Grounding Transformer Applications and Associated Protection Schemes

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***Abstract*—The use of grounding transformers on three-phase ungrounded governmental, industrial, and commercial distribution systems is well known. Ground-fault protection schemes that provide selective and reasonably fast tripping are often incorporated with these grounding transformers. Since grounding transformers are not encountered on an everyday basis by most governmental, industrial, and commercial power systems electrical engineers, improper application of these devices and / or the associated ground-fault protective systems sometimes occurs. This paper first reviews the state of the art of grounding transformers to assist electrical power systems engineers in the proper understanding of the use and applications of these devices and then discusses two governmental system case studies illustrating improperly applied grounding transformers and / or associated ground-fault protection systems. In addition, it describes remedial actions taken to correct these deficiencies. The objective in presenting improper grounding transformer applications is to *highlight* protection concerns that are often ignored. The paper stresses that a single grounding transformer is not adequate for use with a multibus configuration. A unique protection scheme for use on a multibus arrangement is presented.**

I. INTRODUCTION

GROUNDING transformers are often connected to ungrounded three-phase systems. The use of grounding transformers on three-phase ungrounded governmental, industrial, and commercial distribution systems is well known. Ground-fault protection schemes that provide selective and reasonably fast tripping are often incorporated with these grounding transformers. Since grounding transformers are not encountered on an everyday basis by most governmental, industrial, and commercial power systems electrical engineers, improper application of these devices and/or the associated ground-fault protection systems sometimes occurs.

The technical literature covering grounding transformers is scattered. A number of technical publications [1]–[8] discusses various aspects of the purpose, protection philosophy, application, and specifications of different types of grounding transformers. However, some of these articles are not readily available. It appears that no single publication discusses all aspects of grounding transformers. Hence, this paper first reviews the state of the art of grounding transformers to assist electrical power systems engineers in the proper understanding of the use and applications of these devices and then discusses two governmental system case studies illustrating improperly applied grounding transformers and/or associated ground-fault protection systems. In addition, it describes remedial actions taken to correct these deficiencies. The objective in presenting improper grounding transformer applications is to highlight protection concerns that are often ignored.

The authors hope that the contents of this paper will aid engineers in determining the proper number and location of grounding transformers plus the optimum design and settings of the associated protection schemes. Emphasis is placed on the fact that a single grounding transformer is not adequate for use with a multibus configuration. A unique protection scheme for use on a multibus arrangement is presented.

II. GROUNDING TRANSFORMERS—PAST, PRESENT, AND FUTURE

Grounding transformers have been applied to ungrounded three-phase power systems to 1) provide a source of ground-fault current during line-to-ground faults, 2) limit the magnitudes of transient overvoltages when restriking ground faults occur and, 3) stabilize the neutral, and when desired, permit the connection of phase-to-neutral loads.

Ungrounded three-phase systems are used mainly to prevent an automatic shutdown when a ground fault on any one of the three phases occurs. The majority of all faults are of the single phase-to-ground variety. Therefore, continuity of power is maintained when no automatic tripping occurs for this common type of fault. However, ultimately, the fault must be located and repaired. It goes without saying that it can be annoying and time consuming to locate a ground fault by switching loads off and on to pinpoint and remove the single phase-to-ground fault from the system. Consequently, grounding transformers are commonly used to enable automatic detection and, if desired, isolation of phase-to-ground faults.

Many electric utilities, for example, Cleveland Electric Illuminating Company, are converting ungrounded delta primary distribution systems to grounded wye systems to provide for the automatic isolation of line-to-ground faults, to help protect the system components, and to prevent or minimize possible injury to personnel. The authors believe that in future years, the use of grounding transformers on new systems will diminish, because generally, it is cheaper

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and simpler to install a new grounded neutral wye system than a delta system having an associated grounding transformer. In all likelihood, there will always be specialized instances where delta systems having associated grounding transformers can be either technically or economically justified. However, grounding transformers (sometimes referred to as neutral deriving transformers) would normally be retrofitted to existing delta systems—particularly, systems rated for 2400, 4800, and 6900 V. Most older systems in these voltage classes were designed to be operated ungrounded.

III. Protection Philosophy when Using a Grounding Transformer

When a grounding transformer is used on a system, the protection philosophy [1] should be as follows:

- The system must be protected against faults in the grounding transformer; however, any isolation of a grounding transformer must not leave a system in a totally ungrounded or in an inadequately grounded mode.
- Back-up protection should be provided for ground faults in the system that are not cleared by the primary protection device.
- Protection should be selective to prevent unnecessary outages.

IV. Grounding Transformer Types

Three types of grounding transformers are commonly available: 1) zig-zag, 2) grounded neutral wye-delta, and 3) T connected. Zig-zag grounding transformers are more common than the wye-delta connection because they are less expensive and smaller in size [3]. A T-connected grounding transformer-neutral resistor combination can be the most economical path to follow in many industrial applications.

V. Operation of Grounding Transformers

All grounding transformers provide a low impedance path for zero sequence current I_o flow that occurs during related ground faults or unbalanced phase-to-neutral load conditions. In addition, the impedance of all types of grounding transformers to normal 3ϕ currents is high so that when there is no ground fault and no unbalanced phase-to-neutral load on the system, only a small magnetizing current flows in the transformer windings. For example, the impedance offered by a grounded neutral wye-delta connected grounding transformer during normal system conditions is no different from that of a wye-delta transformer bank operating unloaded.

Grounding transformer connections force an equal division of neutral current $3I_o$ through all three phases. The zig-zag transformer winding and core arrangement indicated in Fig. 1 illustrates this. The assumed $A\phi$-G fault causes the $3I_o$ current through the associated neutral resistor R_N. I_{ao}, I_{bo}, and I_{co} are all equal in magnitude and are all in phase with one another. Note that all six coils (two wound on each leg of the magnetic core) making up the zig-zag transformer contain an equal number of turns.

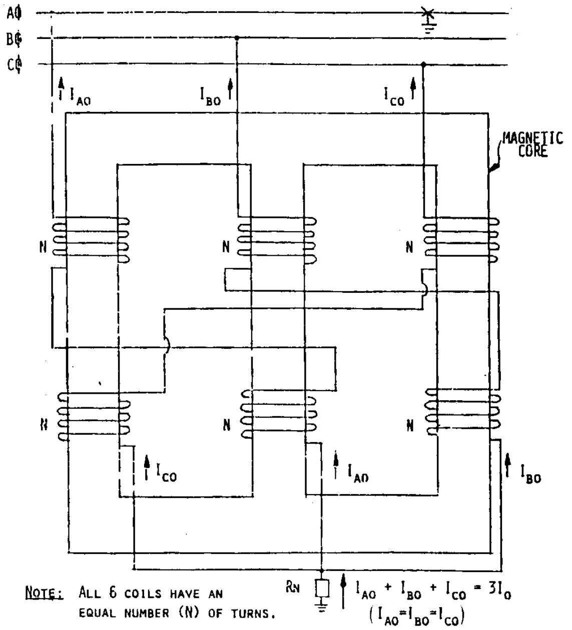


Fig. 1. Zig-zag grounding transformer arrangement.

In addition, the two coils on each magnetic core leg are wound in opposite directions from one another. This allows the ampere-turns produced by the two coils to balance each other, resulting in a relatively low series impedance encountered by the I_o flows.

Fig. 2 illustrates the operation of a T-connected grounding transformer-neutral resistor combination during an assumed $A\phi$-G fault. Two autotransformers are used to form this type of grounding transformer arrangement. Autotransformer #1 has a 1:1 turns ratio, i.e., an equal number of turns exists on each side of the common (midpoint) lead. Autotransformer #2 has twice the number of turns on one side of its common lead as it has on the other side. Because of the geometry of the voltage triangle, the system neutral is located at the common lead of autotransformer #2. Autotransformer action requires an equal number of ampere-turns to exist on each side of the common lead. Consequently, the $3I_o$ current would be forced to divide as indicated in Fig. 2. This results in an equal I_o flow into each of the three phases of the power system—the same effect created by the zig-zag and grounded neutral wye-delta grounding transformers.

A. System Current Flows During ϕ-G Faults

Figs. 3 and 4 illustrate simplified analyses of ϕ-G fault current flows through systems incorporating grounding transformers. The Fig. 3 system utilizes a zig-zag grounding transformer. The total fault current (three units) flows into the $A\phi$-G fault and up through the grounding transformer resistor R_N. One third of the total fault current flows through each of the grounding transformer legs. It is

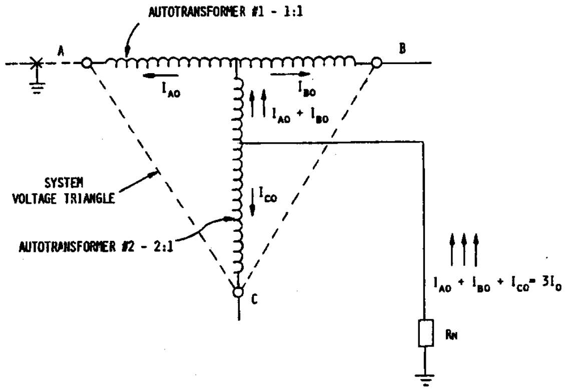
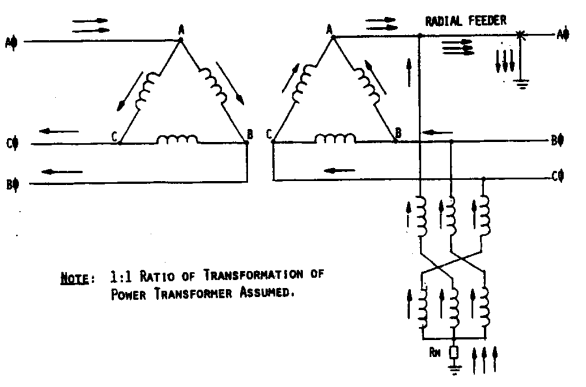
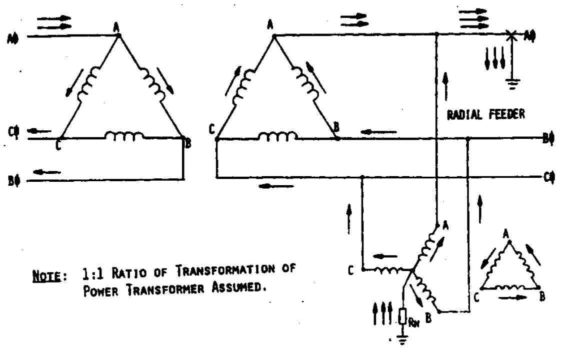


Fig. 2. "T" connection grounding transformer arrangement.



NOTE: 1:1 RATIO OF TRANSFORMATION OF POWER TRANSFORMER ASSUMED.

Fig. 3. Simplified analysis of system current flows during assumed $A\phi$-g fault on secondary of delta-delta system with an associated zig-zag grounding transformer.



NOTE: 1:1 RATIO OF TRANSFORMATION OF POWER TRANSFORMER ASSUMED.

Fig. 4. Simplified analysis of system current flows during assumed $A\phi$-g fault on secondary of delta-delta system with an associated grounded neutral wye-delta grounding transformer.

seen that when assuming a 1:1 ratio of transformation of the main power transformer, two thirds of the total fault current flows in one primary phase, whereas one third of the total fault current flows in the remaining two primary phases. When analyzing schemes such as this, it becomes readily apparent that primary protective devices (e.g., high-side fuses) provide absolutely no protection for low-side ϕ-G faults for the following three reasons:

- Fault current magnitude is very low due to impedance of the grounding transformer plus R_N.
- Currents on primary side are reduced in direct proportion to the main power transformer turns ratio.
- Current magnitude in primary phase carrying the highest fault current is further reduced by a two thirds multiplier.

The Fig. 4 system incorporates a grounded neutral wye-delta connected grounding transformer. Note that the resultant current flows in the delta winding of the grounding transformer are all equal in magnitude and in phase with one another—a definite requirement of a series circuit. The delta winding provides a series circuit to the flow of the I_o current.

VI. GROUNDING TRANSFORMER ARRANGEMENTS AND ASSOCIATED PROTECTION SCHEMES

Figs. 5 and 6 illustrate two methods of connecting grounding transformers to the ungrounded system.

Fig. 5 indicates a connection that is commonly used. This arrangement connects the grounding transformer to the bus through its own dedicated breaker. The grounding transformer provides $3I_o$ to the system when a ground fault occurs. If the fault is on the associated feeder, the feeder ground overcurrent relay would sense this fault current and isolate it by tripping the feeder breaker *C*. Ground faults located between the power transformer secondary and main breaker *B* would be sensed by main breaker *B* ground overcurrent relay 50/51*N* and cleared by breaker *B*. Ground faults at this location are the only faults that can be sensed by this 50/51*N* relay. Consequently, it does not have to coordinate over any other protective device and can be assigned minimum tap, time dial, and instantaneous unit settings. The grounding transformer neutral overcurrrent relay 51*N* will trip high side breaker *A* for low side ϕ-G bus faults. This same relay action would result for feeder phase-to-ground faults that are not properly cleared by the feeder relaying or feeder breaker. Faults within the grounding transformer would result in operation of grounding transformer relay 50 and the attendant tripping of the grounding transformer breaker *D*, thereby leaving the power system to operate in an ungrounded mode. Under such circumstances, the grounding transformer should be repaired or replaced as quickly as possible.

Fig. 6 illustrates an arrangement where the grounding transformer is tapped directly to the secondary side of the delta-delta power transformer. This configuration provides a common zone of protection, i.e., any fault in the grounding transformer will result in tripping the associated high-side breaker *A*, resulting in the isolation of both the power transformer and the grounding transformer. Such an arrangement ensures that the secondary system will always be adequately grounded, but it does result in total system loss for grounding transformer faults.

Identical grounding transformer overcurrent protection schemes are indicated in both Figs. 5 and 6.

The "51*N*" designates a single time-overcurrent relay connected in the neutral of the grounding transformer. As

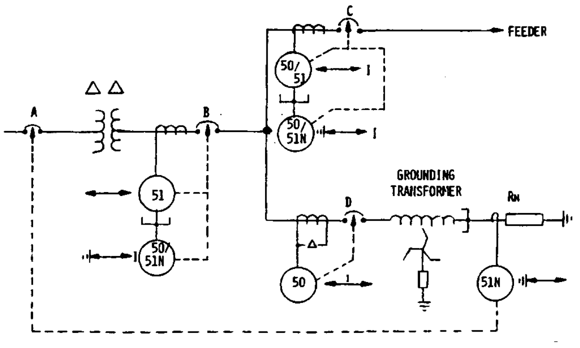


Fig. 5. Common method of connecting grounding transformer on systems 2400 V and above.

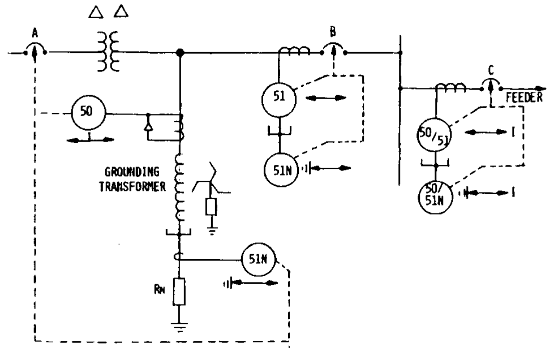


Fig. 6. Alternate method of connecting grounding transformer on systems 2400 V and above.

mentioned previously, this relay provides both primary and backup functions, depending on the ground fault location.

The "50" designates three instantaneous overcurrent relays (or a single three element instantaneous overcurrent relay). The "50" devices are connected to C.T.'s that are arranged in a delta configuration. This protection scheme can employ very sensitive settings and is used to sense and isolate faults occurring within the grounding transformer. The "50" devices do not have to be coordinated above any other protective relays. They sense no current flows for faults external to the grounding transformer zone of protection. In fact, for ground faults external to the grounding transformer zone of protection, the resultant I_0 current circulates around the delta connected C.T.'s and does not enter the "50" relay elements.

More than a single factor must be considered when selecting the ratio of C.T.'s employed in grounding transformer protection schemes. These factors include the magnitude of I_0 flow, the current ranges of the associated protective relays, the magnitude of phase faults that may occur within the grounding transformer, and whether or not the grounding transformer C.T.'s may be interconnected with some other C.T.'s in more complex protection arrangements. See Fig. 12 for an example of this.

VII. GROUNDING TRANSFORMERS USED SO THAT LOADS CAN BE CONNECTED PHASE-TO-NEUTRAL

Some utilities have been known to retrofit delta systems (e.g., 12 kV) with rather large capacity grounding transformers to enable the distribution system to supply phase-to-neutral connected loads. No neutral resistors would be used with the grounding transformers in designs such as these. These types of arrangements are becoming decreasingly feasible because the resultant high X_0/X_1 ratios (i.e., reactance grounding) cause significant overvoltages on the customer loads connected between neutral and the two unfaulted phases during a line-to-ground fault. Such temporary overvoltages are becoming more destructive as customer loads contain ever increasing amounts of voltage-sensitive solid-state equipment.

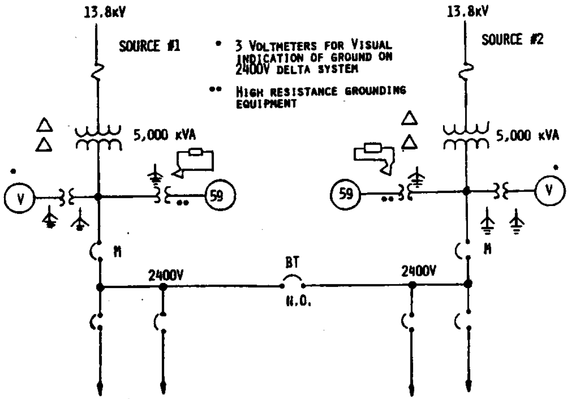
As time goes by and the older delta systems are phased out due to obsolescence, grounding transformers used so that phase-to-neutral loads can be connected will probably become museum pieces. Wye systems, having the capability of neutral grounding (either solid or through a resistor) will become ubiquitous.

VIII. GROUNDING TRANSFORMER AND ASSOCIATED RESISTOR SPECIFICATIONS

Because a grounding transformer is normally a short-time device, its size and cost are less when compared with a continuous duty transformer of equal kVA rating. In cases where ground fault tripping schemes are used, grounding transformers should have adequate short-time neutral current ratings specified for given time periods (e.g., 10 s or 1 min). The short-time kVA rating of a grounding transformer is equal to its rated line-to-neutral voltage times rated neutral current. A continuous or extended time neutral current rating would be required in cases where the grounding transformer is used in a ground-fault alarm (as opposed to a ground-fault tripping) scheme. When grounding transformers are used to establish a neutral to enable the connection of phase-to-neutral loads, continuous neutral current ratings of the devices must be specified because of attendant load unbalance. The authors are familiar with two designs of 12-kV zig-zag grounding transformers that have been utilized by a major utility in order to accommodate phase-to-neutral connected loads. One of these designs has a 75-A continuous neutral current rating, whereas the other is rated for 150 A.

Line-to-line voltage ratings must be specified for 3ϕ grounding transformers. In addition, line-to-line voltage ratings must be specified for the primaries of the three transformers that are used to form a grounded neutral wye-delta grounding transformer bank.

Resistors connected into grounding transformer neutrals should have voltage ratings equal to system voltage/$\sqrt{3}$. Their ohmic values should be specified to allow ground-fault current flows that are high enough to permit reliable operation of the protective relaying but low enough to limit thermal damage. When used with relayed systems, resistors should have current ratings specified for a given time period, e.g., 10 s.



NOTE: THERE ARE ACTUALLY 10 2400V FEEDERS; 5 EMANATING FROM EACH OF THE TWO BUSSES

Fig. 7. Simplified one-line diagram of 2400-V delta-connected system having wye-broken delta grounding transformers.

Resistors connected within the deltas of grounded neutral wye-delta grounding transformers must be specified to have continuous current ratings when used in ground-fault alarm schemes.

IX. CASE STUDY OF 2400-V SYSTEM HAVING HIGH RESISTANCE GROUNDED NEUTRAL WYE-BROKEN DELTA GROUNDING TRANSFORMERS

A. Existing System Configuration

This case study discusses the improper value of grounding transformer resistance used by a large governmental agency—their 2400-V delta-connected system is depicted in Fig. 7. A bank of grounding transformers (connected grounded neutral wye-broken delta) had been added on the 2400 V side of each of the two incoming 13 800–2400-V power transformers in order to limit the formation of dangerous levels of transient overvoltages during restriking ground faults on the 2400-V system. Resistors are incorporated in these grounding transformers. Figs. 7 and 8 indicate that these resistors are connected within the grounding transformer broken deltas as opposed to the concept of being placed in the wye winding neutral connection. The total loop resistance indicated in Fig. 8 is 34 Ω. Note that each of these two grounding transformers is composed of three single-phase 2400-120-V transformers connected in the grounded neutral wye-delta configuration. The turns ratio "*n*" of each of these transformers is 2400/120 = 20.

The 59 (overvoltage) devices are connected as indicated in Fig. 8. These devices can be used to sound an alarm when a ground fault develops on their portion of the 2400-V system. In addition, an operation of a 59 device would illuminate the red "ground fault" light and turn off the green "normal" light. The two sets of three phase voltmeters shown on Fig. 7 (each voltmeter would effectively sense a phase-to-neutral voltage) would provide visual indication of which phase was faulted to ground.

B. Ground Fault Tripping Problem

The grounding transformers were originally retrofitted to this 2400 V governmental system so that ground fault tripping schemes could be utilized. However, the values of resistance that were inserted into the broken delta windings of the grounding transformers were too high to allow ground fault current values of sufficient magnitude to activate the associated relaying systems. Once this deficiency was determined, the grounding transformers were disconnected from the remainder of the system.

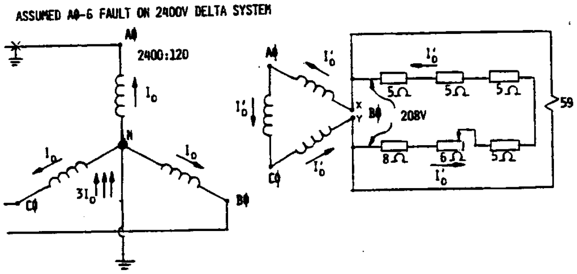


Fig. 8. Resistance connected within broken delta windings of grounding transformer.

C. Ground Fault Alarm Scheme

A later decision was made to reactivate the grounding transformers and institute a ground-fault alarm system. The wye-broken delta-connected transformers (having associated resistors) are usually utilized for alarm as opposed to tripping purposes. The goal was to size the grounding transformer resistors so that the resulting ground-fault current would be large enough to limit the magnitudes of transient overvoltages during restriking ground faults but small enough to minimize thermal damage. In order to ensure the limitation of these transient overvoltages, the ground-fault current $3I_o$ flow at the very minimum must be slightly greater than the total capacitive charging current $3I_{co}$ flow to ground on the associated system. Accordingly, as a starting point, an accurate $3I_{co}$ magnitude had to be determined.

1) Determination of $3I_{co}$ Value: The $3I_{co}$ value can be calculated theoretically as:

$$3I_{co} = \frac{3E_{L-L}}{\sqrt{3}X_c}$$

where E_{L-L} is the line-to-line voltage, and X_c is the capacitive reactance to ground of cables, transformers, motors, etc.

Although calculating this $3I_{co}$ value provides a nice academic exercise, the most accurate method of determining this quantity is by means of a field test. This field test consists of solidly grounding one phase of the ungrounded system (no grounding transformers connected) and measuring the resultant current flow to ground. By using this test method, the $3I_{co}$ value was measured to be 3.4 A.

2) Determination of Grounding Transformer Total Resistance Value: It was mentioned previously that it would be desirable for the ground fault current $3I_o$ flow to be somewhat greater than the total capacitive charging current $3I_{co}$ flow to ground, i.e., greater than 3.4 A. To allow

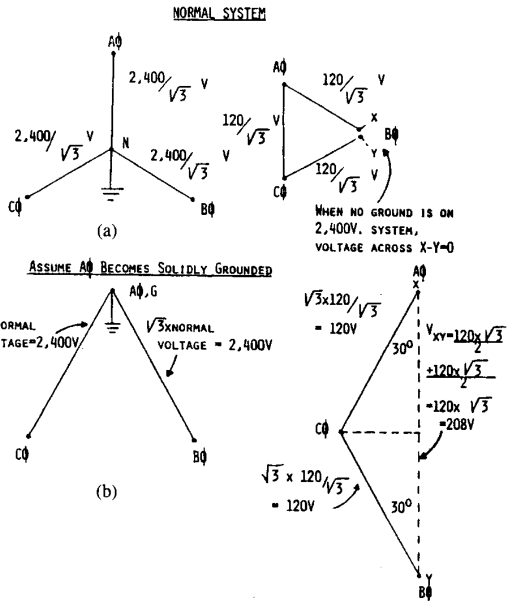


Fig. 9. Broken delta output voltages during normal and solidly grounded single line-to-ground fault conditions.

for meter errors when measuring the $3I_{co}$ valve, plus considering possible system growth, a $3I_o$ value approximating 4.8 A was selected.

A $3I_o$ flow of 4.8 A would result in 4.8/3 = 1.60 A flowing in each of the grounding transformer wye windings, see Fig. 8. This would result in 1.6 × 20 = 32.0 A flowing within the broken delta.

Fig. 9(a) illustrates that the theoretical broken delta output voltage during normal system operation = 0 V. Fig. 9(b) indicates that this voltage becomes 208 V when one of the 2400-V phases becomes solidly grounded.

Therefore, the grounding transformer broken delta resistance value required to limit the $3I_o$ flow to 4.8 A = 208/32 = 6.5 Ω. By connecting the available resistors in the configuration depicted in Fig. 10, a composite value of 6.33 Ω was obtained, which would cause the resultant $3I_o$ flow to be 4.93 A, and this approximates the desired $3I_o$ value of 4.8 A.

D. Calculation of Grounding Transformer Rating

Since the system being discussed uses no ground-fault tripping schemes, the $3I_o$ flow through the grounding transformers during a 2400-V ϕ-G fault will persist until the faulted piece of equipment is located and manually switched from the system; this could be a matter of hours. When a ϕ-G fault occurs, the primaries of the two single-phase grounding transformers connected to the unfaulted phases would detect 2400 V as long as the fault persisted. In addition, during the fault, 32.86 A (see Fig. 10) would circulate around the broken delta, and 32.86/20 = 1.64 A would flow in each of the three wye winding legs. Therefore, each of the three grounding bank single phase transformers would require a minimum rating of

$$\frac{32.86 \times 120}{1000} = \frac{1.64 \times 2{,}400}{1000} = 3.94 \text{ kVA}.$$

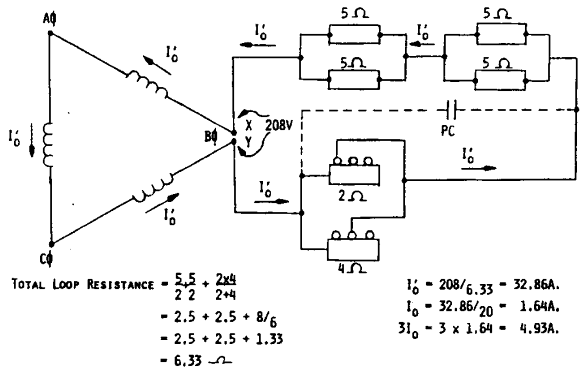


Fig. 10. Grounding transformer broken delta winding resistor arrangement.

A minimum single-phase rating of 5 kVA was specified for this grounding transformer application.

X. CASE STUDY OF A 2400-V SYSTEM HAVING ZIG-ZAG GROUNDING TRANSFORMERS INCORPORATING NEUTRAL RESISTORS

A. Existing System Configuration

This case study discusses the deficiencies of a ground-fault overcurrent tripping scheme utilized by another large governmental agency on a system depicted in Fig. 11. Note that all of the 2400-V breakers are operated normally closed. This effectively ties together the secondaries of delta-delta connected supply transformers $T1$, $T2$, and $T3$. Typical motors emanating from busses A, B, and C are illustrated. The total number of motors supplied from this 2400-V system is 35, ranging in size from 75 to 1500 hp.

On this system, a single grounding transformer (GT) currently supplies the $3I_o$ necessary for ground-fault overcurrent relay protection. This device is of the zig-zag variety, and a 3.48-Ω neutral resistor is associated with it. This grounding transformer has a dedicated breaker, which is connected to Bus C. The total grounding transformer overcurrent protection package is indicated on Fig. 11. In addition, the ground overcurrent relaying associated with breaker M-A (one of the three main breakers) and the ground overcurrent protection associated with one of the motors are illustrated. The protection schemes are identical for all three main breakers; in addition, the ground protection on all 35 motors is the same as that indicated for the one motor on Fig. 11.

B. Problems with the Existing Ground Fault Tripping

Ground faults occurring between one of the power transformers and its associated main breaker would be

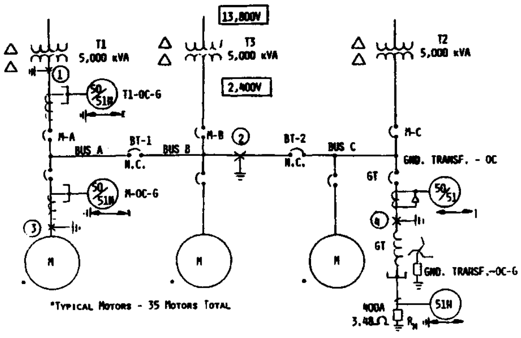


Fig. 11. Simplified one-line diagram of 2400-V delta-connected system having a zig-zag transformer incorporating a neutral resistor.

isolated from the 2400 V system by action of the appropriate ground overcurrent relay. For example, fault 1 on Fig. 11 would be cleared from Bus *A* by means of ground overcurrent relay "T1-OC-G." Because *T*1 is connected delta-delta, no relays located on the 13.8-kV side of this transformer could detect ground fault 1. Manual opening of the appropriate 13.8-kV breaker would therefore be necessary in order to totally isolate this ϕ-G fault.

With the protective system illustrated on Fig. 11, no relay action could ever isolate ground faults appearing on Busses *A*, *B*, or *C*: see fault 2 on Fig. 11. "GND.TRANSF.-OC-G" neutral overcurrent relay would sense the $3I_o$ flowing from the grounding transformer to the fault and operate after it timed out. This relay operation would trip the grounding transformer breaker, but the ground point would remain on Bus *B*. Once the grounding transformer became isolated, all appreciable fault current flow would cease; the only remaining fault current flow would be the capacitive charging current $3I_{co}$ as discussed previously. However, as long as the fault persisted, the voltage of the two unfaulted phases to ground would overstress the 2400-V system insulation by a factor of $\sqrt{3}$. This would make it more likely that one of these phases would fail to ground, thereby creating a ϕ-ϕ fault. This resulting major fault would be detected by phase overcurrent relays that are associated with main 2400-V breakers *M-A*, *M-B*, and *M-C*. The 2400-V protection system currently incorporates no C.T.'s on the bus tie breakers *BT*-1 and *BT*-2. Consequently, this previously mentioned ϕ-ϕ fault would result in the loss of the entire 2400-V system.

If the "GND.TRANSF.-OC-G" neutral relay were reconnected to trip the three main 2400-V breakers (*M-A*, *M-B*, and *M-C*) in lieu of the grounding transformer breaker GT, the entire facility would be lost for a ground fault occurring on any of the three 2400-V busses (Bus *A*, Bus *B*, or Bus *C*).

In the existing system, motor ground fault 3 (see Fig. 11) would be isolated by operation of ground overcurrent relay "M-OC-G" tripping the motor breaker. The resulting $3I_o$ fault current would also be detected by grounding transformer neutral overcurrent relay "GND.TRANSF-OC-G." However, "M-OC-G" would operate first since it has been coordinated under "GND.TRANSF.-OC-G." In the event "M-OC-G" should fail to operate or if the motor breaker should "stick" due to either electrical or mechanical problems, "GND.TRANSF.-OC-G" would time out and trip its associated breaker. This scenario would then present problems identical with those discussed in relation to fault 2.

Grounding transformer fault 4 should be quickly isolated from the 2400-V system by action of the "GND.TRANSF_OC" relays. However, a failure to this single grounding transformer could result in ungrounded operation of this 2400-V delta system (making the system susceptible to high transient overvoltages) for an appreciable period of time. Under such conditions, extensive motor damage could occur.

C. Modifications to the Protective System

Fig. 12 illustrates the pertinent details of the grounding system modifications for the 2400-V governmental system depicted in Fig. 11. In an effort to simplify, details of the grounding and ground fault protection of only one of the three busses (Bus *C*) are indicated.

The salient feature of the grounding system modification is that two additional grounding transformer-resistor packages will be added: one to Bus *A* and one to Bus *B*. The two new packages will be identical to the existing one. The protection for all three bus sections will be equivalent to that shown on Fig. 12.

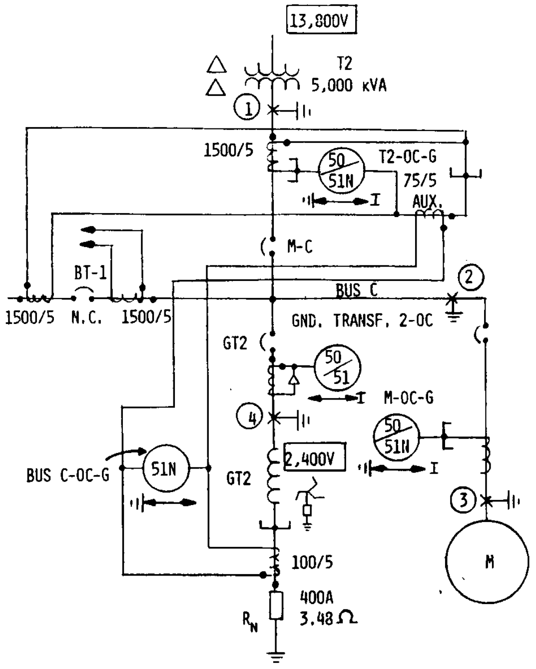
From inspection of Fig. 12, it is obvious that the planned overcurrent relaying will be more complex and selective than the present arrangement. C.T.'s will be placed on both sides of the bus tie breakers, main C.T. circuits will become interconnected, and auxiliary C.T.'s will be employed.

The ground fault tripping on the system given in Fig. 12 should incorporate several advantages when compared with the existing system scheme given in Fig. 11.

Fig. 12 considers the same four ground fault scenarios that were covered in Fig. 11. The clearing of fault 1 in Fig. 12 would be equivalent to the clearing of fault 1 in Fig. 11. In the Fig. 12 case, "T2-OC-G" would detect the $3I_o$ flow supplied by the three grounding transformers and trip main breaker *M-C*. A manual opening of the 13.8-kV breaker associated with *T*2 would be required to finally isolate the ground at location 1.

In this planned arrangement, main bus ground fault 2 would be detected by "BUS C-OC-G." Once this ground overcurrent relay timed out, it would trip breakers *BT*-1 and *M-C*, thereby isolating the fault. One third of the motors would be out of service, but the remaining two thirds would remain in service, supplied from a completely sound 2400-V system.

Motor fault 3 would again be detected and isolated by means of ground overcurrent relay "M-OC-G." In this planned arrangement, if "M-OC-G" should fail to operate, or if the associated motor breaker should "stick," "BUS C-OC-G" would time out and isolate Bus *C* by tripping breakers *BT*-1 and *M-C*.



NOTE: EACH OF THE THREE 2,400V BUSSES (BUS A, B AND C) HAS AN ASSOCIATED GROUNDING TRANSFORMER - ALL THREE GROUNDING TRANSFORMER PACKAGES ARE IDENTICAL.

Fig. 12. Portion of modified 2400-V delta-connected system given in Fig. 11.

Grounding transformer ground fault 4 would be detected by "GND.TRANSF. 2-OC," which would trip breaker *GT*2. Even though this faulted transformer may be out of service for an extended period of time, the two remaining grounding transformers will ensure that the 2400-V delta system maintains an adequate level of grounding.

This planned modification provides a "fix" to a pre-existing problem. It the total system were being designed from scratch, it would be more conventional and straightforward to connect each of the three grounding transformers directly at the secondary of its associated power transformer.

XI. SUMMARY

This paper summarizes the state of the art of grounding transformers to assist power systems engineers in the proper understanding of the purposes and application of grounding transformers and associated protection schemes in medium-voltage systems.

Case studies of the improper application of grounding transformers in two large governmental agencies were discussed. The first case study discussed the use of an incorrect value of resistance in grounded neutral wye-broken delta-grounding transformers associated with a 2400-V ungrounded system. This resulted in rendering the protection system useless. Detailed calculations are given to assist the power system engineer to correctly size the grounding transformer resistance value necessary to limit the magnitudes of transient overvoltages caused by restriking ground faults.

The second case discussed ground fault tripping deficiencies caused by utilizing only a single zig-zag grounding transformer with an associated neutral resistor on a multibus 2400-V ungrounded system. To protect a multibus ungrounded system, the authors recommend that a grounding transformer be associated with each of the power transformers (or bus sections) in order to provide reliable and safe operation of the power system. The optimum location of each of these grounding transformers would be within the zone of protection of its associated power transformer. However, as the second example indicated, pre-existing conditions may dictate that a grounding transformer be located on each of the bus sections rather than with the associated power transformer.

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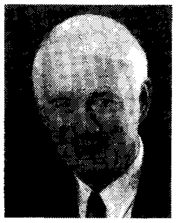

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