. Mechanical b. Electrical c. Contacts d. Leads e. Tracking f. Overheating g. Short Circuits h. Oil Leak i. External fault	5. Core Failures a. Core Insulation Failures b. Ground strap burned away c. Shorted laminations d. Loose clamps, bolts, wedges
3. Bushing Failures a. Aging, Contamination, and cracking b. Flashover due to animals c. Flashover due to surges d. Moisture e. Low oil	6. Miscellaneous Failures a. Bushing current transformer failure b. Metal particles in oil c. Damage in shipment d. External faults e. Bushing flange grounding f. Poor tank weld g. Auxiliary system failures h. Overvoltage i. Overloads j. Unidentified problems

²The numbers in brackets correspond to the references listed in 1.2 of this standard.

Table 2—Failure Statistics for Two Time Periods

	1955–1965		1975–1982	
	Number	% of Total	Number	% of Total
1. Winding failures	134	51	615	51
2. Tap changer failures	49	19	231	19
3. Bushing failures	41	15	114	9
4. Terminal board failures	19	7	71	6
5. Core failures	7	3	24	2
6. Miscellaneous failures	12	5	72	13
	262	100	1217	100

3. Types of Transformer Failures

Transformer failures can be grouped into six major categories. The major categories are detailed in Table 1. Summaries of failures in those categories reported by groups of utilities are given in Table 2.

Transformer failure statistics are available through various organizations that periodically survey owners and users of transformers.

4. Relay Current

Two characteristics of power transformers combine to complicate detection of internal faults with current operated relays:

- 1) The change in magnitude of current at the transformer terminals may be very small, when a limited number of turns are shorted within the transformer
- 2) When a transformer is energized, magnetizing inrush current that flows in one set of terminals may equal many times the transformer rating. These and other considerations require careful thought to obtain relay characteristics best suited to the particular application.

4.1 Minimum Internal Faults

The most difficult transformer winding fault for which to provide protection is the fault that initially involves one turn. With a two-winding transformer, a turn-to-turn fault will result in a terminal current of less than rated full-load current. Possibly, 10% of the winding may have to be shorted to cause full-load terminal current to flow. If the transformer is an autotransformer or a regulating transformer, there are fewer total number of turns in the coils than a two-winding transformer of the same rating. Consequently, a greater percentage of the exciting winding will have to be shorted to provide full-load current at the transformer terminals. Thus, a turn-to-turn fault may result in a terminal current of 10% or less of a transformer rating.

4.2 Maximum Internal Faults

There is no limit to the maximum internal fault current that can flow, other than the system capability when the fault is an internal terminal fault, or a fault external to the transformer but in the relay zone. The relay system should be capable of withstanding the secondary current of the current transformer on a short time basis. This may be a factor if the transformer is small relative to the system fault and if the current transformer ratio is chosen to match the transformer.

4.3 Through Faults

A favorable aspect for the protection of transformers is that fault current through a transformer is limited by the transformer impedance. While current through a transformer thus limited by its impedance can still cause incorrect relay operations or even transformer failure, current transformer saturation is less likely to occur than with unlimited currents.

The above favorable aspect may disappear if the transformer protective zone includes a bus area with two or more breakers on the same side of the transformer through which external fault current can flow with no relationship to the transformer rating. An example is a transformer connected to a section of a ring bus with the transformer protection including the ring bus section.

4.4 Performance of Current Transformers

4.4.1 Internal Faults

During an internal fault, or a fault external to the transformer but in the protected zone, the current transformers may saturate, perhaps severely. Severe current transformer saturation can result in failure of a transformer differential relay to operate or in a delay of its operation. The effect depends on the relay's response to distorted current. On a transient basis, with a saturated current transformer, 2nd and 3rd harmonics predominate initially, and each may be greater than the fundamental. Ultimately, the even harmonics disappear, depending upon the direct current time constant of the short-circuit current. Whether or not the odd harmonics disappear depends on the current transformers steady state saturation characteristic. Harmonic restrained relays usually contain an independent instantaneous overcurrent unit set to operate during saturation of the current transformer when differential relay operation is restrained.

4.4.2 External Faults

If a single set of current transformers is used at each voltage, the current transformer current will be limited by the transformer impedance. If current can flow through the differential zone at the same voltage (for example, ring bus, or breaker-and-a-half applications), then the current is not limited by the transformer impedance. In either case, any deficiency of current output caused by saturation [11] of one current transformer that is not matched by a similar deficiency of another current transformer will cause a difference current to appear in the operating circuit of a differential relay. Time overcurrent relays, without restraint, can overcome this problem only by having their tap and time dial settings made sufficiently high, to override this false differential current. Percentage differential relays offer the advantage of faster speed and security with reasonable sensitivity. Ideally they should be applied with a restraint element in each current transformer circuit. Also, the burden of each current transformer secondary circuit as related to the relaying accuracy class rating of the current transformers involved should not exceed the values established by the relay manufacturer.

4.4.3 Current Transformer Connections

Current transformer performance is a function of the secondary burden. The method of connecting the current transformers and the burden can affect the effective burden (for example, the lead burden of the delta-connected current transformers is three times that of wye-connected current transformers). Also, current transformers paralleled at the current transformer terminals to obtain zero sequence current have no lead burden for three phase or phase-to-phase faults. The physical and electrical locations of auxiliary current transformers can similarly affect the effective burden.

4.5 Nonfault Relay Current

There are nonfault related currents or factors which may result in incorrect or undesirable relay operation. The following sections include a discussion of some of those situations.

4.5.1 Unbalance Caused by Current Transformer Ratios

Even if a transformer has a fixed ratio, it is frequently difficult to match current transformer ratios exactly on the two (or more) sides of a transformer. Current transformer mismatch causes current flow in the operating circuit of the differential relay. If the transformer has a load tap changer, the possible mismatch is increased further. During a through-fault condition, the differential operating current due to mismatch can approach the current rating of the transformer.

4.5.2 Magnetizing Current Inrush

This is a phenomenon which causes the violation of the basic principle of differential relaying since the magnetizing branch of the transformer can have a very low impedance without a transformer fault. Current occasioned by magnetizing inrush can reach many times the transformer rating and these currents appear in the differential relay. See [14] for an explanation of this mechanism.

Although usually considered only in conjunction with the energizing of a transformer, magnetizing current inrush can be caused by any abrupt change of magnetizing voltage. Such transients include the occurrence of a fault, the removal of a fault, the change of character of a fault (for example, the change from a single phase-to-ground fault to a two phase-to-ground fault) and out-of-phase synchronizing. Thus, a desensitizing scheme that is operative only when energizing a transformer may not be adequate.

There are several conditions that cause particularly severe magnetizing inrush phenomena [14]. One involves the energizing of a transformer at a station at which at least one other transformer is already energized. The inrush phenomenon [9] involves the already energized transformers and the one being energized and the inrush transient is of particularly long duration. It is important to realize that the inrush into the transformer being energized occurs during the opposite half cycle to that of the already energized transformer. Thus the net inrush into all transformers may approximate a sine wave of fundamental frequency, and therefore not operate the harmonic restraint unit of a differential relay if it is protecting both parallel transformers. Another inrush phenomenon involves the energizing of a transformer by means of an air switch. Arcing of the switch can result in successive half cycles of arc of the same polarity. Thus if the first half cycle results in substantial residual magnetism in a transformer core, succeeding half cycles can cause a cumulative increase in residual magnetism, each time resulting in a more severe inrush.

An important characteristic of magnetizing inrush current is that it contains substantial harmonics, particularly the second harmonic.

4.5.3 Magnetizing Current During Overvoltage

Sudden loss of load can subject the generator step-up transformer to substantial overvoltage. This can also occur during shutdown of the generator if voltage is maintained while speed decreases (an overexcitation condition). If saturation occurs, substantial exciting current will flow which may overheat the core. The waveform will be distorted and the harmonic content will be dependent on the generator connections and the transformer design and connections. Relay current harmonic content will also be altered by delta current transformer connections. (Because of the abrupt voltage change, there may also be a magnetizing current inrush, but this is of secondary importance.)

4.5.4 Phase Shifting Transformers

A phase-shifting transformer, as its name implies, has a purposely introduced angular voltage difference, usually adjustable in steps, between the primary and secondary voltages. If the angular difference is a fixed 30° , such as with the familiar Y- Δ transformer, current transformer connections for proper differential relaying are easy to obtain. However, if the phase-angle shift is some other angle (15°), orthodox connections of current transformers, either Y or Δ , to a differential relay will not provide proper current balance and an operating (differential) current will flow.

If the 15° phase shift were fixed, it is possible to develop current transformer connections that would provide proper operation for that one phase shift. However, each angle of shift would require different considerations such as a

different ratio of auxiliary current transformers. Thus, it may not be practical to apply the usual percentage differential relay to a given phase-shifting transformer.

5. Electrical Detection of Faults

Fuses are commonly used to provide fault detection for transformers with minimum name-plate ratings up to 5000 kVA, three phase (Category I and II). Transformers larger than 5000 kVA, three phase, minimum nameplate (Category III and IV) are generally protected by a combination of protective devices as shown in Fig 1.

5.1 Fuse Protection

Fuses have the merits of being economical and requiring little maintenance. No dc battery supply is needed. Fuses can reliably protect some power transformers against primary and secondary external faults. They will provide limited protection for internal faults. Generally, more sensitive means for protection from internal faults are provided for transformers of 10 MVA and higher. Fuses have been used at higher transformer ratings depending on the currently available fuse ampere ratings. Primary fuses for power transformers are not applied for overload protection, their main purpose being fault protection (see 5.6.1). It should be recognized that the blowing of one fuse on a three-phase system will not necessarily deenergize the fault. If the fault is not deenergized, the resulting single phase service may be detrimental to the connected polyphase motors and other loads. If required, special protection should be added for single phasing conditions.

The selection of the fuse and proper ampere rating should be based on the following factors:

- 1) Fuse fault interrupting capability and available system fault current
- 2) Maximum anticipated peak load current, daily peak loads, emergency peak loads, maximum permissible transformer load current, and the applicable transformer through fault current duration curve (see Appendix)
- 3) Hot load pickup (inrush current upon instantaneous reclosing of source-side circuit breaker) and cold load pickup (inrush current and undiversified load current after an extended outage)
- 4) Available primary system fault current and transformer impedance
- 5) Coordination with source side protection equipment
- 6) Coordination with low side protection equipment
- 7) Maximum allowable fault time on the low side bus conductors
- 8) Transformer connections and grounding impedance as they affect the primary current for various types of secondary faults
- 9) Maximum degree of sensitivity for protection from high impedance faults
- 10) Transformer magnetizing inrush

Ampere rating selection is facilitated by data published by fuse manufacturers. Such data includes time current characteristic curves, ambient temperature, and preloading adjustment curves, plus daily and emergency peak-loading tables. Coordination examples are included in the Appendix.

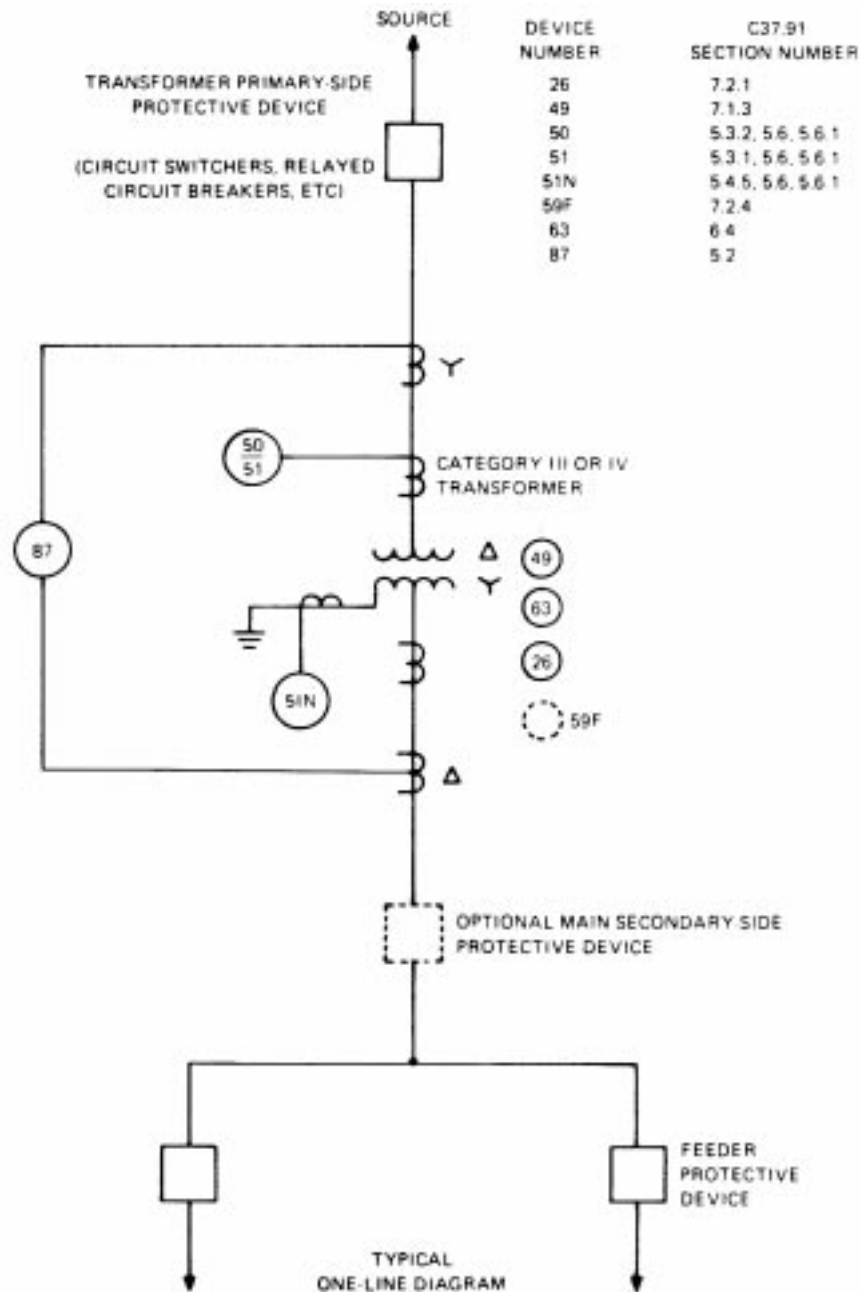


Figure 1—Protection for a Delta-Wye Transformer

5.2 Differential Protection

Current differential relaying is the most commonly used type of protection for transformers of approximately 10 MVA (self-cooled rating) and above [10]. The term refers to the connection of current transformers so that the net operating current to the relay is the difference between input and output currents to the zone of protection.

Relays of three general classes are used with this current differential. They are:

- 1) Time overcurrent relay, which may include an instantaneous trip unit having a high-current setting.

- 2) Percentage differential relay, with restraint actuated by the input and output currents.
- 3) Percentage differential relay, with restraint actuated by one or more harmonics in addition to the restraint actuated by the input and output currents.

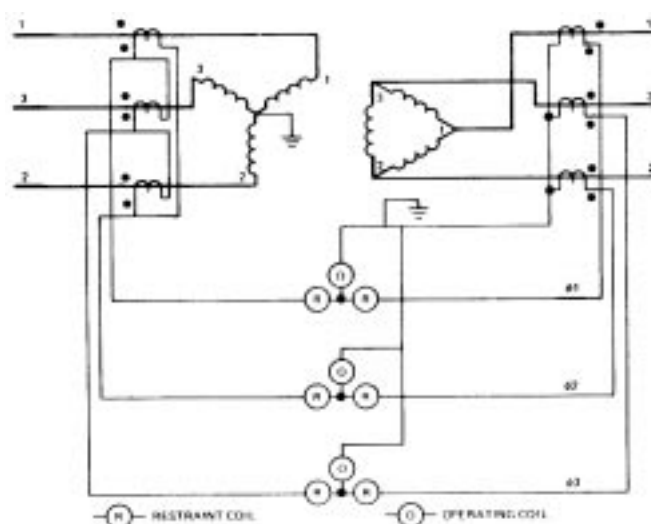
Current transformer connections and ratios must be such that the net current in the relay operating coil for any type or location of external fault is effectively zero, unless relay current matching taps are available. Various types of current transformer connections are shown in Figs 2, 3, and 4. Paralleling of two or more current transformers for connection to a single restraint coil usually should be avoided for the most effective restraint action.

5.2.1 Differential Protection Using Time Overcurrent Relays

Overcurrent relays without restraint are seldom used in present day applications due to their susceptibility to false operation from causes such as: (1) Inrush magnetizing current when energizing the transformer, and (2) saturation errors or mismatch errors of current transformers.

5.2.2 Differential Protection Using Percentage Differential Relays

To avoid undesired tripping due to a mismatch of relay currents or relay taps, restraint is added for through (external) faults. This permits increased speed and security with reasonable sensitivity at low fault currents. There is also some benefit in case of saturation errors. The restraining force disappears or is a much smaller percentage of the operating force, when the fault is internal. These relays are particularly applicable to power transformers of moderate size located at some distance from major sources of generation.



NOTE: See 5.2

Figure 2—Typical Schematic Connections for Percentage Differential Protection of a Wye-Delta Transformer

The amount of restraint is stated as a percent slope relating the operating (differential) current and the restraint current. Each manufacturer uses a slightly different definition for slope. Also, the amount of restraint may be fixed, adjustable, or variable, depending upon the manufacturer. The variable percentage relay increases the restraint as the current increases so that a greater amount of current transformer error can be tolerated at high current levels. A percent slope or restraint characteristic shall be selected to accommodate error currents due to current transformer ratio imbalance and transformer ratio change due to tap changers. Various relays are available with slopes ranging from 15% to 60%. It should be noted that the simple percentage differential relay can misoperate on inrush currents.

While a differential relay is more expensive than an overcurrent relay, the installed cost is usually no more. It is sometimes provided with taps which make auxiliary current transformers to balance currents unnecessary. The overcurrent relay in many instances requires an auxiliary current transformer and additional wiring which increases its installed cost.

5.2.3 Differential Protection Using Percentage Differential Relays With Harmonic Restraint

To avoid undesired tripping due to inrush currents, harmonic restraint is incorporated in certain differential relays. These relays utilize at least the 2nd harmonic current which is present in all transformer energizing surges to restrain or greatly reduce the sensitivity of the relay during this period. These relays use frequency selective circuits to develop the needed restraint. Several designs utilize harmonics in addition to the 2nd harmonic to develop the restraint, while others utilize only the 2nd harmonic.

The purpose of all of these designs is to provide a relay which properly restrains regardless of the amount of inrush and yet permits operation if an internal fault occurs during the inrush period. Another design objective is not to have excessive restraint resulting from the harmonic distortions of the secondary currents due to current transformer saturation during a severe internal fault. Thus, each relay design attempts to optimize the amount of harmonic restraint to ensure correct operation under all service conditions.

Frequently, the differential harmonic restraint relay will also include an instantaneous relay unit. The instantaneous unit is set above possible transformer inrush current, but below that current which might result in current transformer saturation. The usual factory setting is 8 to 10 times the tap value.

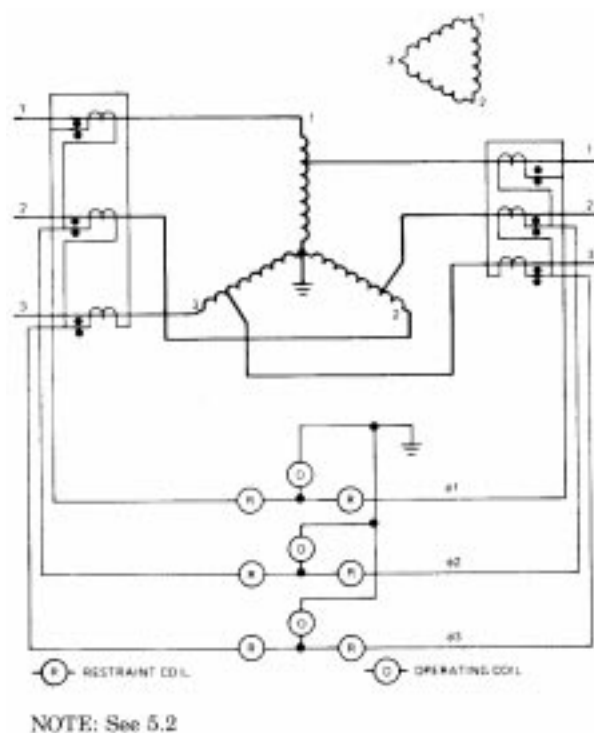


Figure 3—Typical Schematic Connections for Percentage Differential Protection of a Wye Autotransformer with an Unloaded Tertiary

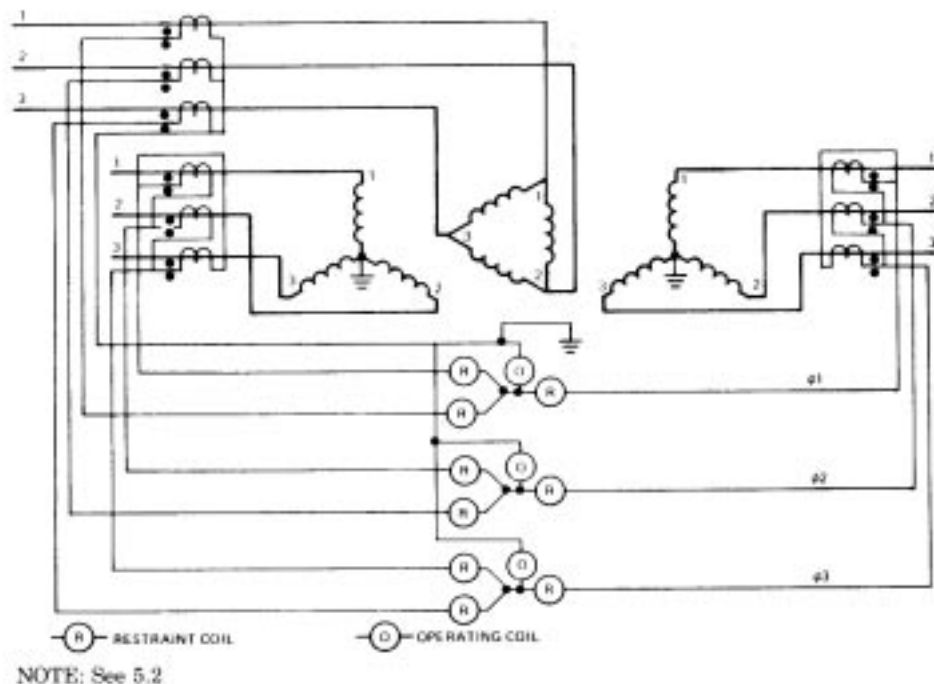


Figure 4—Typical Schematic Connections for Percentage Differential Protection of a Wye-Delta-Wye Transformer with a Loaded Delta Tertiary

Another consideration in the use of harmonic restraint relays is the performance during transformer overexcitation (see 4.5.3). Whether or not a differential relay will operate on exciting current due to overexcitation depends on the magnitude of exciting current, the harmonic content of the current (predominately odd harmonics), and the restraint characteristic of the relay. A relay which restrains on odd harmonics is less likely to operate under such conditions. The relay application engineer should check Section 13 for assistance in defining his specific transformer protection objectives and hence preferred type of harmonic restraint relay characteristic.

Harmonic restraint differential relays often can be justified by considering the following points:

- 1) Fewer investigations of false trips due to inrush
- 2) Faster operating time (0.03 s to 0.05 s versus 0.1 s to 0.2 s for the percentage restraint type)
- 3) Lower pickup (20% to 40% of transformer rating versus 40% to 100% for the percentage restraint type)

5.2.4 Unit Generator Transformer Sets

On cross-compound generators, the fields may be applied while the generators are on turning gear, or at speeds of 15% to 35% of synchronous speed, depending on the design and users' preferences. Application of the fields to such machines normally excites the generator step-up and unit station service transformers and the generator so that protection is required for all of the unit system. The filter circuit of some harmonic restraint relays may block relay operation if a fault occurs before the machine is up to synchronous speed. Since relay designs vary, the relay performance at reduced frequency should be checked.

5.2.5 Generator Station Service

Where a startup or station service transformer is connected to the high voltage bus, high speed fault clearing is usually required for stability reasons, even though the transformer is relatively small. The low current transformer ratio required for satisfactory sensitivity may result in severe current transformer saturation for high side faults. If the burden is high, the high peak voltages could result in insulation breakdown, and thus failure of the differential to

operate. An additional current transformer with a high ratio, supplying an overcurrent relay with instantaneous unit would then be required to back up the differential, if such an instantaneous trip is not built into the differential relay. If high sensitivity is not required, the differential relay may be omitted.

When a unit auxiliary transformer is connected at a point between the generator and step-up transformer, a current transformer connection shall be provided for the overall differential scheme. A connection from the overall differential to the low side current transformers of the unit auxiliary transformer avoids the saturation problem that may occur with high side current transformers. This saturation problem could prevent the operation of the unit auxiliary transformer differential relays. The overall differential thus connected provides protection for the unit auxiliary transformer and the generator and the step-up transformer. It should be noted, however, that the relay sensitivity for the unit auxiliary transformer faults may be low due to the high current transformer ratios.

5.2.6 Multiple Winding Transformer Differential

Differential relays for three winding transformers are available in the percentage differential and harmonic restraint relay types. These relay types are also available to accommodate additional windings or terminals.

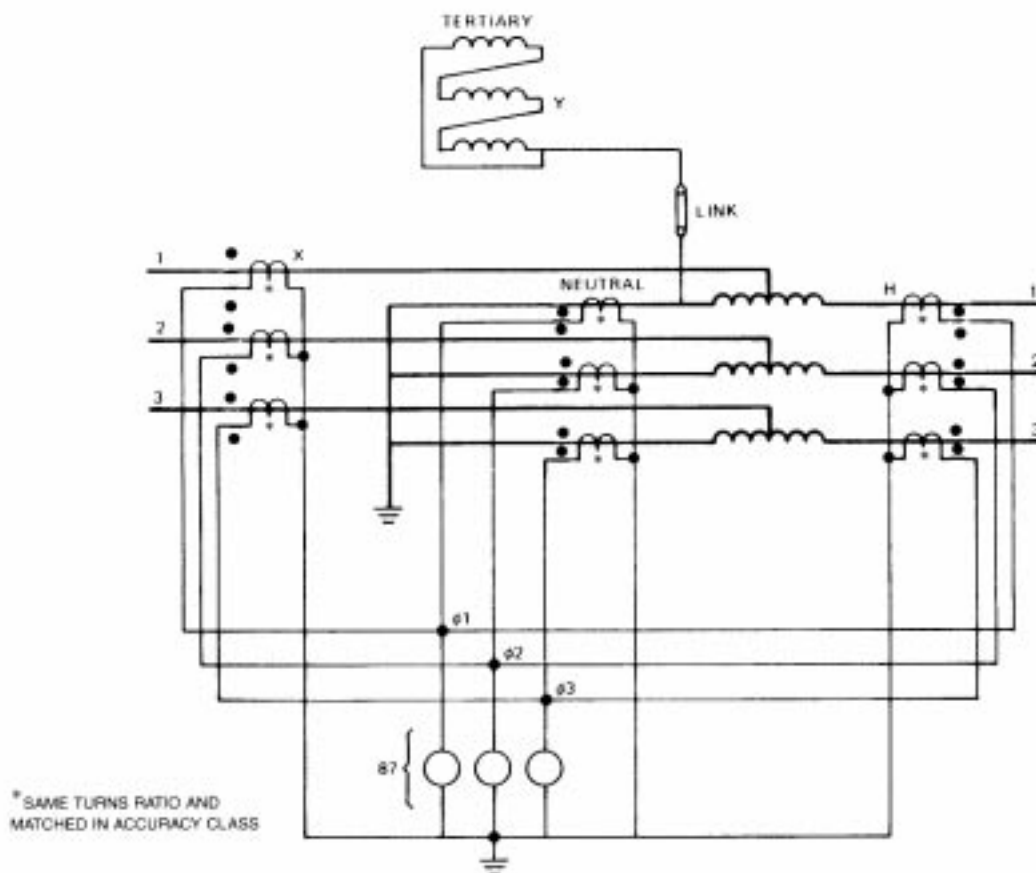
Multiple winding transformers frequently have different capacity ratings on the individual windings. For example, a three winding transformer may have a high side rating of 90 MVA with the other two windings each rated at 50 MVA. The sum of the small windings' ratings can be greater than the main (input) winding rating. Care should be taken in selecting current transformer ratios and selecting differential relay current balancing taps. These should be based on the through flow of current equivalent to the largest winding rating regardless of the rating of the other winding considered. Proper restraint tap selection may be accomplished if through-fault current involving only the high side and one other winding is studied at a time.

5.2.7 Parallel Transformers

A major disadvantage of using one differential relay to protect two transformers is the reduction in sensitivity. The current transformer ratios are selected on the basis of total kilovoltampere, (kVA) and hence, the sensitivity for each transformer is less than one-half of what it would be if individual protection was provided. When a transformer is energized in parallel with an already energized transformer (see 4.5.2), the harmonic restraint unit on a differential relay protecting both transformers may not restrain. Thus, an undesired trip may occur. Therefore, each transformer should be protected by separate sets of differential relays.

5.2.8 Differential Protection of Autotransformers Using High Impedance Relays

In some countries, it is common practice to provide greater protection for large, high-voltage and extra-high-voltage autotransformers by using voltage operated bus-type high impedance differential relays. Typical connections of this protective system for autotransformers, with the neutral point of the wye winding solidly grounded, are shown in Fig 5. This arrangement provides protection against all types of phase faults and ground faults but not turn-to-turn faults. In this application, three sets of three-phase current transformers are required, one set on the high voltage side, another set on the low voltage side and the third set in the neutral ends of the winding. All current transformers shall have the same turns ratio and should be reasonably matched in accuracy class. A single relay connected in a ground differential scheme is also applicable for autotransformer protection.



NOTE: See 5.2.8

Figure 5—Typical Schematic Connections for High Impedance Differential Relay Protection of a Wye Autotransformer with an Unloaded Tertiary

This protection is immune to the effects of magnetizing inrush current because inrush current is cancelled by the neutral current transformers. Also, there is no imbalance current in the relay circuit due to the load tap changing equipment. Thus a high impedance differential relay can be applied without any harmonic restraint, load bias, or time delay.

Autotransformers are often provided with a tertiary delta winding. It should be noted that with this type of scheme no protection is afforded against faults occurring in the delta tertiary winding. Where the terminals for this winding are not brought out to supply load, one corner of the delta can be connected between the end of one phase of the main winding and its neutral current transformer. This connection is shown in Fig 5. In such an arrangement, the tertiary winding is included in the differential protection zone and the relay would sense ground faults in the tertiary winding. This scheme does not provide protection against phase faults or turn-to-turn faults in the tertiary winding.

Where the tertiary winding is used to supply load, the delta winding corner connection cannot be used. Hence, separate protection is required. The tertiary winding overcurrent protection is described in 5.3.3.

5.3 Overcurrent Relay Protection

A fault external to a transformer can result in damage to the transformer. If the fault is not cleared promptly, the resulting overload on the transformer can cause severe overheating and failure. Overcurrent relays (or fuses, see 5.1)

may be used to clear the transformer from the faulted bus or line before the transformer is damaged. On some small transformers, overcurrent relays may also protect for internal transformer faults, and on larger transformers, overcurrent relays may be used to provide relay backup for differential or pressure relays. Thermal relays (Section 7) may also be used to protect transformers against overload. However, thermal relays often are used for alarm only. Coordination examples are included in the Appendix.

5.3.1 Phase Time Overcurrent

Time overcurrent relays are inexpensive, simple, and reliable protective devices. Since sensitive settings and fast operation are usually not possible with overcurrent relays, they will provide limited protection for internal transformer faults. Since the pickup value of phase overcurrent relays must be high enough to take advantage of the overload capabilities of the transformer and be capable of withstanding energizing inrush currents, insensitive settings result. Fast operation is not possible, since the transformer relays shall coordinate with load-side protection including consideration for reclosing cycles and service restoration inrush. Where time overcurrent relays are used for primary transformer protection, extensive damage to the transformer from an internal fault may occur.

Settings of phase overcurrent relays on transformers involve a compromise between the requirements of operation and protection. The pickup setting should be high enough to permit overloading the transformer when necessary, but the higher the setting, the less the protection. A setting of 200% to 300% of the minimum nameplate rating of a transformer is common, although higher values are sometimes used. On multiple rated transformers, a higher setting may be necessary so as to utilize the full capability of the transformer at the higher forced cooled rating.

If only overcurrent protection is applied to the high-voltage (Δ) side of a Δ -Y grounded transformer, it can have a problem providing sensitive fault protection for the transformer. For low voltage (Y side) line-to-ground faults, the high side line current will be only 58% of the low voltage per unit fault current. (See Fig 6 and Appendix Figs B6, B7, and B8.) When the Y is grounded through a resistor, the high side fault current may be less than the maximum transformer load current. Similar concerns are applicable when the Y is grounded through a reactor.

The time setting should coordinate with relays on downstream equipment. However, transformers are mechanically and thermally limited in their ability to withstand short-circuit current for finite periods of time. For proper backup protection, the relays should operate before the transformer is damaged by an external fault. (Refer to the Appendix for the transformer through fault current duration limits and relay setting examples.)

When setting transformer overcurrent relays, the short time overload capability of the transformer in question should not be violated. Low values of 3.5 or less times normal base current may result from overloading rather than faults. For such cases see ANSI/IEEE C57.91-1981 [3] and ANSI/IEEE C57.92-1981 [4] since allowable time durations may be different from those in the through fault current duration curves. Pending establishment of additional transformer standards, it is recommended that the manufacturer be consulted for the capability of a specific transformer.

Although electromechanical overcurrent relays have time proven reliability, static (solid state) relays with special features such as fast reset should be evaluated for these applications.

5.3.2 Phase Instantaneous Overcurrent

Fast clearing of severe internal faults may be obtained through the use of instantaneous overcurrent units. Instantaneous overcurrent units, when used, should be set to pick up at a value higher than the maximum asymmetrical through-fault current. This is usually the fault current through the transformer for a low side three phase fault. For instantaneous units subject to transient overreach, a pickup of 175% (variations in settings of 125%–200% are common) of the calculated maximum low side three-phase symmetrical fault current generally provides sufficient margin to avoid false tripping for a low side bus fault, while still providing protection for severe internal faults. For instantaneous units with negligible transient overreach, a lesser margin can be used. The settings in either case shall also be above the transformer inrush current to prevent nuisance tripping. In some cases, instantaneous trip relays cannot be used because the necessary settings are greater than the available fault currents. In these cases, a harmonic restraint instantaneous relay may be considered to provide the desired protection.

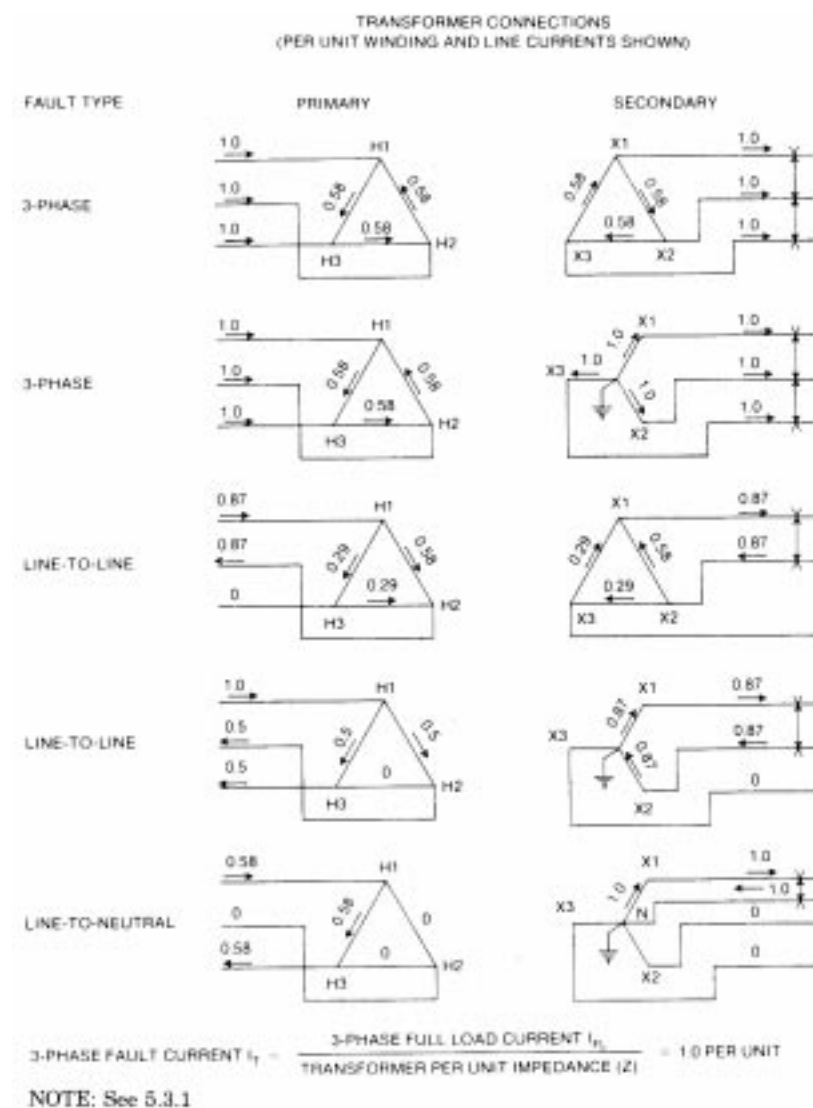


Figure 6—Line and Transformer Winding Currents for Delta-Delta and Delta-Wye Connected Transformers

5.3.3 Tertiary Winding Overcurrent

The tertiary winding of an autotransformer, or three-winding transformer, is usually of much smaller kilovoltampere rating than the main windings. Therefore, fuses or overcurrent relays set to protect the main windings offer almost no protection to such tertiaries. During external system ground faults, these tertiary windings may carry very heavy currents. Hence, in the event of failure of the primary protection for external ground faults, separate tertiary overcurrent protection may be desirable.

The method selected for protecting the tertiary generally depends on whether or not the tertiary is used to carry load. If the tertiary does not carry load, protection can be provided by a single overcurrent relay connected to a current transformer in series with one winding of the Δ . This relay will sense system grounds and also phase faults in the tertiary or in its leads.