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False Tripping of Feeders in Distribution Networks: (Sympathetic Tripping)

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***Abstract*— The stability of power system networks is very important in the provision of electrical services. The aim of this paper is to determine the reasons behind the tripping of healthy feeders in electrical distribution network, due to a fault in other feeders. This phenomenon is called sympathetic tripping, which can frequently be observed in distribution network. The aim of this paper is to observe how the transformer vector groups can contribute to this problem. The focus in this paper will be on Star-Star vector group. ASPEN ONLINER is used to study and simulate short circuit analysis. The result showed that any fault on some feeders will lead to earth fault tripping of each feeder having a star-star transformer. This solution lead to good stability of each feeder has star -star transformer when actually applied. Real disturbance record and events of faulty and healthy feeder for sympathetic tripping are used. Calculation zero sequence current based on the network with existing protection has been used to solve sympathetic tripping of healthy feeder. Delayed in voltage recovery following fault Events has increased due to stall Motor of Air conditioning which lead to sympathetic tripping of the generator or transformer due high current.**

Keywords*— *Sympathetic, earth fault, voltage recovery. inrush current, zero-sequence test,

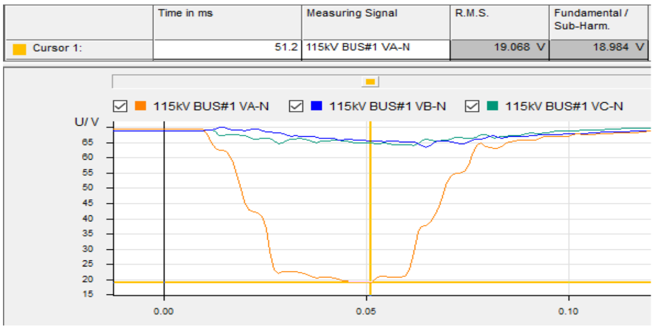
I. INTRODUCTION

Power system protection study is important for the safe, efficient, and economic operation of any electricity network (generation, Transmission, distribution…etc. The aim of protection scheme is to keep the power system stable by isolating the faulty zone while leaving as much of the network as possible still in the operation). Selectivity is ability to of a protection system to coordinate with other protection system to minimize the outage area when a faulty component of the system is isolated from system. Coordination refers to the process of applying relays to operate for faults in their primary zone. The main Aim of co-ordination between relay to give correct discrimination. That is to say, each one must isolate only the faulty section of the power system network, leaving the rest of the network undisturbed. And simultaneous trip to protection at the same time. It has been observed that, there is simultaneous tripping in two feeders meanwhile the fault only in the one feeder which break the coordination. In other work healthy feeder in distribution network trips due to the fault in the other feeder; this phenomenon was known sympathetic tripping or false tripping. There are many reasons for sympathetic. The aim of this study to find out the reason behind this mal-operation. Power system protection program; (ASPEN ONLINER) has been used to simulate case study of false tripping in substation in distribution network, 34.5 KV network using actual parameter in distribution network. ASPEN ONLINER has been used to analyze and evaluate the case.

The motivation for this paper comes from the actual case study and to study how protection engineer can contribute to solve these problems. There are many reasons for sympathetic tripping such as delayed voltage recovery which could happen because of motor stalling phenomenon [1]. Another reason, could be sympathetic inrush current phenomenon which might occur when a transformer is switched on in a power system network containing other energized transformers [2]. This paper focuses in transformers of distribution voltage level, where it has special considerations related to magnetization impedance. The distribution transformers, could have quite low magnetization impedance. this unique feature could lead to wrong tripping for some healthy distribution feeders in case of ground faults occur on one of adjacent outgoing feeder. In this paper, practical tests for distribution transformers have been highlighted, explaining the actual values for the magnetization branch in distribution transformers. These practical test results have been used in the simulation which helped us in discussing and solving the case study problem.

II. LITERATURE REVIEW

The delay voltage recovery sympathetic problem, delayed voltage recovery conditions are commonly initiated by a fault of on adjacent lines of the same voltage level [1]. The delay voltage recovery problem is a result of the type of connected load. The problem has been observed during summer season in countries with hot weather. There are two factors appear to predominate in influencing the voltage recovery problem: the population of Air conditioners experiencing the voltage dip during a fault and reduced load impedance under stalled motor condition or locked-rotor condition, (these motor draw 5-6 times their steady state current). When faults on transmission system cause voltage dips to less than 60 % as presented in figure 1, the Air conditioners might go into the stall mode depending on the fault duration [5], as on a large load block, most air conditioner motors stall and will not recover speed with restoration of full voltage. The combined and uninterrupted locked rotor current has led to delayed voltage recovery in power network serving high concentrations of air conditioner and this problem [2] lead to trip transformer by overcurrent. The phenomenon in which the system voltage remains at excessively low levels for the duration of several seconds, even after the clearing faults is classified as fault induced delay voltage recovery (FIDVR) [5]



	Time in ms	Measuring Signal	R.M.S.	Fundamental / Sub-Harm.
Cursor 1:	51.2	115kV BUS#1 VA-N	19.068 V	18.984 V

Figure 1 Voltage collapse and recovery, due to single-phase fault

Sympathetic inrush current phenomenon occurs when a transformer is switched on in a power system network containing other transformers which are already energized. Magnetizing inrush current occur during the energization of a single transformer connected to a power system network in presence of other transformers. However, the energization of a transformer connected to network in the presence of other transformers as shown in figure 2 which are already in operation, leads to the phenomenon of sympathetic inrush current. This inrush current may lead to a false operation of transformer differential relay [2]

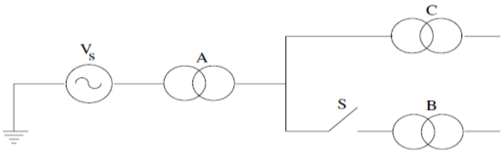


Figure 2 sypathetic inrush current

When the power system is subjected to a fault, the most common consequence of the fault is a huge increase in the current. Hence, the easiest way to identify abnormalities is by monitoring the current value of the system. The overcurrent protection is primary used for this purpose and it does monitor the current in all three phases. However, the overcurrent protection should be integrated with earth fault element, in order to increase fault identification capability during some scenarios of ground faults with high impedance value. The earth fault element can also be called as earth fault protection

The overcurrent and earth fault protections can be triggered by any fault occurs on the power system, so could mal-operate for far faults not within their allowable boundaries. This fact necessitates making operation coordination between the overcurrent and protection relays in the entire power system

as per IEC standard at least 250ms coordination time to be set between numerical relays however not less than 300ms is allowed to coordinate between electromechanical relays.

In this paper ASPEN ONLINER software has been used for the problem simulation. Mathematical model using symmetrical components has been also used to conduct short circuit study for ground faults. The Mathematical calculations and simulation results have been compared with an actual ground fault case taken from a distribution network.

The paper is arranged as follows. Section III problem description, Section IV mathematical modelling V showing the case study from the site Section VI simulation by ASPEN software VII Result and discussion. Finally, Section VII provides the final conclusion for the study

III. PROBLEM DISCRIPTION

The flow of the zero-sequence current in the transformer depends on the transformer vector group connection, whenever the transformer has a DELTA winding (DELTA-STAR or STAR-DELTA), it will be a source for the zero-sequence current. This point is required to be consider during planning stage in order to better evaluate the actual ground fault levels. It is also required to be considered by protection engineers because the zero-sequence current could impact the performance of the protective relays. The STAR-STAR transformers are not considered usually as a source for the zero-sequence current. However, some transformers (usually 3 limbs transformers), that are often equipped in distribution level, have the same effect of DELTA-STAR or STAR DELTA windings. In a sense, be a source for the zero-sequence current. This because of the fact that the magnetization branch for these transformers are significantly low for zero sequence current. In this case study, a (13.8/0.415) KV transformer of STAR -STAR connection will be used. This transformer has low magnetization branch based on tests. Therefore, a low path for the zero-sequence current would be available and may cause what is so called distribution feeders sympathetic tripping phenomenon (|tripping of healthy feeders along with a fault on another feeder). The phenomenon has been described in this paper and the proposed solutions have been suggested.

All equipment's in the electrical network can be implanted by positive and negative and zero sequence impedance, for static network i.e. no-rotating plants, the positive and negative sequence impedance are the same. Zero sequence impedance of overhead line and cable is determined by return path of the zero sequence currents through earth, earth wires or cable sheaths. The zero-sequence impedance is generally greater than the positive and negative sequence impedance, being usually of the order of two to three times the positive sequence value in the case of overhead. For transformer, if zero-sequence currents have an available path and can flow, they will again see the leakage reactance in each phase. If no path exists, an open circuit must be shown for the particular windings in zero sequence network. The flow of zero sequence current in any winding is possible only if other winding provides a path for the flow of balancing zero sequence currents [9].

As general in larger transformer, magnetizing impedance Zm (magnetizing impedance) is of the order 2000%, compared to the leakage impedance (primary (Z_{lP})and secondary+ (Z_{LS}) impedance). Therefore, magnetizing impedance can be ignored and the transformer can be implemented in the positive and negative sequence networks by a series impedance (Z_{Lp} + ZLS) but in distribution transformer magnetizing circuit should be considered. [10]

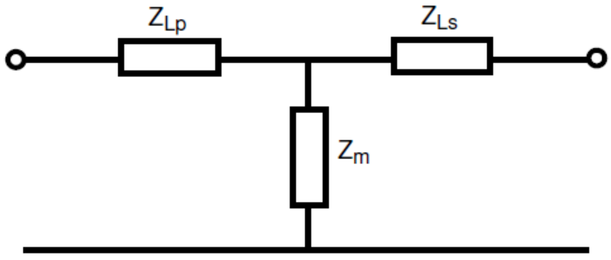


Figure 3 Transformer equivalent circuit

In the transformer, the zero-sequence network magnetizing impedance is identical to positive and negative sequence impedance (if there is path for zero sequence). Zero sequence magnetizing impedance is dependent upon the transformer core construction [12], [14]. Three-phase banks of single-phase transformers and in three phase shell cored transformers, the zero-sequence magnetizing impedance is large and can be ignored as in the positive and negative sequence network. three-limb core type transformers, the zero-sequence flux must be completed through the oil or tank. due to the high reluctance of the flux path, zero sequence magnetizing impedance is of the order of only 100% to 400%. However, this is still high enough to neglected in most fault studies [9]. Shell (3-limb) core transformers have very different zero-sequence impedance when compared with other core structure types. Since accurate fault analysis is essential for proper protection system design, determining the correct impedance for distribution transformers becomes more important [12].

In figure 4, Switch a,b are used to explain the zero sequence path for example if the primary side connected STAR ,that is link a is closed and b is open. Table 1 explains all possible availability connection for winding connection

Table 1: The switch for zero sequnce path depnds on winding of transformer's connection

Earthed star winding	Close link a
	Open link b
Delta winding	Open link a

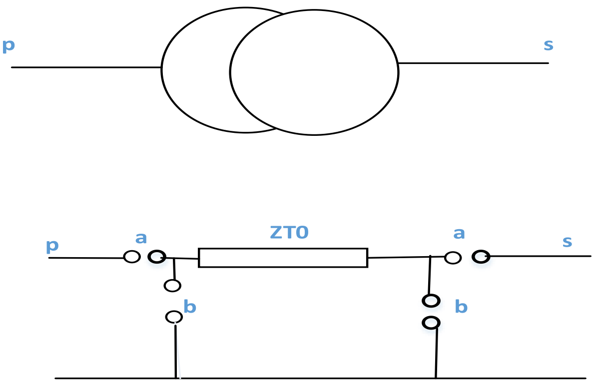


Figure 4 for explaining zero sequnce path depend for tranforerm connectiob

False tripping due to earthed Wey/Wey (YN/YN) connected transformer. If any distribution feeder is connected to earthed Wey/Wey transformer this will become a reason for false tripping when an earthed fault happens in another feeder as per figure 5 .

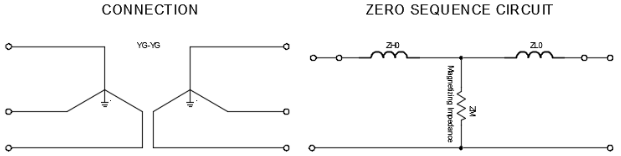


Figure 5 Sta-star transformer and zero sequnec with magnetizing circuit

In figure 6 if an earth fault happens in feeder -2, the earthed fault current will flow through the neutral point of transformer -1 and transformer 2 due to low path for magnetizing current which exist in the feeder-1 due to path from magnetizing circuit which will not consider as open circuit. The current will be flowing through line-1 to return to the fault point in feeder-1.

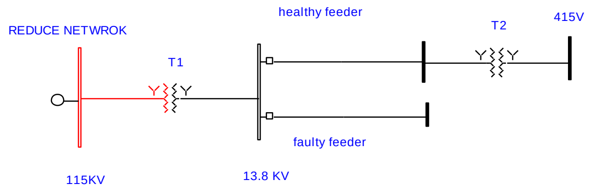


Figure 6 actual situation of the network

IV. MATHEMATICAL MODELLING OF NETWORK

Figure 7 shows, system Modelling during Single Line to ground fault on the feeder and the healthy feeder:

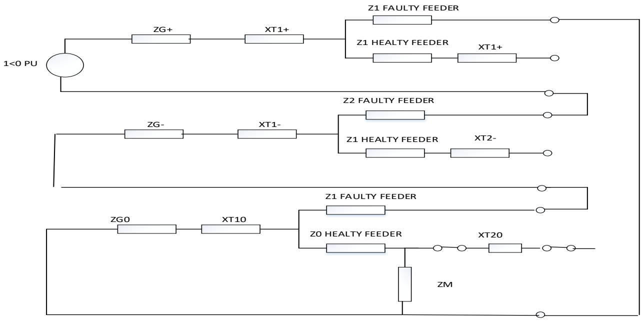


Figure 7 Modelling for Single Line to Ground Fault

During single phase to ground fault scenario, all symmetrical components quantities will be available (positive sequence, negative sequence and zero sequence). They are connected in series. The zero sequence impedances of the power transformer, which exists in the healthy feeder, will be considered in the fault current calculations, because of the low path of transformer magnetizing branch for transformer

The total current flows on the above circuit is:

$$I_{F(1\emptyset-E)\,(pu)}=\frac{v}{zt}$$

115KV REDUCED NETWORK MODEL:

V $_{base}$= 0.91231<10.2926° P.U

Impedance transient per Unit:

Z+=0.00094+j0.02764 P.U

Z-= 0.00094+j0.02764 P.U

Z0=0.00462+j0.05209 P.U

TRANSFORMER -1 (T1):

Z+=Z-=Z0=j0. 46667P.U

TRANSFORMER -2 (T2):

Z+=Z-= j0.77067 P.U

Y0=-j0.1388 P.U

Z0= j7.225 P.U

FAULTY FEEDER:

Z1=Z2=0.15+j 0.3 P. U

Z0= 0.5+j 1.2 P. U

HEALTHY FEEDER:

Z1=Z2= 0.05+j 0.1 P. U

Z0= 1.4+j 0.02 P. U

Calculation:

$Z_t=Z_{+}+Z_{-}+Z_0$

$Z_{+}=Z_{G+}+Z_{T1+}+Z_{+\text{faultyy feeder}}$

=0.00094+j0.02764+ j0.46667+0.15+j 0.3

=0.15094+j0.79431 P.U

$Z_{-}=Z_{G-}+Z_{T1-}+Z_{-\text{faultyy feeder}}$

0.00094+j0.02764+ j0.46667+0.15+j 0.3

=0.15094+j0.79431 P.U

ZERO SEQUENCE CALCULATION:

Xg0+XT10
=0.00462+j0.05209+ j0.46667
=0.00462+j0.51876
Zm+healthy feeder
= j7.225+1.4+j 0.02
=1.4+j7. 245P.U
(Zm+healthy feeder)//(Xg0+XT10)
(1.4+j7.225)//((0.00462+j0.51876)
-3.741573+j0.7596435/(1.40462+j7.74376)
=0.01012303956+j0.4850088359
=0.4851145 <88.8 P.U
Zero sequence total =
(Zm+healthy feeder)//(Xg0+XT10)
+zeor sequence for faulty feeder
=0.01012303956+j0.4850088359+0.5+j 1.2
=0.51012303956+j1.6850088359
Ztotal=0.15094+j0.79431+0.15094+j0.79431+0.51012303956 +j1.6850088359
=0.812+j3.274=3.3732 <76 P. U

CALCULATION CURRENT AT FAULTY FEEDER:

I0=V/Z
0.91231<10.2926°/3.3732<76
=0.27045<-66
3I0 (Faulty Feeder) =0.81135
Ibase =100000/13.8*1.32=4184
3I0=3722A

CALCULATION CURRENT AT HEALTHY FEEDER:

From modelling of symmetrical components impedance, figure (7):
I0 in healthy feeder=
0.27045<-66* (Xg0+XT10) *(Zm)/(Xg0+XT10+Zm)
Xg0+XT10+Zm:
0.00462+j0.51876+ j7.225
0.00462+j7.74376 P. U
0.27045<-66*(0.00462+j0.51876)/ 0.00462+j7.74376
0.27045<-66*0.0669534 <-0.48
I0=0.0181 <110
I1=I2=Zero
3I0 (healthy feeder) =0.0543 P. U
=245A

V. CASE STUDY

Figure 8 and figure 9 show actual disturbance records for faulty and healthy feeders. The feeders are connected to star /star transformer. The record of the current on the healthy feeder proves that there is a returning path for zero sequence current, feeding the fault on the faulty feeder.

Figure [10] shows the disturbance record of the faulty feeder, which has a phase to ground fault. The faulty feeder protection operated correctly and C.B isolated fault within the permissible time

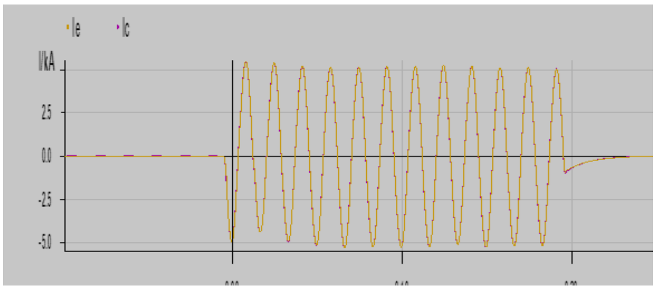


Figure 8 disturbance record at the faulty feeder

Figure 9, the disturbance record from the healthy feeder and Cleary that all phase has the same value and same magnitude which means that this zero-sequence contribution .3I0 qual summation of these phase. From the disturbance it has been noticed that the zero-sequence current (688A) figure 14 is higher than positive and negative sequence (I+=I-=0) which means there is no real fault (there is some generation of zero sequence). Also, it is clearly that any phase has same zero sequence (229)

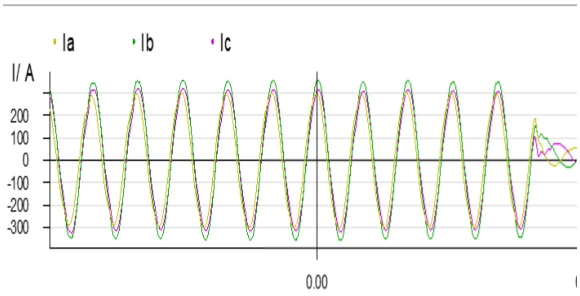


Figure 9-disturbance record at healthy feeder

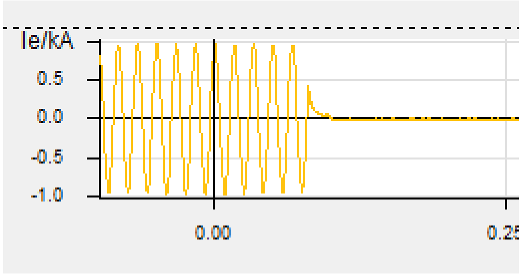
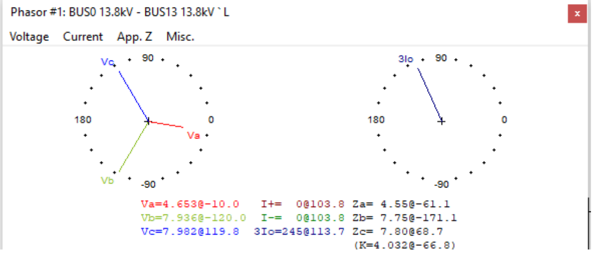


Figure 10 disturbance record at the faulty feeder (SLG fault)



```
Va=4.653@-10.0   I+=  0@103.8 Za= 4.55@-61.1
Vb=7.936@-120.0  I-=  0@103.8 Zb= 7.75@-171.1
Vc=7.982@119.8  3Io=245@113.7 Zc= 7.80@68.7
                              (K=4.032@-66.8)
```

Figure 11-simulation by ASPEN positive, negative, zero sequence current at healthy feeder

Transformer’s manufacturers do not provide zero-sequence data for distribution’s transformer. So actual test for star-star transformer (case study) has been tested at the side to measured zero sequence impedance as per the figure 12 The results have been got from the test of zero sequence test on primary side (13.8 KV). As per the table [2].

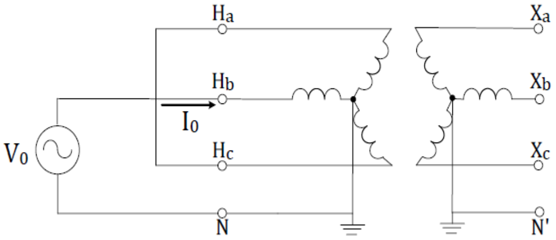


Figure 12-zero sequence test for transformer

Table 2, Table 3,test report for transformer’s zero sequence

Test method	Applied voltage	Measured current (A)-3I0
Applied one phase voltage on high side and open low side	126.1	27.5

From the above table:

$$Z_0 = \frac{V0}{I0} =$$

$$I_0 = \frac{27.5}{3} = 9.16A$$

$$Z_0 = \frac{126.1}{9.16} = 13.76i:P.\ U$$

VI. SIMULATION OF THE CASE STUDY BY ASPEN

Convert the above value to per Unit system and implemented in ASPEN software

Transformer name plate

KV_{base} =13.8 KV

MVA_{base}= 7.5 MVA

$$Zbase = \frac{KV*KV}{MVA} =$$

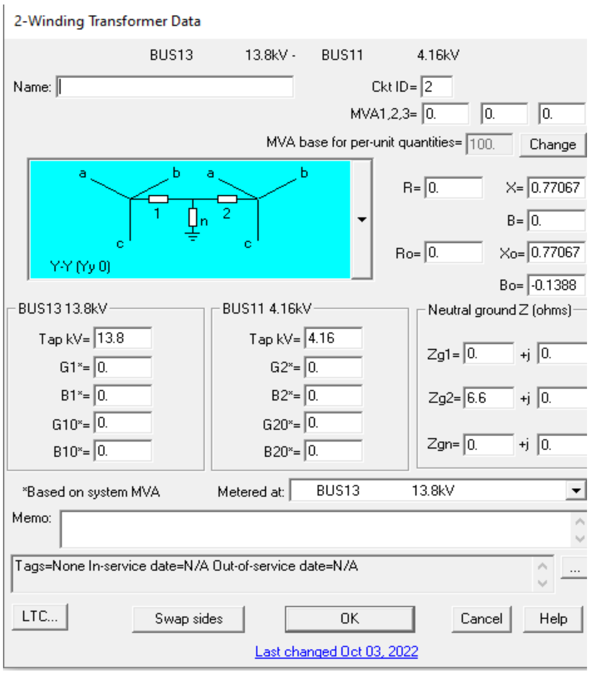
$$\frac{13.8*13.8}{7.5} = 25.392A$$

$$Z\ P.U = \frac{Z\ actual}{z\ base}\ \frac{MVA\ New}{MVA\ old} =$$

$$\frac{13.76}{25.392} * \frac{100}{7.5} = j7.225\ P.U$$

$$Y0 = \frac{1}{Z0} =$$

$$\frac{1}{J7.225} = -J0.1388\ P.\ U$$



2-Winding Transformer Data

BUS13 13.8kV - BUS11 4.16kV

Name:

Ckt ID= 2

MVA1,2,3= 0. 0. 0.

MVA base for per-unit quantities= 100.

R= 0.

X= 0.77067

B= 0.

Ro= 0.

Xo= 0.77067

Bo= -0.1388

BUS13 13.8kV

Tap kV= 13.8

G1*= 0.

B1*= 0.

G10*= 0.

B10*= 0.

BUS11 4.16kV

Tap kV= 4.16

G2*= 0.

B2*= 0.

G20*= 0.

B20*= 0.

Neutral ground Z (ohms)

Zg1= 0. +j 0.

Zg2= 6.6 +j 0.

Zgn= 0. +j 0.

*Based on system MVA

Metered at: BUS13 13.8kV

Memo:

Tags=None In-service date=N/A Out-of-service date=N/A

Last changed Oct 03, 2022

Figure 13-implemnted measured zero sequence for transformer at ASPEN

From ASPEN simulation by simulate earth fault in feeder-1 its clearly that, there is fault currents distributed in both line and there is zero sequence in healthy feeders' figure [6]. From figure [15] the phase current at IA=IB=IC=82 A

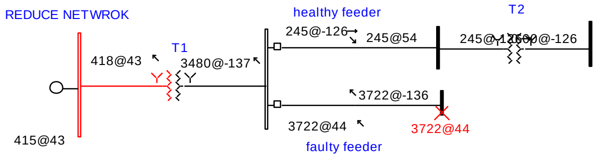


Figure 14-simulation case by aspen -indicate there is current in healthy feeder (zero sequence current I0)

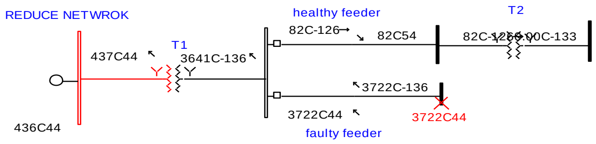


Figure 15- simulation case by aspen -indicate there is current in healthy feeder (current per phase -AT phase-A)

Both disturbance records (actual and simulated) are typical and have same behavior. This proves that this analysis has same results.

System implanted per unit as per the following:

MVA=100 MVA

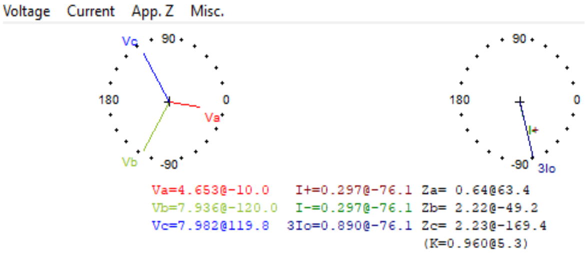
KVbase=13.8 KV

Then Z_O per unit

=25.392*

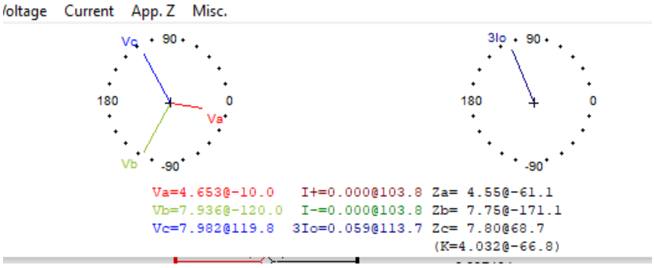
Actual data has been implemented in the ASPEN ONLINER software, and actual fault has been simulated

Figures 18 and 19 show positive, negative and zero sequence for healthy and faulty feeder from simulation by software. They indicate that, there is zero sequence current in the healthy feeder



```
Va=4.653@-10.0   I+=0.297@-76.1 Za= 0.64@63.4
Vb=7.936@-120.0  I-=0.297@-76.1 Zb= 2.22@-49.2
Vc=7.982@119.8  3Io=0.890@-76.1 Zc= 2.23@-169.4
                                (K=0.960@5.3)
```

Figure 18 measurements for healthy feeder by aspen (P.U



```
Va=4.653@-10.0   I+=0.000@103.8 Za= 4.55@-61.1
Vb=7.936@-120.0  I-=0.000@103.8 Zb= 7.75@-171.1
Vc=7.982@119.8  3Io=0.059@113.7 Zc= 7.80@68.7
                                (K=4.032@-66.8)
```

Figure 19 measurements for faulty feeder by aspen (P. U)

VII. RESULT AND DISCUSSION

Simulation by aspen and mathematical calculation show same results: a fault at the faulty feeder flows on the healthy feeder. Therefore, the protection settings should be revised accordingly.

Fault current	HEALTHY FEEDER		FAULTY FEEDER	
	I^0	$3I^0$	I^0	$3I^0$
In PU	0.0181	0.0543	0.2704	0.81135
In A	81.6A	245A	1240	3722A

There are many solutions that could be used to solve the problem of sympathetic tripping due to magnetizing circuit in distribution's transformer. Some of these solutions can be stated as follows:

- The setting for earth fault and overcurrent should be calculated based on actual parameters for zero sequence network and zero sequence for distribution transformer and protection engineer should consider the path of zero sequence current through low magnetizing circuit of transformer in distribution side.
- Another solution, if possible, to use directional overcurrent earthed fault toward the feeder but this solution is very costly due to the need of using voltage transformer and a directional relay which might be more expensive compared with no directional relay.
- The problem can also be solved by making the high side of the distribution transformer to be ungrounded. So, there will not be a returning path for zero sequence current that could lead to wrong operation for the earth fault relay

VIII. CONCLUSION

This paper has clearly proven that the sympathetic tripping phenomenon, of wrong tripping of healthy feeder with a faulty feeder, is highly expected in distribution networks even with STAR-STAR transformers. From this fact, it can be concluded that distribution transformers of STAR-STAR vector group are also needed to be dealt with same as the transformers of STAR-DELTA connection by considering its the magnetization branch. Protection and planning engineers should consider this fact in their fault calculations studies and protection setting calculation in order to avoid this phenomenon by adopting any of the practical and feasible measures.

ACKNOWLEDGMENT

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