Alarming Experience with Ungrounded Tertiary Bus Ground Detection

Gary L. Kobet, P.E.
Tennessee Valley Authority
Chattanooga, Tennessee, U.S.
glkobet@ieee.org

Abstract—**The detection of ground faults on ungrounded tertiary buses is usually provided by three single-phase voltage transformers (VT) connected wye-grounded/broken-delta, with output connected to an overvoltage relay. The overvoltage relay in many cases provides only a control center alarm. This paper will describe ground fault detection on ungrounded buses and will present a case for tripping instead of alarming, or if alarming, for not sending operating personnel into the yard to inspect until after the tertiary bus is deenergized.**

Keywords—tertiary; delta-connected; ungrounded; tertiary ground fault; zero sequence voltage

I. Introduction

The Tennessee Valley Authority (TVA) is a corporate agency of the United States that provides electricity for business customers and local power companies serving 10 million people in parts of seven southeastern states. The TVA transmission system consists of over 16,000 circuit miles of transmission lines and 513 transmission substations, with transmission operating voltages primarily at 500kV and 161kV. Of those transmission substations, 36 have one or more three-winding transformer banks with 500kV wye-grounded primary, 161kV (or 230kV) wye-grounded secondary, and 13kV or 26kV delta-connected tertiary windings connected to ungrounded buses.

Such ungrounded buses present a protection challenge for the single-phase-to-ground fault, during which practically zero fault current flows. While the insulation in such yards is typically rated for full phase-to-phase voltage, faults can and do occur for several reasons, including animal intrusion, insulation deterioration due to contamination or age, or surge arrester failure.

In addition, while insulation should be rated to withstand full phase-to-phase voltage, the first phase-to-ground fault, if not cleared, leads to a multiphase fault should another phase fault to ground. Multiphase fault currents on these buses can be extremely high, in some cases exceeding 200kA, depending on the transformer impedances to the tertiary bus.

TVA has had at least five ground faults (two at the same location) on tertiary buses over the past dozen or so years, two of which began as single-phase-to-ground but quickly (minutes or seconds) evolved into double-phase-to-ground faults and resulted in catastrophic damage. In both cases, quick tripping of the bank upon detection of a single ground fault would have prevented catastrophic damage and more importantly, protected operating personnel.

The original design for tertiary bus ground fault detection schemes at TVA called for alarm only, which is in agreement with at least one industry guide. But as a result of the events described herein, TVA is in the process of modifying the schemes from alarming only to tripping after a short time delay. In cases where alarming is still the control action, operating personnel are not sent into the yard to inspect until after the tertiary bus is deenergized.

This paper describes ungrounded systems and their use. It discusses ground fault detection on such systems in general, then specifically in how TVA implements ground fault detection on ungrounded tertiary buses in 500kV substations. TVA experience with such schemes is discussed by describing and illustrating five different events. This is followed by a review of relevant industry standards and a discussion of pertinent settings for the schemes, which includes TVA present practices.

II. Ungrounded Systems

A. General

Ungrounded systems are intentionally used in some industrial plants where continuity of service is extremely important and loss of control would be unsafe [1]. Their main benefit is they allow the system to continue in operation for a short time even when one phase becomes grounded. They are also used in transmission substations on transformer bank tertiary buses where the station service transformers serve three-phase loads such as oil circulating equipment, SF6 gas handling equipment, control house air conditioning, station battery chargers, air compressors for legacy air blast breakers, and fans and pumps for power transformer cooling.

B. What is an ungrounded system?

An ungrounded system is one that has no intentional grounding, such as a three-phase delta transformer winding connection. Note the system is still "grounded" through the natural system capacitance to ground as shown in Fig. 1 (albeit via very high capacitive impedance).

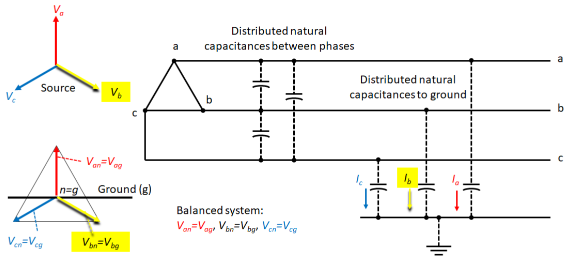

Fig. 1. *Ungrounded system - unfaulted*

C. *Ground faults on ungrounded systems*

When ground faults occur in such systems, note the following from Fig. 2:

- the faulted phase-to-ground voltage is zero;
- the neutral point shifts so that the neutral-to-ground voltage equals the faulted phase-to-neutral voltage; and
- the unfaulted phase-to-ground voltages rise to full phase-to-phase voltage.

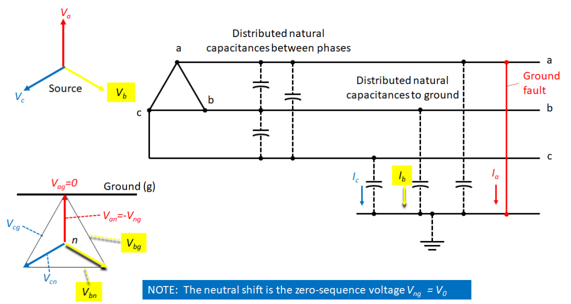

Fig. 2. *Ungrounded system - phase-to-ground fault*

Due to the delta-connected transformer winding which blocks zero sequence current, and because the distributed capacitive impedances are very large relative to the system source and transformer impedances (Fig. 3), the resulting fault current is very low, even insignificant, which minimizes equipment damage. This advantage has led some to ignore ground faults and continue operating, even if a ground detection system has indicated a fault.

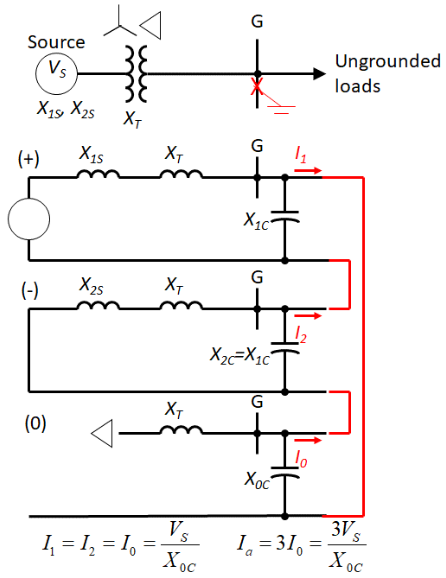

Fig. 3. *Sequence networks for ungrounded system - phase-to-ground fault*

However, ungrounded systems have these disadvantages: (1) destructive transient overvoltage, (2) unfaulted phase-to-ground voltages rise to 173% of normal phase-to-ground voltage. This can be critical if insulation deterioration caused the first fault, because the higher stress on the unfaulted phase insulation may accelerate their failure, resulting in a severe multiphase fault. This leads to the most critical disadvantage: (3) if a second ground were to occur on another phase, extremely high fault currents (thousands to hundreds of thousands of amperes) would flow, resulting in potentially catastrophic equipment damage and posing a very real risk of harm (injury or death) to operating personnel. Thus it is critical to detect, locate and clear ground faults.

III. Ungrounded Tertiary Bus Ground Fault Detection

A. *General*

The detection of ground faults on ungrounded tertiary buses is usually provided by three single-phase voltage transformers[1] (VT) connected wye-grounded/broken-delta, with the output connected to an overvoltage relay (Fig. 4). The loading (damping) resistor is for ferroresonance suppression [2].

[1] TVA actually uses distribution class overhead-type power transformers for this application because instrument transformers are not available with the required kVA rating. But for the purposes of this paper, the term “voltage transformer (VT)” is used.

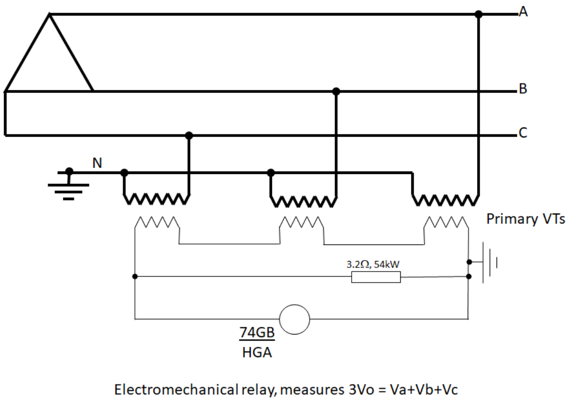

Fig. 4. *Ungrounded Tertiary Bus Ground Detection - single electromechanical relay*

This function could also be implemented in a digital relay which can calculate zero sequence voltage from the three-phase voltages (Fig. 5).

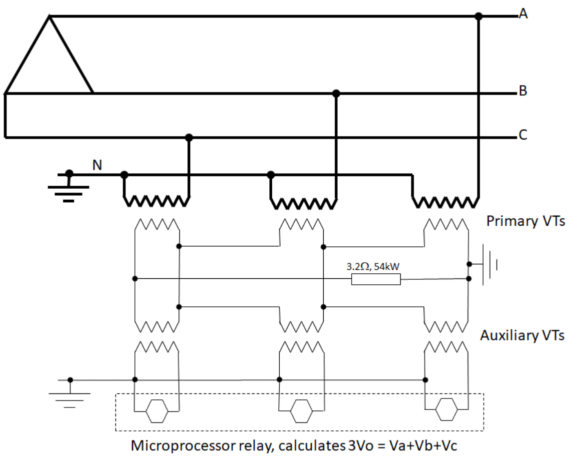

Fig. 5. *Ungrounded Tertiary Bus Ground Detection - microprocessor relay calculating 3Vo from auxiliary VTs*

For no ground on the tertiary bus, the output voltage across the broken delta transformer connection will be near zero (Fig. 6).

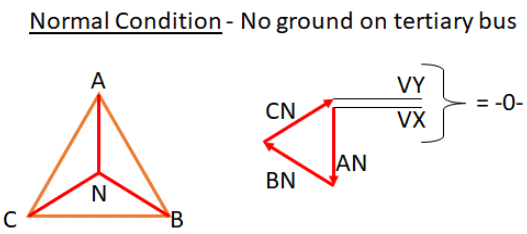

Fig. 6. *Tertiary bus voltage phasors - no ground fault*

However, for a single-line-to-ground fault, the faulted phase-to-ground voltage is obviously zero for a bolted fault, while the unfaulted phase-to-ground voltages rise to full phase-to-phase voltage (Fig. 7). The resulting relay voltage is 3 times nominal phase-to-neutral voltage.

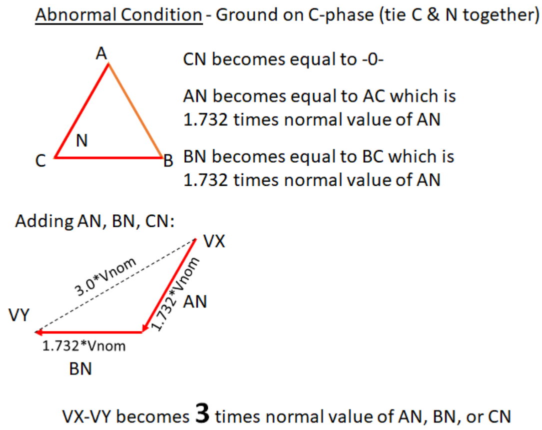

Fig. 7. *Ungrounded Tertiary Bus Ground Detection*

The symmetrical component analysis for a phase-to-ground fault on the tertiary bus is shown in Fig. 8.

The resistor in the broken-delta secondary of the voltage transformer reflects into the primary as the square of the turns ratio. For example, if the VT ratio is 14400/240=60/1, a 3.2 Ω resistor in the broken-delta secondary reflects as 3.2*60*60 = 11.5 kΩ. On 100MVA and 13kV, this is 6800 per-unit. In the zero-sequence network, this resistor is represented as R/3 = 2270pu. For a solid phase-to-ground fault on the tertiary bus, the relay voltage will be 375V secondary.

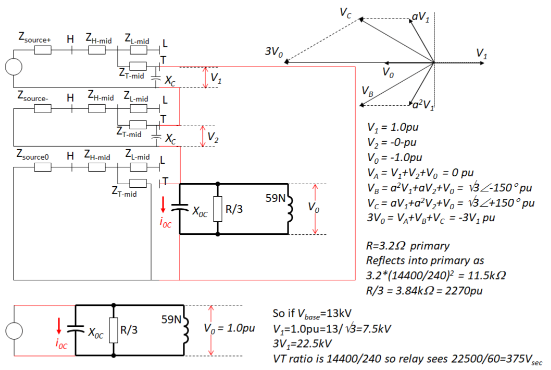

Fig. 8. *Symmetrical component networks for phase-to-ground fault*

This scheme was originally applied only in transmission substations and was configured to only send an alarm to the control center. This is not peculiar to TVA given the direction found in industry guides (discussed later). Around 2015 TVA began implementing tripping after a short time delay. The following section describes why the practice was changed.

TVA uses a 3.2 ohm resistor rated 130A continuous (54kW). The voltage transformers have single-phase ratings of 25kVA.

IV. Experience with Tertiary Bus Ground Detection

TVA has experienced operation of tertiary bus ground detection schemes at four locations over the past dozen years or so, with catastrophic damage at two sites.

A. 9/22/2010 Location 1 - No ground detection scheme, catastrophic damage

A 500/161/13kV transformer bank was energized; 15 minutes later A-phase transformer failed catastrophically due to a phase-phase fault (174kA) and subsequent fire. Root cause was determined to be failed 13kV tertiary bushings. It is suspected at some point after energization the insulation of one tertiary bushing faulted to ground, causing a single-phase-to-ground fault when the bank was energized (Fig. 9). The bank had no tertiary ground fault detection scheme installed, and the fault evolved to double-phase-to-ground when 23 minutes later insulation of a second tertiary bushing also faulted to ground (Fig. 10), producing the double-phase-to-ground tertiary fault. The insulation on one of the tertiary bushings was destroyed (Fig. 11, Fig. 12).

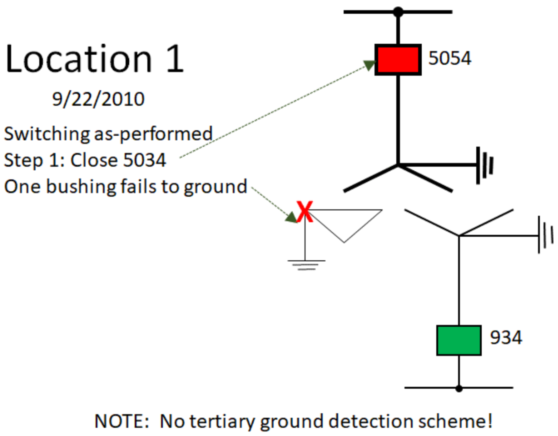

Fig. 9. *9/22/2010, Location 1: Tertiary bushing failure*

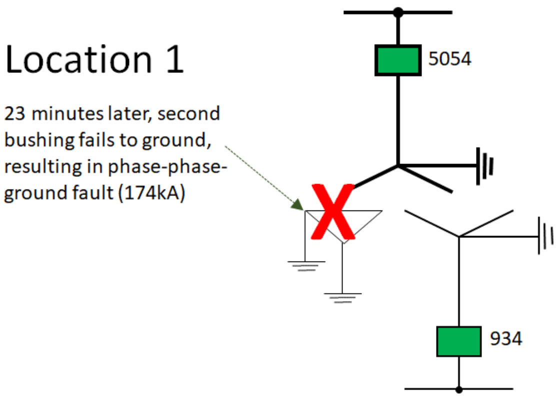

Fig. 10. *9/22/2010, Location 1: Tertiary bushing failure*

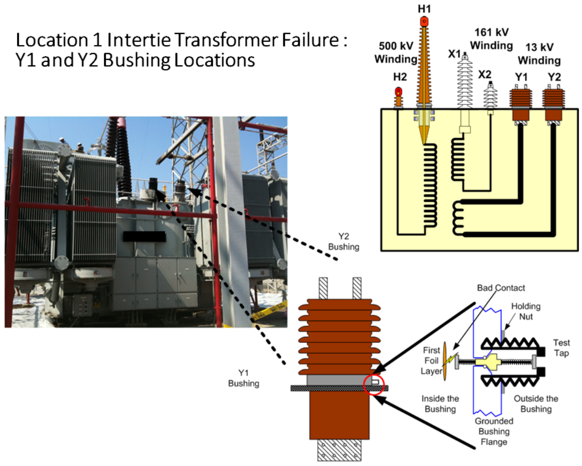

Fig. 11. *9/22/2010, Location 1: Tertiary bushing failure*

Fig. 12. *9/22/2010, Location 1: Tertiary bushing failure*

This was one of seven EHV transformers across six locations with tertiary buses having no ground fault detection scheme. But if there had been a scheme that alarmed only, any personnel sent to the yard to investigate would have been exposed to the 174kA phase-to-phase fault and fire.

The A-phase transformer had to be replaced due to this fault, at a cost of several million dollars.

B. 6/15/2015 Location 2 - One hour trip setting, catastrophic damage 23 seconds after alarm

At a different location, another 500/161/13kV transformer bank was energized; two seconds later tertiary ground alarms asserted and locked in after another second; 23 seconds after energization, a three-phase tertiary bus fault occurred (57kA), resulting in a fireball that destroyed the tertiary bus VTs. Root cause was one of the VTs had faulted to ground causing the initial alarm; the other two faulted 23 seconds later. The sequence and resulting damage are illustrated in Fig. 13 through Fig. 18.

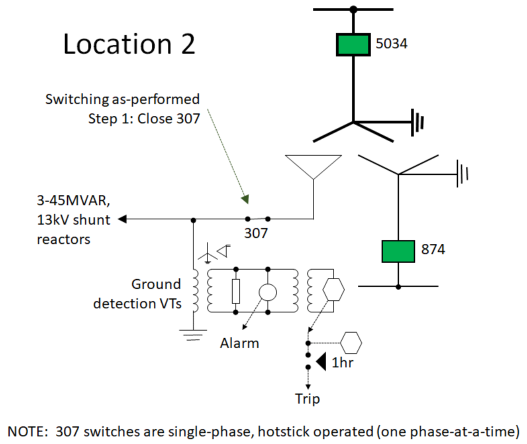

Fig. 13. *6/15/2015, Location 2: Switching as performed, step 1*

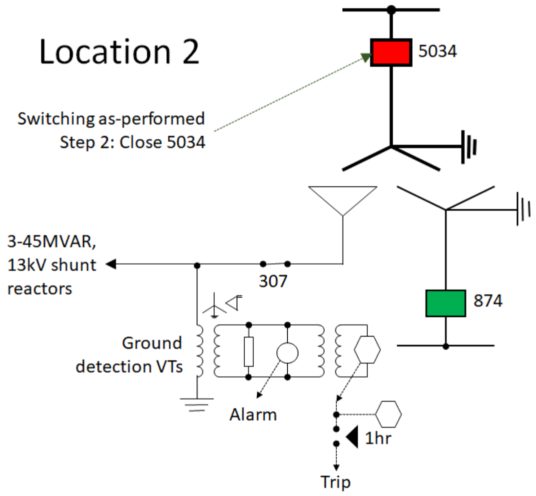

Fig. 14. *6/15/2015, Location 2: Switching as performed, step 2*

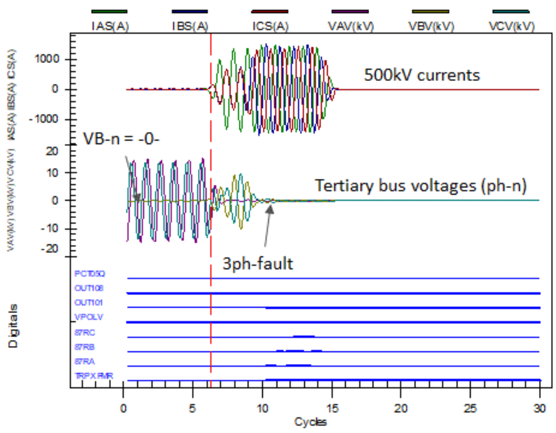

Fig. 15. *6/15/2015, Location 2: Relay event record*

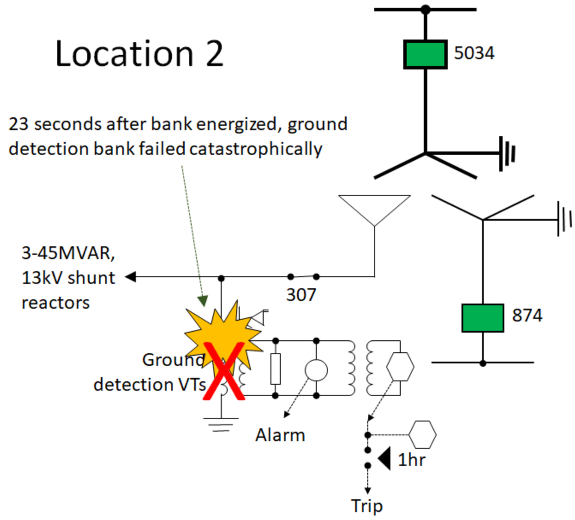

Fig. 16. *6/15/2015, Location 2: 57kA three-phase fault*

Fig. 17. *Location 2 6/15/2015 - Tertiary VT failure*

In this case, the tertiary ground detection scheme alarmed and also started a one hour timer. There was not enough time to send anyone in the yard to investigate, but if there had been, they also could have been in the yard investigating, and been exposed to the 57kA three-phase fault & fireball.

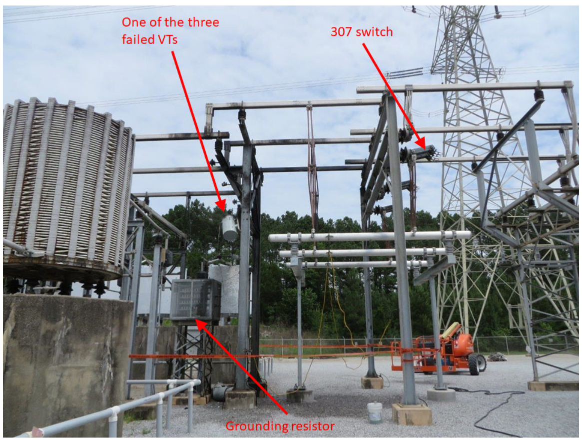

Fig. 18. *Location 2 6/15/2015 - Tertiary VT failure*

Note the VT that failed was the original equipment installed in the 1960s. The most recent test results indicated severely compromised insulation, but the paper records were misplaced immediately after testing and not reviewed until after the failure.

The disturbing thing about this event was that the switching was written initially to energize the 500/161/13kV transformer bank, and then send an operator in the yard to energize the tertiary bus VTs by closing the 307 switches with a hot-stick, one phase at a time. If this had been done, the operator may very well have been engulfed in the fireball that destroyed the VTs. However the switching was rewritten before it was performed to be in accordance with present TVA practice to close the 307 switches before the bank and 13kV yard were energized.

C. 2/28/2018 Location 3 - Intermittent alarms, no trip

At a third location (Fig. 19), another 500/161/13kV transformer bank experienced a ground fault on the 13kV tertiary bus. The fault resulted in chattering ground detector alarms for over two hours, some alarms lasting almost four minutes, but the trip timer was set for one hour. No testing was performed but the trip timer was reduced to 15 cycles after this event.

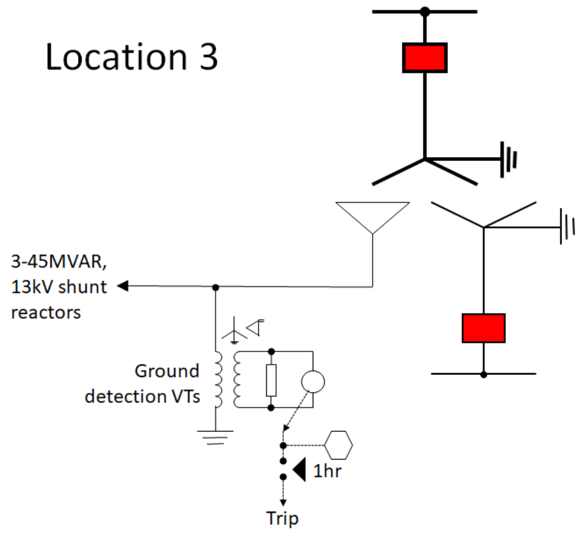

Fig. 19. *2/28/2018 and 8/18/2018, Location 3 (no trouble found)*

D. 8/18/2018 Location 3 - Trip after 15 cycles, no cause found

At that same location, another ground fault occurred on the same tertiary bus of the same transformer bank, this time lasting longer than the 15 cycle trip timer. The bank tripped and was subsequently cleared (Fig. 20). All tertiary equipment was tested, including tertiary bus work, transformer tertiary windings and bushings, station service transformers, and the ground detector transformers themselves. Nothing was found. It is suspected in both cases that the faults were probably caused by debris blowing through the station during severe storms.

It is noted that tripping fast certainly could result in not finding the problem, but that possibility is ALWAYS the case for any protection scheme.

It should also be noted that the pickup of the overvoltage element was set on 100V, which is just over 50% of the voltage for a bolted phase-to-ground fault. This is a highly sensitive setting relative to that for most installations (see VI.A).

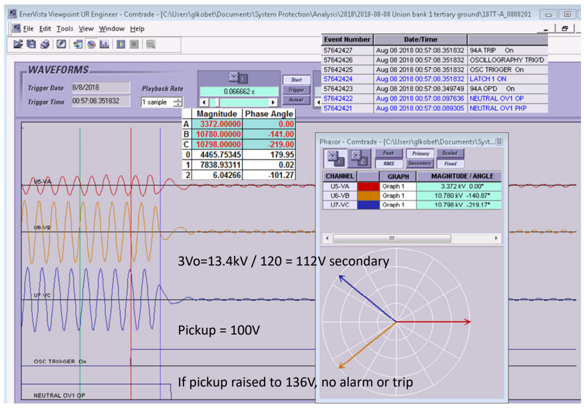

Fig. 20. *2/28/2018 Location 3 - Relay event record*

E. 4/30/2019 Location 4 - Trip after 15 cycles, failed VT

At a fourth location, a 500/161/13kV transformer bank tripped for a ground fault on the 13kV tertiary bus (Fig. 21, Fig. 22). The bank had been energized and loaded for about one month following spring outage work.

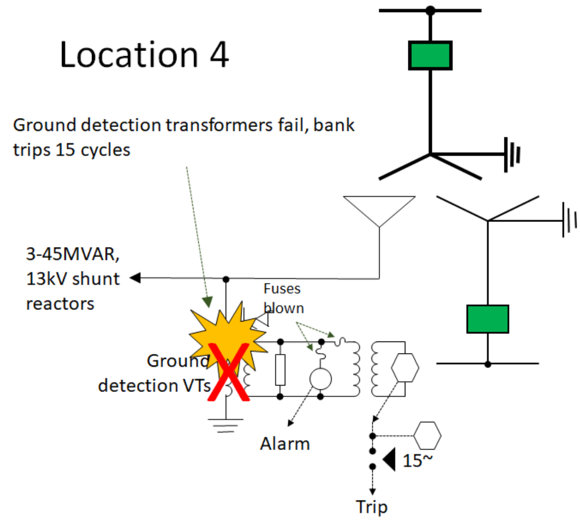

Fig. 21. *4/30/2019 Location 4 - VT failure*

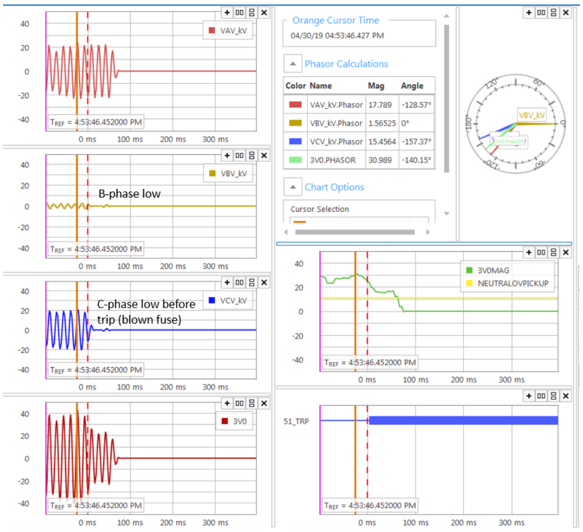

Fig. 22. *4/30/2019 Location 4 - Relay event record*

The field investigated the tertiary bus work & equipment and found the following damage:

- A-phase VT had shorted primary-to-secondary-to-ground;
- B-phase auxiliary VT shorted primary-to-secondary;
- Three fuses had also blown in the ground detector secondary circuit: B- and C-phase fuses on the primary of the 240/120 auxiliary VTs, as well as the fuse ahead of the electromechanical 59N alarm relay (Fig. 23).
- Analog input to the A-set bank protective relay for B-phase tertiary voltage was damaged

The conclusion was the A-phase VT failed primary-to-secondary which damaged secondary equipment. These were the original VTs (installed mid 1960s), shown in Fig. 24.

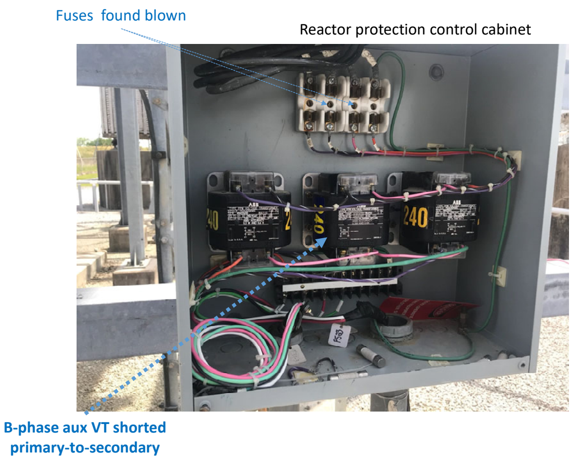

Fig. 23. *4/30/2019 Location 4 - Auxiliary VTs and fuses*

Fig. 24. *4/30/2019 Location 4 - Tertiary bus voltage transformers*

V. Industry Standard Review

A. *Industry Standard for Tertiary Bus Ground Detection*

Locating guidance on ungrounded tertiary bus ground detection in IEEE standards was somewhat difficult. It was not mentioned in the IEEE Std C37.234-2009 *Guide for Protective Relay Applications to Power System Buses*, nor in the IEEE Std C37.91-2008 *Guide for Protecting Power Transformers*. Oddly enough, the material was found buried in the IEEE Std C37.109-2006 *Guide for the Protection of Shunt Reactors* [3]. This seemed strange given that not all ungrounded tertiary buses have shunt reactors connected. In any event, this is what was found in C37.109-2006:

- Subclause 7.3 states *"If there is a strong possibility, due to physical arrangement, for example, of a phase-to-neutral fault evolving to a phase-to-phase fault, this fault should be detected as quickly as possible and the reactor isolated by tripping its associated switching device."*
- Subclause 7.4.2 states *"An accepted practice is to alarm but not trip for this condition."*
- Table 4 in Subclause 9 (Summary of shunt reactor protection) states for Miscellaneous faults, under "Time clearing requirements": *"Alarm: sufficient time required for operators to respond."* But no guidance is provided on what operators might actually do once they respond to a standing alarm for a phase-to-ground fault. And this can be very dangerous, as the previous operating examples have graphically illustrated.

It should be noted that C37.234 is presently undergoing revision, and part of that revision involves adding a subclause on bus protection in ungrounded systems.

VI. Discussion of Settings for Ungrounded Tertiary Bus Ground Detection

The following section discuss the three aspects of a tertiary bus ground detection scheme: Neutral overvoltage pickup, time delay, and control action (alarm/trip).

A. Overvoltage Pickup

The pickup of the neutral overvoltage element should be set above any normal unbalance present, but below the value for a bolted phase-to-ground fault on the tertiary bus. Field measurements across several sites revealed a maximum primary relay voltage of about 150V (2.5V secondary) for 13kV installations, and about 1700V (15V secondary) for 26kV installations.

Recall from III.A that for a bolted phase-to-ground fault the relay voltage will be 375V secondary if the VT ratio is 60/1 (13kV bus) and a 3.2 ohm resistor is used in the broken-delta secondary. If the maximum normal unbalance is 150V primary, the relay pickup should be above 150/60 = 2.5V secondary.

Next the question of required sensitivity to maximum fault should be addressed. This question is may be similar to that when discussing resistive ground fault detection in transmission lines.

Perhaps one way to consider this question is to determine the fault resistance required to reduce the zero sequence voltage to half the value for a bolted phase-to-ground fault. With VT=60:1 and the 3.2 Ω resistor in the broken delta secondary, the fault resistance $3Z_f$ would be equal to the zero sequence impedance of the 3.2 Ω resistor or 2272pu. This results in a fault resistance Z_f of 2272*1.69 / 3 = 1280 Ω primary. So with a pickup of 375 / 2 = 188V, the relay will detect faults with resistance up roughly 1.3 kΩ. The symmetrical component network for this analysis is shown in Fig. 25.

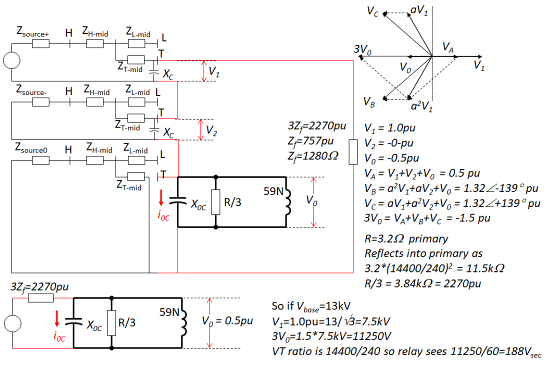

Fig. 25. *Symmetrical component networks for resistive single-phase-to-ground fault*

TABLE I. lists resistive coverage for this application for various pickup settings for the overvoltage relay. Similar calculations can be performed for different VT ratios or resistor values.

TABLE I. ZERO SEQUENCE VOLTAGE MAGNITUDES FOR DIFFERENT FAULT RESISTANCES (VT=60:1, 3.2 Ω RESISTOR)

Fault resistance (Ω primary)	3Vo mag (kV primary)	3Vo mag (volts secondary)
0	22.5	375
500	16.2	270
1000	12.6	211
1500	10.4	173
2000	8.8	146
2500	7.6	127
5000	4.6	76
7500	3.3	55
10000	2.6	43
25000	1.1	18
50000	0.6	9
100000	0.3	5
500000	0.1	1
1000000	0.0	0

The pickup of the overvoltage element has been set as low as 94V secondary (about 4000 Ω resistive coverage) up to 368V secondary (less than 50 Ω resistive coverage).

The draft revision of C37.234 states that a typical setting is 70% of the voltage seen for a bolted phase-to-ground fault. According to the above table, that would provide roughly 500 Ω of resistive coverage (263V pickup).

It is interesting to note that in the case of Location 3 where no damage was found for the 8/18/2018 event, the pickup was set for 100V or 30% of a bolted fault, which provided over 3000 ohms of resistive coverage. It might be concluded this was a nuisance trip, with consideration perhaps given for raising the pickup to provide adequate but not overly sensitive protection.

It should be mentioned that depending on the chosen pickup, the tertiary ground detection scheme may not pickup for a double-line-to-ground condition on the tertiary bus. See the symmetrical component networks in Fig. 26. But as was pointed out in a previous paper [4], any multiphase fault will be detected and cleared by the transformer differential relay, so there is no need for the tertiary ground detection scheme to operate for this fault.

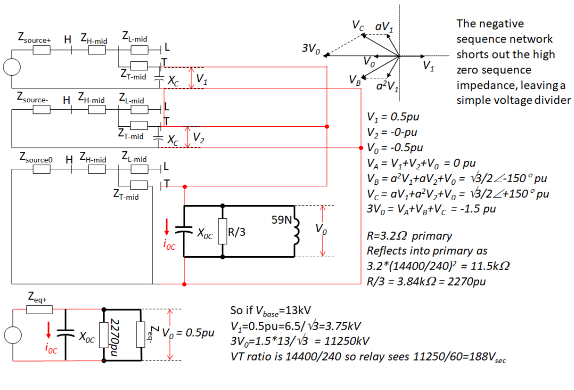

Fig. 26. *Symmetrical component networks for double-phase-to-ground fault*

B. Time Delay

It seems the time delay for alarming or tripping could be instantaneous, since there seems to be no other protection with which to coordinate, and no external fault condition should result in the scheme picking up.

If the control action is to trip, to avoid any unexpected transient condition, perhaps a short delay of 5 or 6 cycles would be appropriate. The time delay should be shorter than the resistor short-time overload capability (should consult manufacturer for this value), if the resistor does not have a continuous power rating adequate for the voltage applied during a bolted phase-to-ground tertiary bus fault (e.g., for the example in III.A, the resistor rating should be at least $375V^2/3.2\Omega = 44kW$).

Of 22 schemes that trip, TVA has used various time delays, but at last report, TVA's practice is to alarm instantaneously and trip after 15 cycles. Note the pickup for the alarm and trip are the same, but the alarm level could possibly be set somewhat lower if a separate neutral overvoltage element was available.

C. Control Action - Alarm or Trip?

TVA has 49 EHV transmission transformers with tertiary buses, three of which still have no ground detection scheme. Of the 45 tertiary buses which do have ground detection, about half still only send an alarm to the control center. But following the events at Location 1 on 9/22/2010 and Location 2 on 6/15/2015, a change was made to initiate tripping after a time delay, and this is being implemented at all locations.

It should be noted that alarm-only should only be considered if all equipment including the resistor has a continuous power rating adequate for a bolted phase-to-ground tertiary fault (see B).

An alarm-only philosophy begs the question of what the control center operator is expected to instruct the field operator to do once a single phase becomes grounded on the tertiary bus. If a second phase became grounded, the resulting arc and fault current would be extremely dangerous, as the operating examples have illustrated.

Also, as discussed in [4], sending alarms to the control center is inadequate if appropriate direction is not given regarding actions to be taken. Protection engineers and managers should consider the following questions: "Given the elevated risk, would I walk in the yard to inspect? If not, why would I expect someone else to do that?"

If the chosen relay action is to alarm only, serious consideration might be given to deenergize the tertiary bus prior to permitting operating personnel in the yard to inspect. For safety reasons, TVA has decided to do just that: On receipt of a tertiary ground fault alarm, the yard is deenergized before operators are allowed to inspect the tertiary bus and equipment.

The following arguments might be raised against tripping on detection of a single-phase-to-ground fault on a normally ungrounded tertiary bus:

1. "*Practically zero fault current flows, and there is thus no risk of damage.*"
2. "*Unfaulted phase voltages may rise to full phase-to-phase voltage, but all equipment should be rated for full phase-to-phase voltage continuously, so there is thus no risk of damage.*"
3. "*System operators should have time to plan the loss of the power transformer bank.*"
4. "*This transformer bank or load is SO important that the bank can't be tripped for a ground fault.*"

The first argument regarding fault current is a good one and is certainly granted, at least from the viewpoint of damage due to current flow.

Regarding the second argument concerning high unfaulted phase voltages, consider two of the events described in this paper. In both cases, and in fact in every case at TVA and probably for many other companies, all the equipment was and is rated for full phase-to-phase voltage, even the components that failed.

However, at locations 1 and 2, the first ground fault led directly to additional ground faults which resulted in multiphase faults. It might be said that more thorough testing or evaluation of test results may have precluded energizing the equipment, but it is not the task of the protection engineer to prevent faults by evaluating test records and prevent energization; rather, it is to ensure that protective schemes take appropriate action <u>when</u> faults occur. And it is impossible to predict when equipment insulation will fail. Applying full phase-to-phase voltage across insulation that normally experiences phase-to-neutral voltage involves a significant increase, and certainly seems to be a problem for aging insulators, bushings, etc. at least in these two cases.

Regarding the third argument mentioning the loss of the bank, it should be understood that the potential impact (if any) of this contingency is already studied by the operators with the real-time state estimator (required by regulatory standards), and is no worse than losing the transformer bank for any other type of unplanned protection system operation.

As for the fourth argument concerning the importance of the transformer, would that mean all bank protection (i.e., differential, sudden pressure, overcurrent) should therefore alarm only? The answer would likely be no; those elements would still be configured to trip the transformer bank in order to limit damage to the bank itself as well as collateral damage to the station, and for the safety of operating personnel. Note again that tripping quickly at locations 1 and 2 for the first ground fault would in all likelihood have prevented damage sustained following the second ground fault.

Now, what if the control action is to trip, but after tripping nothing is found (e.g., Location 3 on 8/18/2018)? The same question could be asked about alarming: What if the control action is alarming only and nothing is found? Someone might argue if the action is to alarm only, leaving the equipment energized might actually raise the probability that the cause of the alarm might be evident by the time the equipment is inspected. This may or may not be true. The catastrophic failures presented in this paper, one which occurred 23 minutes after energization, the other after 23 seconds, would seem to argue against this line of thinking. And TVA has at least one example where tripping quickly (Location 4 on 4/30/2019) revealed significant damage.

VII. Conclusion

The events described in this paper led to an evaluation of protection practice as applied to tertiary bus ground detection at 500kV transmission substations and generating plants.

As a result of the evaluation TVA has now adopted tripping after a short time delay. It is recognized that tripping quickly may result in unexplained operations, but that is also true for alarming only.

At stations that have not yet been converted to tripping, receipt of an alarm in the control center requires operators to deenergize the faulted bus before operating personnel are permitted to enter the yard for inspection.

Additional consideration of required resistive coverage may be needed to avoid nuisance tripping for highly resistive ground faults

It is strongly suggested that other utilities review their operating and protection practices and philosophy for such schemes in order to limit equipment damage and keep personnel safe.

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Biography

Gary Kobet is an Electrical Engineer for the Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. His responsibilities include oversight of TVA's Phasor Measurement system and implementation of applications including oscillation monitoring, voltage unbalance calculation, and linear state estimation. Previously he worked in the Operations Engineering department performing machine and voltage stability studies for the operating horizon, developing operating guides, and disturbance analysis. He has also worked in the System Protection department scoping relaying schemes for transmission and generation projects, as well as developing relay set point calculations and performing transient studies using EMTP for transient recovery voltage, ferroresonance, and switching surge overvoltage. Previously he worked as a field engineer and as power quality specialist. Mr. Kobet earned the B.S.E. (electrical) from the University of Alabama in Huntsville in 1989 and the M.S.E.E. from Mississippi State University in 1996. He is a member of the IEEE/PES Power System Relaying and Control Committee, and is a registered Professional Engineer in the state of Alabama.