

## ENHANCED EARTH FAULT DETECTION ON MV FEEDERS USING CURRENT UNBALANCE PROTECTION

S. PAPATHANASSIOU  
National Technical  
University of Athens  
(NTUA) - Greece  
st@power.ece.ntua.gr

M. TSILI  
National Technical  
University of Athens  
(NTUA) - Greece  
mtsili@central.ntua.gr

G. GEORGANTZIS  
Public Power Corporation S.A.  
(PPC) - Greece  
g.georgantzis@dei.com.gr

G. ANTONOPOULOS  
Public Power Corporation S.A.  
(PPC) - Greece  
g.antonopoulos@dei.com.gr

### ABSTRACT

*The detection of high impedance faults (HIF) occurring on distribution lines is particularly difficult or even impossible, using conventional phase or earth over-current detection schemes, due both to the low fault currents involved and the arcing nature of such faults. This paper investigates the application of the “phase discontinuity” (essentially current unbalance) protective function to enhance the performance of the traditional over-current protection schemes, used in MV distribution networks with resistance-earthed neutral. The analysis is performed via simulation for a variety of single-phase fault types and the results obtained show that the application of this function can enhance significantly the sensitivity and effectiveness of earth fault detection, particularly in the case of downed conductors.*

### INTRODUCTION

High impedance earth faults are mainly encountered in overhead MV networks, where live conductor contact is possible with earthed objects (ground, trees, buildings, poles etc.). The associated fault resistance may vary from a few  $\Omega$  up to several tens of k $\Omega$ . In general, the term HIF refers to fault currents less than 100 A. Safety issues and difficulties in detecting HIF are well known and documented, [1-3].

The standard MV distribution feeder protection practice in networks with solidly or low-resistance grounded neutral is based on the detection of increased phase or earth (i.e. zero sequence) current values, [4]. Such schemes are inefficient in detecting and isolating HIFs, due both to the low value of the currents involved and the arcing nature of such faults.

In this paper, the application of the “phase discontinuity” protective function (essentially current unbalance protection, ANSI dev. 46) is investigated, to enhance the detection performance of the traditional protection schemes, particularly for the frequent and unfavourable case of broken and downed phase conductors (combination of open conductor with downstream single-phase earth fault). This protection is based on the calculation of a simple unbalance factor

$$\Delta I(\%) = 100 \frac{I_{\max} - I_{\min}}{I_{\max}} \quad (1)$$

using the maximum and minimum of the three phase currents,  $I_{\max}$  and  $I_{\min}$ , rather than the zero-sequence current of the line. As a study case, a typical part of the Greek 20 kV urban network has been selected, consisting of underground and overhead line segments. Simulation results are presented and discussed for a variety of faults on the network. PSCAD/EMTDC has been used for the simulations.

Main outcome of the investigation is that the current unbalance protection is a relatively inexpensive addition to the conventional over-current protection scheme of MV distribution feeders, which can enhance the sensitivity and effectiveness of HIF detection.

### STUDY CASE SYSTEM

To evaluate the effectiveness of the phase discontinuity protection for detecting high impedance earth faults, the study case network of Fig. 1 is used, which is characteristic of the 20 kV urban networks encountered in Attica, Greece. A 150/20 kV, 50 MVA transformer (YNyn0) supplies 12 distribution feeders, comprising mostly underground cable lines, but also overhead line segments. The assumed lengths and feeder loads at maximum/minimum load conditions are indicated on the diagram. To simplify the simulation, the load (Dyn11 distribution substations) is aggregated at four nodes along each feeder.

The earth fault protection concept of the MV network is outlined in Fig. 2 and reflects the current practice of the utility. The secondary of the 150/20 kV power transformers is Y-connected and the neutral is grounded via a 12  $\Omega$  resistance (the additional 0.5  $\Omega$  resistance shown in Fig. 1 corresponds to the substation grounding mat). High- and low-set earth fault (EFH and EFL) relays are used at the T/F neutral. EFL is set at 1.8 A/5 s and provides only an alarm to the operator, while the EFH protection, set at 600 A/1.6 s, trips the transformer. A definite time earth over-current relay ( $I_E \gg$ ), set at 400 A/1.4 s, is used at the 20 kV breaker of the T/F. Another such relay ( $I_E \gg$ ), set at 160 A/0.6 s, is used at the departure of each underground cable feeder, while an additional low-set ( $I_E >$ ) function, to be set at 20 A/2.0 s, is considered by the utility, to increase earth fault detection sensitivity. The phase discontinuity ( $\Delta I >$ ) function, examined in this paper, is applied also at each feeder departure. Finally, an earth fault setting ( $I_E >$ ) of 5-15

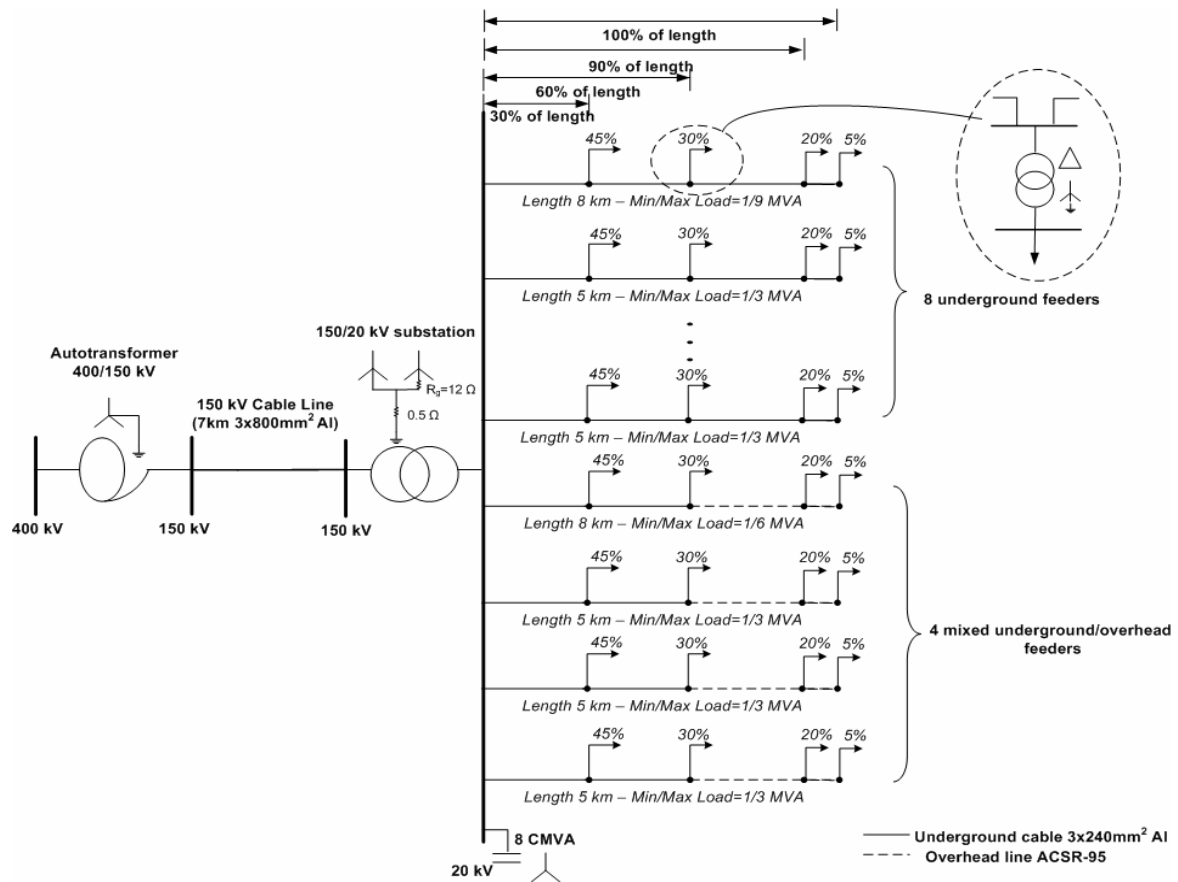


Fig. 1. 20 kV distribution network model used in the simulations.

A/0.3 s is used for large users of the MV network, connected via circuit breakers.

The analysis has included all types of earth faults occurring along each feeder. For space limitation reasons, however, results will be presented only for the following two types, being the most representative:

- Single-phase earth fault and
- Broken and downed conductor (downstream the interruption point)

Although the network considered is predominantly underground, it still makes sense to discuss earth faults of these types, because several feeders include significant overhead segments. Further, overhead, pole-mounted distribution substations, where high impedance earth faults may occur, are often connected to underground cable feeders.

For each fault type a parametric analysis has been conducted, for varying network loading conditions, fault position along the feeder and fault resistance, varying between 1 Ω and 10 kΩ. Each case has been simulated in PSCAD/EMTDC and the resulting currents have been recorded in the faulted and unfaulted feeders, as well as at the transformer neutral, to decide upon the sensitivity of the considered protections.

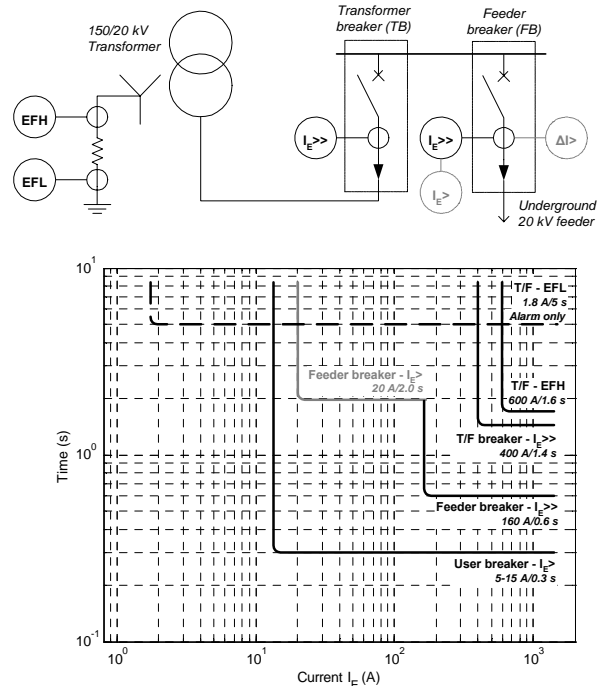


Fig. 2. Earth fault over-current protection concept.

## RESULTS AND DISCUSSION

### Single-phase-to-earth faults

In the diagram of Fig. 3(a) the resulting fault current ( $3I_0$ ) is shown for a single-phase fault along a feeder, as a function of the fault resistance. The four curves correspond to fault locations near the beginning and the end of the line and to minimum and maximum loading conditions of the network. The corresponding phase current unbalance, calculated using eq. (1), is shown in Fig. 3(b).

It is observed that the feeder earth over-current relays ( $I_E \gg$ ), using the 160 A pick-up applied by the utility, are effective for fault resistances up to 70  $\Omega$ . Implementing additional low-set ( $I_E >$ ) feeder relays, set at 20 A, expands the detection range to faults resistances up to 800  $\Omega$ . The location of the fault along the feeder and the loading conditions do not affect noticeably the performance.

Since current unbalance ratios in excess of 10% have been measured in urban feeders under normal operation, a setting of 20% or higher is appropriate for the phase discontinuity ( $\Delta I >$ ) protection. Using such a setting, this protection is effective for fault resistances up to 150  $\Omega$  – 2k $\Omega$ , depending strongly on the network loading conditions. However, unlike the conventional earth over-current protection, the effectiveness of the  $\Delta I >$  protection will not be compromised by the stochastically varying nature of HIF currents, because the measured phase currents are directly employed (eq. (1)).

Both protective functions ( $I_E >$  and  $\Delta I >$ ) will not encounter selectivity problems. The zero-sequence current and the current unbalance on the unfaulted feeders (not shown in the diagrams) remain below 20 A and 20%, respectively, excluding thus the possibility of parasitic tripping of healthy feeders. These thresholds are approached only in the case of low impedance faults near the substation. In these cases, however, time-selectivity is achieved, since the  $I_E \gg$  protection of the faulted feeder will trip (in 0.6 s, using the settings of Fig. 2), before activation of the  $I_E >$  or  $\Delta I >$  functions of healthy departures.

The performance of the EFH and EFL transformer relays may be deduced from Fig. 3(c), which shows the transformer neutral current for the considered disturbances. Although faults near to the substation may excite the EFH relays, time selectivity is again achieved with the  $I_E \gg$  relays of the feeders. The EFL relays, set at 1.8 A, will provide an alarm for relatively high resistance faults, well beyond 1 k $\Omega$ .

Identical remarks are valid for faults on mixed underground/overhead lines. Only small differences exist due to the smaller total shunt capacitance of these lines, which however do not affect the conclusions already drawn.

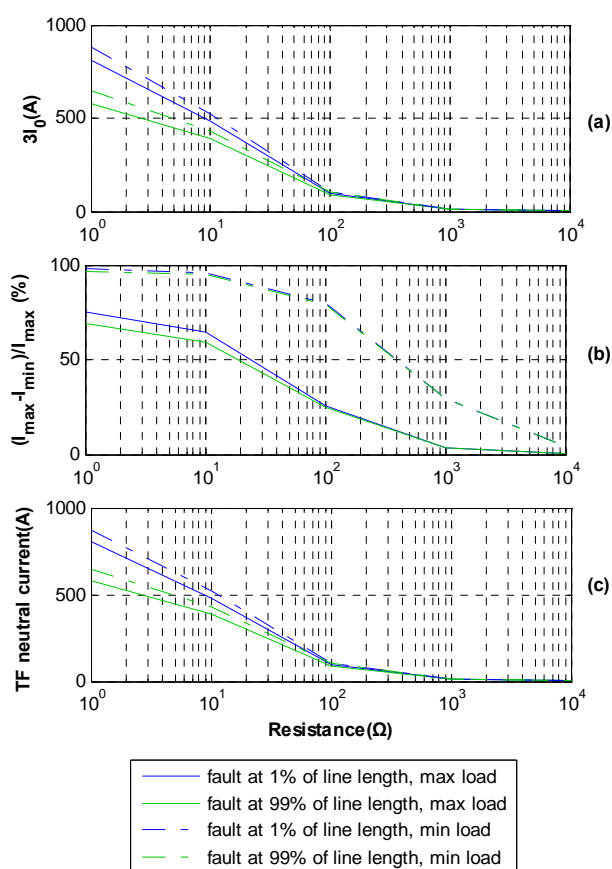


Fig.3. Single-phase fault on underground feeders: (a) Earth current ( $3I_0$ ) on the faulted feeder, (b) Current unbalance on the faulted feeder and (c) Transformer neutral current as a function of the fault resistance, for different fault locations and network loading conditions.

### Broken and downed conductors

Broken and downed phase conductors (a combination of open conductor with downstream earth fault) are quite common in overhead MV networks. In such a case, the fault is fed via the delta connected MV windings of the distribution transformers located downstream the fault position, which introduce significant impedance and therefore result in currents that cannot be securely detected by conventional over-current protection schemes. Depending on the resistance of the fault, the earth current may be lower than 1 A, being comparable to the zero-sequence currents present in normal operating conditions. Hence, such faults may remain undetected for long intervals, raising serious safety issues.

In Fig. 4(a) and (b) the variations of earth current and current unbalance are shown as a function of the earth contact resistance. Such disturbances remain entirely undetected by the high-set earth over-current protection ( $I_E \gg$ ). The low-set relays ( $I_E >$ ) may respond only when the faults occur near the departure of the feeder, the fault resistance is low and the network loading is high. Further, the performance deteriorates significantly for faults on

feeders with large overhead parts, where occurrence of such faults is most probable. Hence, the vast majority of downed conductor disturbances remain undetected by the conventional earth over-current protection, particularly in overhead feeders and at low network load conditions. As it is evident from Fig. 4(c), showing the transformer neutral current, only the EFL relays provide an indication (alarm) for such disturbances. Hence, the current utility practice consists in the successive disconnection of all feeder departures, to locate the faulted one, and then location of the fault by on-site inspection by utility crews.

Fig. 4(b) demonstrates that the sensitivity of the current unbalance protection ( $\Delta I >$ ) is completely unaffected by the fault resistance or the network loading (as well as by the type of feeder – overhead/underground). The determining factor is actually only the load downstream the fault position, since  $\Delta I(\%)$  in eq. (1) is roughly equal to the percentage of this load with respect to the total feeder load. Hence, the current unbalance protection is capable of detecting the majority of such faults, as long as the load downstream the fault position is greater than 20-25% of the total feeder load.

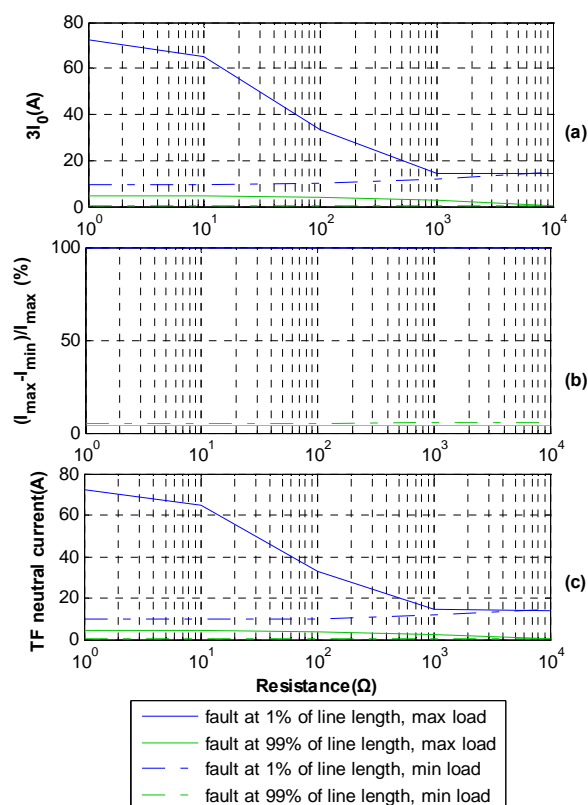


Fig 4. Broken and downed conductor fault on underground feeder: (a) Earth current ( $3I_0$ ) on the faulted feeder, (b) Current unbalance on the faulted feeder and (c) Transformer neutral current as a function of the fault resistance, for different fault locations and network loading conditions.

The main drawback in applying the phase discontinuity protection lies with its lack of discrimination capability between earth faults and simple open conductor situations. A single-phase opening on a lateral with fuse cut-outs or single-pole sectionalizers might excite the  $\Delta I >$  relays, tripping the feeder. Although this may not be a concern in underground urban networks, it constitutes the main inhibiting factor for applying such a protection to extended overhead networks.

Further practical implementation issues exist, as well. Namely, relays equipped with such a function disable its operation at low feeder currents (e.g. below 10% of CT rated), rendering the protection inactive during the lowest load conditions.

## CONCLUSIONS

In this paper, the performance of current unbalance protection has been investigated, as a means for detecting high impedance earth faults. The investigation was carried out via simulation, considering different types of faults and a broad range of fault resistances. A typical Greek urban MV distribution network has been used as a study case.

Main conclusion of the investigation is that the phase discontinuity protection is quite effective in detecting downed conductor faults (i.e. combined phase interruption and earth fault), where the conventional earth over-current protection schemes are clearly ineffective, provided that sufficient load exists downstream the fault position.

Main drawback of this protection is the fact that it cannot discriminate for simple open conductor situations, possible in networks with fused laterals of single-pole sectionalizers, where tripping the entire feeder is undesired.

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