Back to Table of Contents

# SELECTIVE DETECTION OF GROUND FAULTS ON UNGROUNDED WYE OR DELTA SYSTEMS AND CLEARANCE OF CROSS COUNTRY FAULTS BY A CYCLIC PRIORITY BETWEEN PHASES

**Prepared by**

**SINAN SAYGIN**

**AREVA T&D , USA**

**Presented before the**

**31sth Annual**
**Western Protective Relay Conference**
**Spokane, Washington**
**October 2004**

# SELECTIVE DETECTION OF GROUND FAULTS ON UNGROUNDED WYE OR DELTA SYSTEMS AND CLEARANCE OF CROSS-COUNTRY FAULTS BY A CYCLIC PRIORITY BETWEEN PHASES

**Sinan SAYGIN**
**AREVA T&D**

## 1. ABSTRACT

Ground faults on delta connected systems and on systems with insulated neutral can selectively be detected by highly sensitive relays employing residual voltage and current quantities.

Applications involving detection of a ground fault condition by a residual voltage element only,does not provide any selectivity ,where the faulted feeder can be identified by a trial –and-error method based on sequentially opening of each feeder one-by-one until the residual voltage disappears.

However, during such fault conditions ground, which normally has no reference to any system quantities, assumes the identity of the faulted-phase voltage and hence capacitive line charging currents start flowing between the healthy phases and ground, sum of which yields a residual current.

It is shown that the residual current for the faulted feeder and the healthy feeders are in opposite directions and are in quadrature with the residual voltage of the system. Hence; it is possible to detect such faults selectively with total fault currents as low as 5ma secondary.

The relay elements can be set as residual directional overcurrent , residual wattmetric or varmetric, cos $\phi$ or sin$\phi$, and, directional ground overadmittance protections ( susceptance / conductance ) depending on the system grounding conditions and utility practices.

Modern digital relays are equipped with all of these protection elements and provide a wide variety of setting options for the users.

On the other hand; the system may be allowed to operate with a ground fault as the system delta voltages remain balanced and the system is insulated to operate indefinitely with sound phase to ground voltages elevated by $\sqrt{3}$ . However ; with such high voltages on the phases during an uncleared ground fault, the insulation of the whole system is overstressed and a second ground fault may result on another feeder in the system, which would probably be cleared by tripping of both feeders with phase overcurrent elements , while, tripping of only one feeder would revert the situation back to a single ground fault case, which would be permitted to remain uncleared for extended periods of time.

This paper discusses detection of cross-country faults by a reverse directional residual element and tripping of only one feeder with a cyclic priority between the involved phases , in this way limiting the service interruption to a minimum.

## 2. INTRODUCTION

The advantages of operating a power system insulated from ground is the fact that during a single phase to ground fault condition, no ground fault current is allowed to flow. Consequently, it is possible to maintain power flow on the system even when a ground fault condition is present.

However, this advantage is offset by the fact that the resultant steady state and transient overvoltages on the sound phases can be very high.

Therefore, insulated systems are mainly used in low / medium voltage networks where it does not prove too costly to provide the necessary insulation against such overvoltages. Systems with higher voltages would normally be solidly grounded or grounded via a low impedance. Grounding limits the transient overvoltages during arcing faults and also facilitates the detection and clearance of ground faults.

Ungrounded systems have no intentional direct grounding but are grounded by the natural capacitance of the system as shown in Figure 1.

Impedance grounding has the advantage of limiting damage incurred by plant during ground fault conditions and also limits the risk of explosive failure of switchgear, which is a danger to personnel.

In addition, it limits touch and step potentials at a substation or in the vicinity of a ground fault.

An insulated system is shown in Figure 1 under normal operating conditions, the vector diagram displaying the balanced phase to ground voltages is shown in Figure 2.

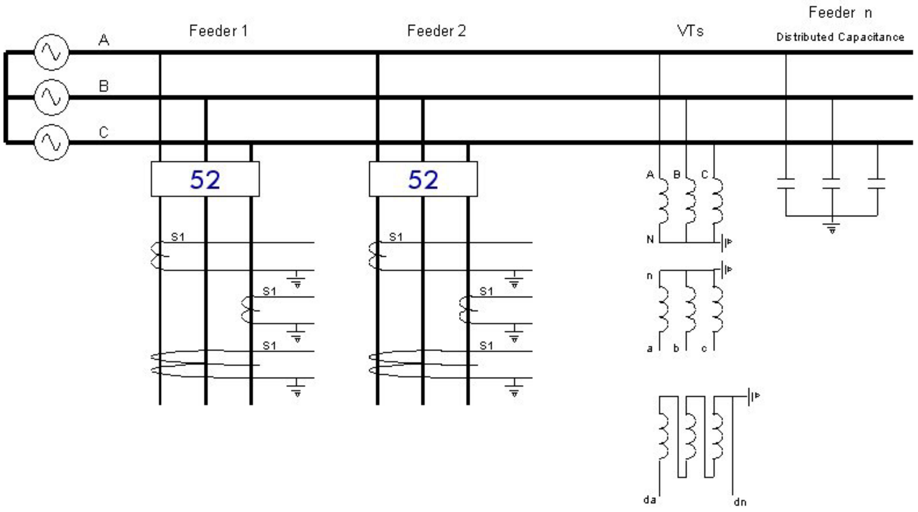


**Figure 1** Ungrounded system under healthy operation.

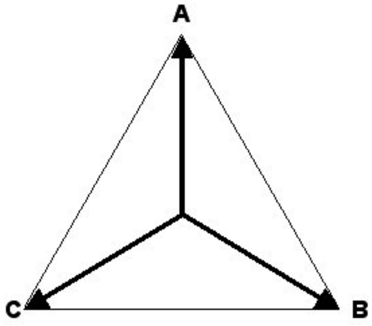


**Figure 2** Phase to ground voltages under healthy operation.

## 3. PHASE TO GROUND FAULTS ON UNGROUNDED SYSTEMS

The isolated system shown is displayed in Figure 3 with an A-phase to ground fault. A three feeder network is shown in Figure 4, with details of current distribution in the faulted and healthy feeders and phases.

It is assumed that feeder ground elements are fed from core balance type residual current transformers. This eliminates the possibility of spill current that may arise from slight mismatches between residually connected line CTs. It also enables a much lower CT ratio to be applied, thereby allowing the required protection sensitivity to be more easily achieved.

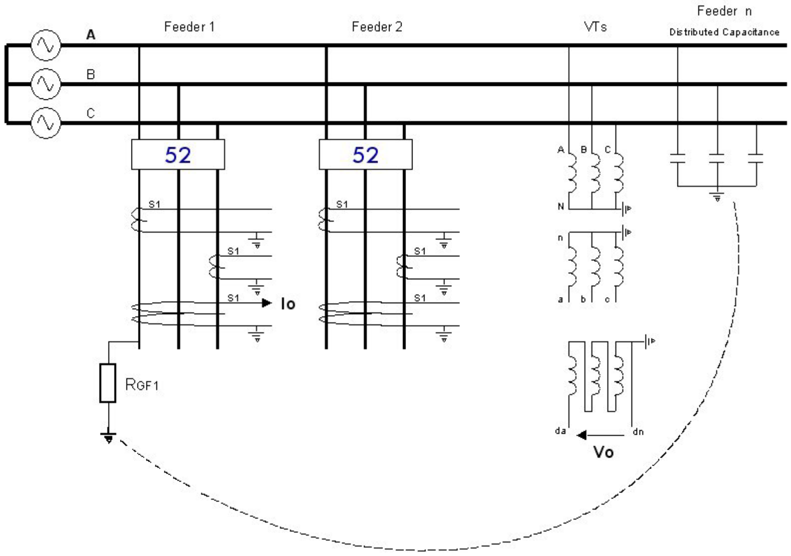


**Figure 3** Ungrounded system with A-phase to ground fault.

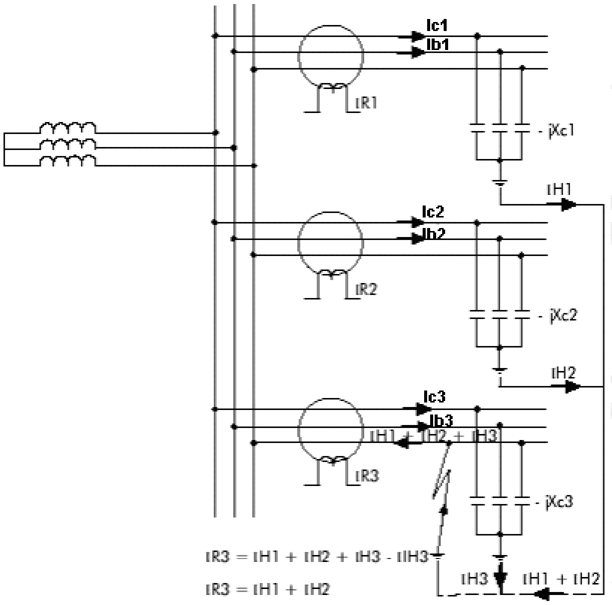


**Figure 4** Current distribution during an A-phase to ground fault on Feeder 3.

Assuming fault resistance RGF1 and line and source impedances are negligible, during an A phase to ground fault, ground potential, floating before the fault , rises to VA:

VG = VAN ( balanced A-phase voltage value before the fault )

Hence , the currents with this new identity of ground can be calculated from Figure 4 as:

$I_{b1} = V_{BA} / -jX_{C1}$ , $I_{b2} = V_{BA} / -jX_{C2}$ , $I_{b3} = V_{BA} / -jX_{C3}$

$I_{c1} = V_{CA} / -jX_{C1}$ , $I_{c2} = V_{CA} / -jX_{C2}$ , $I_{c3} = V_{CA} / -jX_{C3}$

.

Noting that feeder ground current IH:

$IH = I_b + I_c$

$IH1 = ( V_{BA} + V_{CA} ) / -jX_{C1} = [ (a^2 - 1 ) + ( a-1 ) ]V_A / -jX_{C1}$

Or;

$IH1 = 3V_A / jX_{C1}$

Similarly ;

$IH2 = 3V_A / jX_{C2}$

$IH3 =3V_A / jX_{C3}$

Are obtained.

Residual voltage can be calculated as:

$3V_0 = V_{AG} + V_{BG} + V_{CG}$

with $V_G = V_A$ ;

$3V_0 = 0 + (a^2 - 1 ) V_A + ( a – 1 ) V_A$

or;

$$3V_0 = - 3 V_A \tag{1}$$

Thus; the residual voltage is equal to –3 x the pre-fault voltage of A-phase to neutral.
The overall residual currents in the feeders can be calculated as :

$$IR1 = IH1 = - 3V_0 / jX_C \quad , \quad IR2 = IH2 = -3V_0 / Jxc \tag{2}$$

$$IR3 = - ( IH1 + IH2 ) = 3V_0 ( 1/jX_{C1} + 1/ jX_{C2} ) = - ( IR1 + IR2 ) \tag{3}$$

From Figure 4, it can be seen that the relays on the healthy feeders see the unbalance in the charging currents for their own feeder. The relay on the faulted feeder, however, sees the charging current from the rest of the system (IH1 and IH2 in this case), with it's own feeders charging current (IH3) becoming cancelled out.
The corresponding vector diagram is shown in Figure 5.

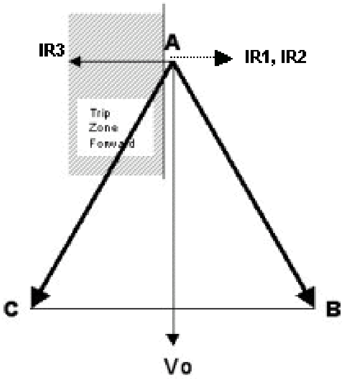


**Figure 5** Vector diagram for A phase to ground fault.

The relation between the residual current and voltage will be exactly the same for ground faults on B and C phases, however, in these cases the residual voltage will be identified by VB and VC , respectively. Calculations and the vector diagrams indicate that the residual currents on the healthy feeders, IR1, IR2 and, the faulted feeder IR3 , are in anti-phase. A directional element can therefore be used to provide discriminative ground fault protection.
The polarizing voltage of this element, chosen as 3Vo, leads the residual current seen by the relay on the faulted feeder by $90^0$ while the relays on healthy feeders will see the same fault in the reverse direction, as shown in Figure 5.

## 4. SELECTIVE PROTECTION AGAINST PHASE TO GROUND FAULTS ON UNGROUNDED SYSTEMS

Following are some types of protection elements that may be applied for ground fault detection:

1. A suitably sensitive directional ground overcurrent relay having a relay characteristic angle setting of ninety degrees,
2. A sensitive directional zero sequence power relay having similar requirements to 1 above with respect to the required directional settings,
3. A sensitive directional ground fault relay having cosϕ /sin ϕ characteristics,
4. a ground overadmittance protection, overconductance/ oversusceptance.

Some utilities prefer to use cosϕ / sinϕ for Peterson Coil grounded or insulated networks.
Overadmittance protection is based on directional ( forward and reverse ) overconductance / oversusceptance settings for Peterson coil grounded or insulated systems ,respectively.
Some methods of providing directional selectivity based on residual quantities include communication between the relays in the substation, especially, applicable to Peterson coil grounded systems where ground fault current is reduced to practically zero by tuning a variable grounding reactor to system capacitances.
Some relays are equipped with all of these protections and provide a wide selection of applications .
As the philosophy of operation of these elements are all based on the residual voltage vector at the busbar and the individual relay residual current vectors, following studies could be limited to calculation of these vectors and determination of directional settings to enable correct selectivity under different fault conditions. However, for the sake of convenience and ease of understanding directional ground relays were selected for the purpose of the foregoing analysis.

### 4. 1 Directional ground overcurrent relay:

As shown, the residual current detected by the relay on the faulted feeder is equal to the sum of the charging currents flowing from the rest of the system. Furthermore, the addition of the two healthy phase charging currents on each feeder gives a total charging current which has a magnitude of three times the per phase value. Therefore, the total unbalance current detected by the relay is equal to three times the per phase charging current of the rest of the system.

A typical relay setting may therefore be in the order of 30% of this value, i.e. equal to the per phase charging current of the remaining system. Practically though, the required setting may well be determined on site, where suitable settings can be adopted based upon practically obtained results.
For the healthy feeders it may be interesting to verify the operation of the protection system by setting a reverse element to appropriate values.
The unbalance current detected by a core balance current transformer on the healthy feeders results in a residual current which leads the polarizing voltage (3Vo) by 90°. The magnitude of the unbalance current is equal to the three times the per phase charging current of the feeder in question and the relay should be set accordingly.
Residual voltage and current waveforms from an actual field test are shown if Figure 6. The figure displays the operation of directional ground relays for both faulted and healthy feeders for a fault current of only 8.7 A primary.

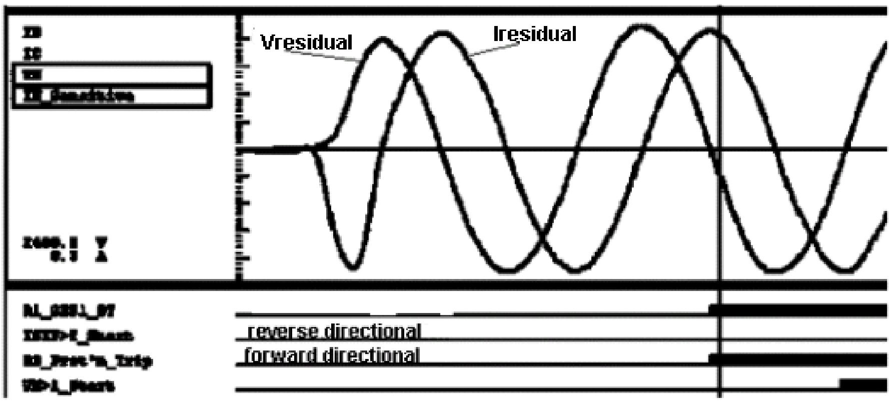


Figure 6 A   Faulted feeder, operation of forward set relay.

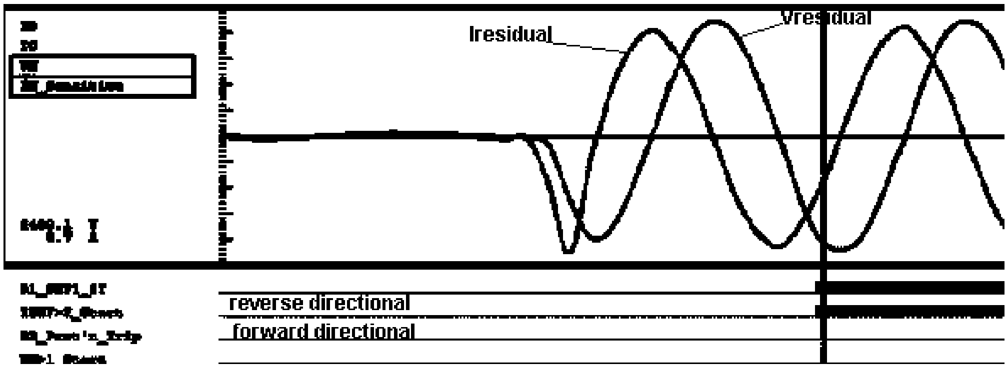


Figure 6 B   Healthy feeder, operation of reverse set relay.

**Figure 6** Current and voltage waveforms for faulted and healthy feeders (actual test ).

### 4.2 Wattmetric/Varmetric Characteristic

Zero sequence power measurement offers improved relay security against false operation with any spurious core balance CT output for non-ground fault conditions.

Relays based on reactive ( insulated systems ) or active ( Peterson coil grounded systems ) component of the residual power are designed to measure;

QN > or PN > from;

$QN = V_{res}.I_{res}. \sin ( \phi - \phi c ) = 9.V0. I0. \sin ( \phi - \phi c )$

$PN = V_{res}.I_{res}. \cos ( \phi - \phi c ) = 9.V0. I0. \cos ( \phi - \phi c)$

where;

$\phi$= Angle between the residual voltage and the Residual Current,

$\phi c$ = Relay Characteristic Angle Setting,

Vres = Residual Voltage

Ires = Residual Current

V0 = Zero Sequence Voltage

I0 = Zero Sequence Current

### 4.3 Sin $\phi$ / Cos$\phi$ Characteristic :

In some applications, utilities prefer to use the reactive/ active component of the residual current in stead of the residual power. For insulated ground applications, it is common to use the Sin$\phi$ characteristic. The settings and operating criteria are similar in all cases.

### 4.4 Overadmittance protection :

Ground admittance is measured as the vector ratio of residual current to the residual voltage. A convenient directional element based on the reactive ( susceptance ) or the resistive ( conductance ) component of the admittance provides a highly sensitive ground fault protection for isolated and Peterson coil grounded systems, respectively.

## 5. FAULT IMPEDANCE

Ground faults involve considerable amounts of fault impedances. In distributions systems many faults are due to tree contacts, conductors falling onto ground , which can have high impedances. Fault impedances are generally assumed to be purely resistive.

Fault impedance also includes the power arc, which can be approximated by the following expression (Warrington 1962) ;

$$R = 8750 . L / ( 0.305 .I^{1.4} ) \qquad (4)$$

Where;

R is the arc resistance in ohms, L length of arc in meters and I is the fault current in Ampers

Tower footing resistance is another component of the fault impedance.

The fault impedance can be introduced into the analysis by using the equivalent network at the point of fault as shown in Figure 7. The residual currents for feeder relays and the residual voltage are shown on the figure 7.

Where , E is the pre-fault voltage at the fault location ( i.e for A phase fault , VAN , phase to neutral voltage under balanced conditions ). The fault current magnitude and the residual voltage are calculated as follows:

$$IF =3.IF0 = 3\, VA\, \omega. C / \sqrt{1 + ( 3.\omega.C.RF )^2} \qquad (5)$$

where;

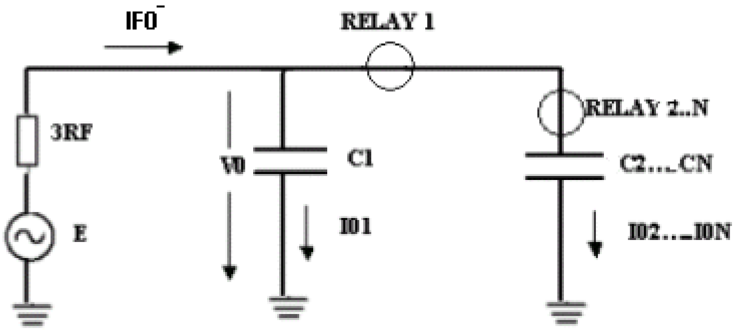
IF0 is zero sequence component of the fault current,

C; total capacitance of the system ( C= total capacitance C1+C2+…CN ), $XC = 1 / j.\omega. C$

$$3V0 = 3.IF0. XC = 3VA / \sqrt{1 + ( 3.\omega.C.RF )^2}$$

or ;

$$V0 / VA = 1 / \sqrt{1 + ( 3.\omega.C.RF )^2} \qquad (6)$$



.

**Figure 7** Equivalent network at the fault point.

Comparing with the previous case with RF= 0 , we can make the following observations;
- as the fault resistance increases the fault current reduces,
- residual voltage also decreases at the same rate as the residual current,
- the 90 $^0$ angular difference between the residual voltage and the relay residual currents is unaffected ( i.e. voltage lagging for the faulted and leading for the healthy feeders residual currents).

For example; for a 4.8kV system with a ground fault current of 1A and a residual voltage setting of only 5% the fault resistance is calculated as RF = 2768 ohms and total capacitance as 6.4 μF. Fault arc will generally self extinct in a very short time if the fault current is less than 5A.

## 6. EXTINCTION OF GROUND FAULT ARC

Majority of ground faults result in fault arcs. The fault is interrupted by a breaker operation or is cleared by self extinction of the arc at the zero crossing of the current waveform. The factors influencing the arc extinction are fault current amplitude, recovery voltage, period of the arc, length of the arc and wind velocity.

In most distribution lines fault arc is expected to self extinct if the fault current is less than 5A. About 70% of the faults on distribution lines are ground faults and approximately 80% of them are cleared by autoreclosing of the feeder breaker.

## 7. CROSS COUNTRY FAULTS

As stated before it is possible to run an insulated power system during a single phase to ground fault condition as no ground fault current is allowed to flow and the balance of the voltage triangle is not affected. Consequently, it is possible to maintain power flow on the system during a ground fault condition.

The power arc may self extinct or cleared by reclosing , or the feeder may manually be opened for a persistent fault after transferring the load on the faulted feeder to others. However, under ground faults, the resultant steady state and transient overvoltages on the sound phases can be very high. The healthy phase steady state voltages rise by √ 3, and, a new fault may develop on one of the sound phases of the faulted feeder or one of the adjacent feeders due to overstresses on the insulation.

### 7.1 Cross country faults on the same feeder

If the second fault occurs on the same feeder as shown in Figure 8 , the fault current flowing out from one of the phases ( C–phase ) will return from the second involved phase ( B-phase ) via the ground loop. In this figure fault resistances, system capacitances and circuit impedances are neglected. The residual current will be zero as the currents flowing in and out at the core balance CT will cancel out. The relay would trip the feeder with a phase-to-phase fault.

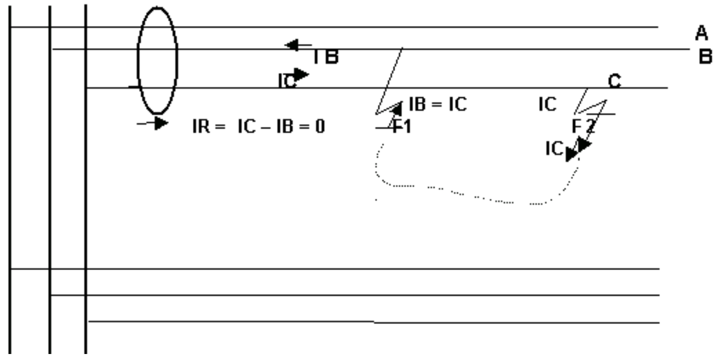


**Figure 8** Cross country faults on the same feeder.

### 7.2 Cross country faults on two different feeders

However , when cross country faults involve two different feeders the current distribution will be quite different (Figure 9). In this case the fault loop current will be returning from the adjacent feeder resulting in the measurement of pseudo residual currents of same magnitude but of opposite signs at both feeders` relay locations,as shown in the figure.

In both cases a residual voltage of about 1.5 VA ( e.g. phase-to-phase to ground fault condition ) would be measured at the busbar ,and, this voltage can be used to polarize the directional ground relays.

With such cross country faults both of the feeders would be tripped by phase overcurrent relays ( feeder 1 with C phase and feeder 2 with B phase ) and service would be interrupted to the distribution area served by both of the feeders.

However; if only one of the involved feeders could be tripped, the system would revert back to the single ground fault condition which does not require any immediate action for extended periods of time. Next chapter studies a method of directional prioritizing of the tripping for such faults.

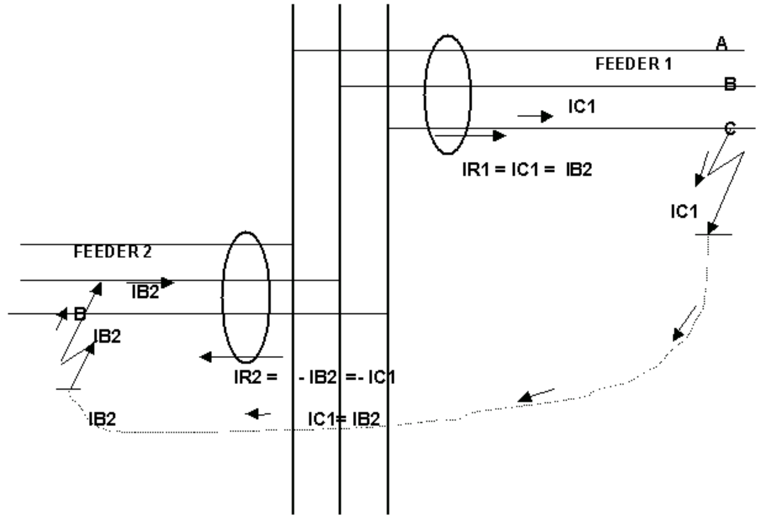


**Figure 9** Cross country faults on adjacent feeders.

### 7.3 Calculation of residual voltage and currents during cross country faults

Considering the system shown in Figure 10 with an A phase fault on feeder 1 and a B phase fault on feeder 2.

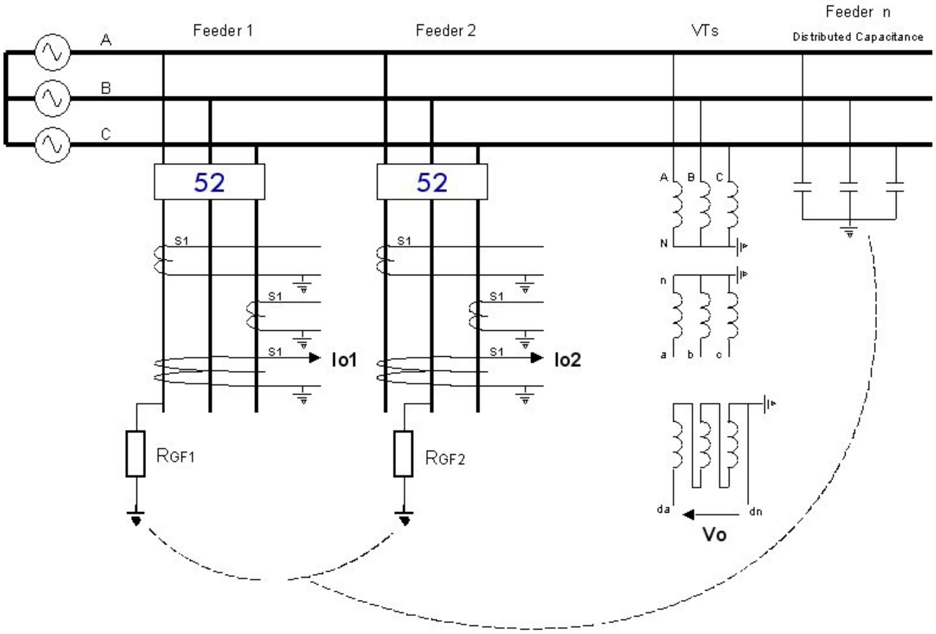


**Figure 10** Analysis of Cross country faults

Defining:
VAG, VBG, VCG = phase to ground voltages during fault conditions,
VAB, VBC, VCA = phase to phase reference voltages, assumed not to be affected by fault conditions,
VAN, VBN, VCN = balanced phase to neutral reference voltages,
RGF1 , RGF2 = respective fault resistances to ground for faults on Feeders 1 and 2.

From figure:

$$VAG = VAB\,[\,RGF1 / (RGF1 + RGF2)\,] = k.\,VAB = k.\,(1-a^2).VAN$$

Where;

$$k = RGF1 / (RGF1 + RGF2) \qquad (7)$$

$$VBG = VAB\,[\,-RGF2 / (RGF1 + RGF2)\,] = (k-1).VAB = (k-1).\,(1-a^2).VAN$$

$$VCG = VCB + VBG = VCA + VCG$$

$$VCG = (a-a^2)\,VAN + (k-1).VAB = [(a-a^2) + (k-1)(1-a^2)\,].VAN$$

$$VCG = [\,a - 1 + k(1-a^2)\,]\,VAN$$

Residual voltage is calculated as;

$3.V0 = VAG + VBG + VCG$

$3.V0 = 3 [ k ( 1- a^2) – 1 ] VAN$
or;

$3.V0 = 3 [k. \sqrt{3}\angle 30^0 - 1 ] VAN$ (8)

Feeder currents :

$IA1 = - IB2 = VAB / (RGF1 + RGF2 )$

$IA1 = ( 1- a^2) VAN / (RGF1 + RGF2 )$

Neglecting capacitive charging currents and any unbalance in the load currents :

$IB1 = IC1=IA2 =IC2 = 0$

Residual currents are calculated as;

$3.I01 = - 3.I0\ 2 = 1A1 = - IB2 = ( 1- a^2) VAN / (RGF1 + RGF2 )$

$3.I01 = - 3.I02 = \sqrt{3} \angle 30^0 . VAN / ( RGF1 + RGF2 )$ (9)

Assuming for example :

$RGF1 = RGF2$ or $k = 0.5$

residual quantities are calculated as:

$3.V0 = 1.5\angle 120\ ^0.VAN$

$3.I01 = \sqrt{3} \angle 30^0 . VAN / ( RGF1 + RGF2 )$

noting :

$VAN = (VAB / \sqrt{3})\angle 90\ ^0$

the Vector diagram in Figure 11 is obtained for the residual quantities.

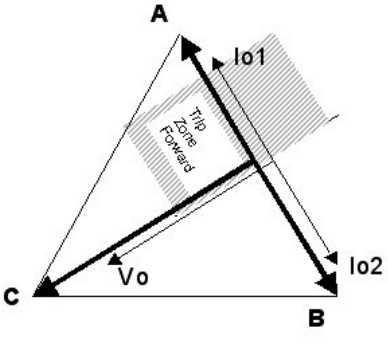


**Figure 11** Vector diagram for residual quantities during cross country faults.

The pseudo residual current measured by the relay on feeder 2 ( I02 ) leads the residual voltage by $90^0$, while the one on feeder 1 lags it by $90^0$ degrees. Thus, one of the directional ground elements of the feeder relays may be set to reverse direction , as a forward ground element has already been used for detection of single ground fault conditions.

In fact, a reverse ground directional element has also already been used for indication of adjacent feeder ground faults as a double check for selectivity of the fault direction ( Section 4.1 ). It is also reminded here that this reverse element is subjected to the charging current of the own feeder during an adjacent ground fault. Therefore, the value of cross country element setting should exceed this setting value.

In this case during a cross country fault only one of the relays will operate ( feeder 2 relay ) to trip the respective feeder and the cross country fault will revert back to phase to ground ( phase A on feeder 1) which does not have to be tripped.

### 7.4 Loci of residual currents and voltage during cross country faults

Repeating from Section 7.3;

$$3.V0 = 3\,[k.\sqrt{3}\ \angle 30^0\ - 1\,]\ VAN \qquad (8)$$

$$3.I01 = -\,3.I02 = \sqrt{3}\ \angle 30^0 \cdot VAN\ /\ (\,RGF1 + RGF2\,) \qquad (9)$$

where ;

$$k = RGF1\ /\ (\,RGF1 + RGF2\,) \qquad (7)$$

It is seen that the phase angle of the residual current is fixed at $+30^0$ with respect to reference VA, however the phase angle of the residual voltage depends on k , which can have any value between 0 and 1. Thus, we have to consider the effects of variation of k on the residual voltage.

The residual quantities are plotted as shown in Figure 12 with 3.VAN taken as reference.

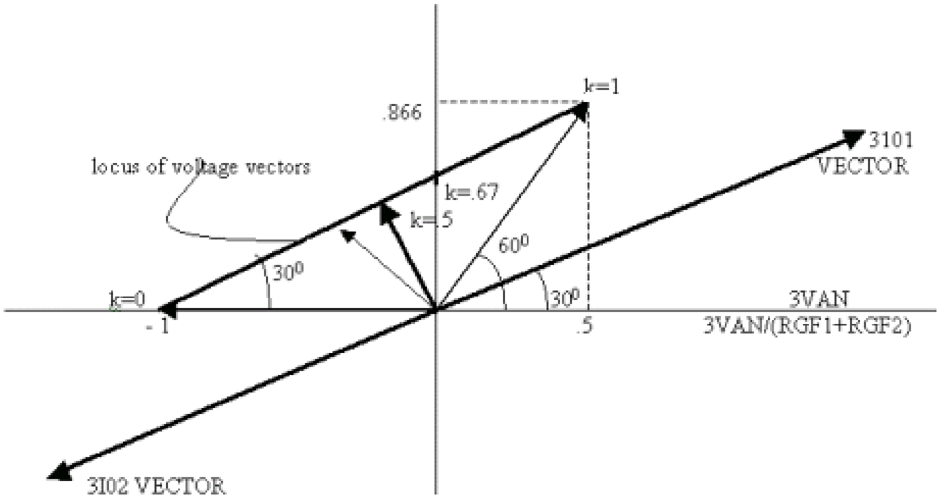


**Figure 12** Locus of residual voltage and currents during cross country faults.

From Figure 12 it can be seen that, 3I01 vector lags the residual voltage vector by $30^0$ to $150^0$ degrees and 3I02 leads residual voltage vector by $30^0$ to $150^0$ , as k varies between 0 and 1.
Therefore; the reverse directional angle setting of $90^0$ would provide sufficient selectivity for operation of feeder 2 relay only; while feeder 1 would be kept operating with a single phase to ground fault until it is cleared by other measures.

Considering now a B-phase fault on Feeder 1 and a C-phase on Feeder 2 ;

In this case:
$VBG = k.VBC= k. (a^2- a).VAN$

$VCG = ( k-1)( a^2 - a) .VAN$
And;
$VAG = VAB + VBG = [ 1- a^2 + k(a^2 - a ) ] VAN$

Residual voltage is ;

$3.V0 = VAG + VBG + VCG$

or;

$3.V0 = 3 [k. \sqrt{3}\angle -90^0 - a^2 ] VAN$
or;

$$3.V0 = 3 [k. \sqrt{3}\angle 30^0 - 1 ] VBN \qquad (10)$$

The currents are calculated as :

$3.I01 = - 3.I0 2 = IB1 = - IC2 = ( a^2- a). VAN / (RGF1 + RGF2 )$

$3.I01 = - 3.I02 = \sqrt{3}\angle -90^0. VAN / ( RGF1 + RGF2 )$
or;

$$3.I01 = - 3.I02 = \sqrt{3} \angle 30^0. VBN / ( RGF1 + RGF2 ) \qquad (11)$$

Finally ; for a C-phase fault on Feeder 1 and an A-phase on Feeder 2 ;

$VCG = k.VBC= k. (a - 1).VAN$

$VAG = ( k-1)( a - 1) .VAN$
And;
$VBG = VBC + VCG = [ a^2 – a + k(a – 1) ] VAN$

Residual voltage is ;

$3.V0 = VAG + VBG + VCG$

$3.V0 = 3 [k. \sqrt{3} \angle 150^0 - a ] VAN$
or;

$$3.V0 = 3 [k. \sqrt{3} \angle 30^0 - 1 ] VCN \qquad (12)$$

The currents are calculated as :

$3.I01 = - 3.I0\,2 = IB1 = - IC2 = ( a^2 - a). VAN / (RGF1 + RGF2 )$

$3.I01 = - 3.I02 = \sqrt{3} \angle 150^0 .VAN / ( RGF1 + RGF2 )$

or;

$$3.I01 = - 3.I02 = \sqrt{3} \angle 30^0 . VCN / ( RGF1 + RGF2 ) \qquad (13)$$

The above sets of equations for the residual voltage and currents during all types of cross country faults, ( Equations 8 and 9 for A-B , Equations 10 and 11 for B-C and Equations 12 and 13 for C-A) define the very same relation between the residual current and voltage but with reference to voltages VA , VB and VC, respectively. The vector locus drawings in Figure 12 are valid for all types of faults but only to a different voltage reference.

Therefore; a ground element supplied by the residual current of I02 and set at reverse direction will trip;

- the feeder with B phase fault for A and B phase cross county faults,
- the feeder with C phase fault for B and C phase cross country faults,
- the feeder with A phase fault for A and C phase cross country faults.

Thus; we may conclude that the relays will trip with a cyclic priority of B before A phase – C before B phase – A before C phase and clear the fault on the feeder with the fault of prioritized phase while the other feeder will remain in service with a single ground fault.

It is noted here that the forward ground relay element on the non-priority feeder, set for selective detection of single ground faults as per Section 4.1 will also operate ( with current I01) but will not cause any tripping if it is used for indication purposes only, otherwise it should be delayed to allow operation of the reverse looking relay.

## 8. CONCLUSIONS

The paper includes a short description of the operating conditions of the ungrounded star or delta distribution systems, various advantages including the uninterrupted operation during a ground fault on one of the feeders.

It is shown that during a ground fault , the faulted feeder can selectively be detected by different methods employing the residual voltage and current quantities , these include;

- sensitive directional ground overcurrent elements,
- directional residual watt / var protection elements,
- sinϕ / cos ϕ protection elements,
- directional overadmittance elements.

As all these protection elements are based on the residual voltage and current vectors, these vectors were calculated for different fault cases.

The single ground fault analysis has shown that;

- a residual voltage of 3V0 = - 3.Vphase can be used to polarize the relays,
- the residual current detected by the relay on the faulted feeder is equal to the sum of the charging currents flowing from the rest of the system ,and, lags the polarizing voltage by $90^0$,
- on the healthy feeders the residual current is equal to three times the per phase charging current of the feeder in question and leads the polarizing voltage by $90^0$,
- therefore, a forward looking element set at per phase charging current of the rest of the system will selectively detect a feeder fault,
- simultaneously, a reverse looking element set at per phase charging current of the feeder in question, can be for used indication and verification purposes,
- the forward directional element may trip and reclose the feeder or just give a selective indication of the faulted feeder,
- it is clear that if there is only one energized feeder in the substation the forward element will not be able to measure any residual current ( no adjacent feeders to supply any current ), therefore fault indication has to be given by the residual voltage criteria only , nevertheless, there will not be any problem of defining the faulted feeder as there is only one at the substation.

Therefore, it is necessary to provide a delayed residual voltage element as well, the feeder may or may not be tripped and reclosed.

The operation of the system under ground fault conditions results in steady state and transient overvoltages on sound phases of all feeders connected to the system and this, may cause development of cross country faults.

If the second fault is on the same feeder the ground relay will not measure any residual current and the fault would be cleared as a multiphase fault by operation of phase overcurrent elements.

However, if the cross country faults occur on two different feeders , both feeders would be tripped out with phase overcurrent elements.

The paper describes an application where feeder directional ground elements are used for tripping of only one of the involved feeders by a cyclic priority between the phases. It is shown that during cross country faults a residual voltage of sufficient magnitude is available to polarize feeder ground overcurrent elements that are fed by pseudo residual currents of same magnitude but of opposite direction.

A reverse directional ground element is used as it is easier to coordinate with the single fault case where the reverse element is subject to only the charging current of the feeder in question. The element ,time coordinated with the phase overcurrent elements, will instantaneously trip the feeder with priority , and, the system will revert back to a single fault condition.

It is shown that with the recommended settings the cyclic priority would trip out the feeders depending on the identity of the phases in fault , with a priority of B before A phase – C before B phase – A before C phase.

The second involved feeder will remain closed giving an alarm by the forward ground fault element (i.e the element used for detection of single ground faults ).

## BIBLIOGRAPHY

1. Warrington, A. R. Van C. , *Protective Relays their Theory and Practice,* John Wiley & Sons Inc. ,1962.
2. Blackburn, J.L. , *Symmetrical Components for Power Systems Engineering*. : Marcel Dekker, Inc. 1993.
3. Hanninen S., *Single phase earth faults in high impedance grounded networks Characteristics, indication and location ,* VTT Publications 453, Espoo, Finland, 2001.
4. AREVA T&D , *MICOM P144 Feeder Protection Relay, Technical Guide*, 2002

## BIOGRAPHICAL SCETCH

Sinan Saygin was born in Turkey, he received his B.S and M.S degrees in Electrical Engineering at Middle East Technical University , Ankara in 1968 and 1969. During 1971-1972 he has carried out post-graduate studies on distance protection in Helsinki Technical University , Finland .

In 1968 he joined TEK ( Turkish Electricity Authority) as Protection and Measurement Specialist.

He has worked in SCECO West, Saudi Arabia, as Substations Project Manager during 1980- 1982.

In 1982 he joined AREVA T&D as a technical consultant, and has worked in different positions since then. His works included series compensated line protection applications and design, distance relay numerical algorithms, marketing and applications of distance relays in the global scale , customer training and Area Sales Management.

He has moved to USA in 2000 and is working as Western Region Application Engineer. He is a member of the IEEE.

Back to Table of Contents