Assessment of Logic Algorithms for Faulted Phase Earthing Protection Relays on 10 kV Networks

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ABSTRACT

In order to mitigate safety issues during a single phase to ground fault, faulted phase earthing (FPE) is implemented on the 10 kV network in Ireland. The FPE protection relay triggers the FPE switch in the substation which earths the faulted phase to the substation earthgrid. The majority of the fault current will flow into the substation earthgrid which in turn improves the fault site safety, allowing the system to be operated without disconnecting customers who are fed from the faulted section of network.

As the load on the network increases, due to growth on the system, the voltage set point is also increased in order to avoid low voltage situations at the end of long sections of network. This increase in voltage can lead to spurious tripping of the FPE relay during unfaulted conditions, as one of the logic settings is related to under voltages.

A study was carried out to determine if the present logic algorithm settings can be altered to reduce spurious trippings and to examine the implementation of newly proposed logic algorithms for newer FPE relays. The new logic was selected in order to reduce spurious fault detections while increasing the fault resistance range which can be detected by the relay.

This paper outlines the assessment of the present logic functions in the faulted phase earthing (FPE) relays on the 10 kV network in Ireland. It also outlines the process used to determine if a newly proposed logic algorithm will be sufficient to increase the sensitivity of the relay to pick up high resistance faults without increasing spurious operations.

INTRODUCTION

The 10 kV distribution network of Ireland is run as an isolated neutral network. When the network is in a sustained single line to ground fault condition, the three phases remain in service, continuing to provide electricity to customers.

In order to maintain security of supply the faulted phase is not tripped, however in order to improve fault site safety the faulted phase is earthed back at the feeding substation. This FPE system is used across the 10 kV distribution network in Ireland.
The existing method has two logic requirements to determine if a single phase is faulted, which will lead to the FPE earthing that phase in the substation.

A study was carried out to determine if newly proposed additions to the logic could make improvements in the fault detection of the system.

Background

In an isolated neutral system, when there is a single line to earth fault, the voltage on the faulted phase (reference phase) will reduce in proportion to the fault resistance.
The leading and lagging phase voltages will increase in relation to the voltage drop on the faulted phase as a result of the shift in the neutral voltage. The phase leading the faulted phase will have the higher of the two healthy phase voltages. It is important to define the leading and lagging phases, as they will be referenced separately in the logic algorithm of the relay.
The leading and lagging phases for each of the references voltages are as follows:

Reference Voltage	Leading Phase	Lagging Phase
R	T	S
S	R	T
T	S	R

Table 1 Reference (Faulted) Phase and Associated Leading and Lagging Phases

FPE logic

The FPE system continuously monitors all three phases and inputs the resulting voltages through an algorithm in order to determine if a particular phase is faulted.
When the algorithm detects that an earth fault has occurred on a phase the faulted phase is earthed in the substation.
The logic used on the network at present uses 0.95 per unit (pu) as the low setting limit and 1.25 pu as the high setting limit to determine a single phase to earth fault. The proposed altered settings to the existing logic are as follows.

If the leading phase is greater than 1.15 pu
AND
If the reference phase is less than 1.0 pu
AND
The neutral voltage is greater than 0.15 pu

EMTP-ATP

A model of a section of 10 kV network was created in EMTP-ATP software to test the ability of the logic to determine single phase to earth faults.

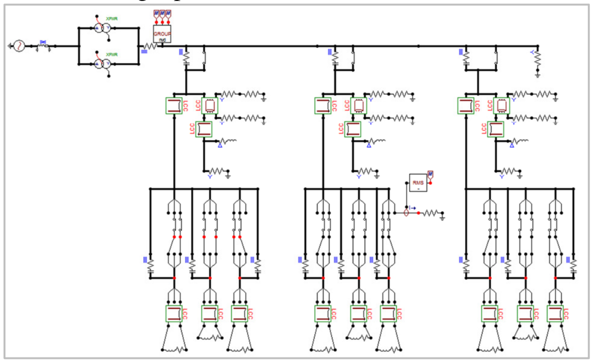

Table 2 EMTP-ATP Model

Modelling components

The voltage source was modelled as 38 kV voltage source.

A lumped RLC 3 phase sequence line was used to represent the impedance of the 38 kV network.

The 38 kV/20 kV transformers were modelled as 2 winding Yd11 transformers.

Three phase overhead lines, single phase overhead lines (OHL) and three phase cables were modelled. In each case a Pi model type was used to construct the feeder as the simulation was a steady state type.
50 mm^2 Steel Core Aluminium (SCA) was used for the OHL and 185 mm^2 Cross Linked Polyethylene (XLPE) were used for the cables.

2 phase loads were represented as an RL impedance. Balanced loads were used, equally distributed on each phase.

Three different network sizes in terms of capacitive charging current were modelled, one of 20 A, 40 A and 60 A.
The majority of the capacitive charging current was generated from the underground cables.

Simulations

A single phase to earth fault was simulated for different scenarios and the resultant value of the voltage for each phase, as seen at the substation was recorded.
In order to get a comprehensive view of how the FPE relay would function under different fault conditions, the fault resistances were varied from small values (1 Ω) to large values (200 Ω), where a graph of the resulting voltages against fault current was plotted.
Another variation examined was the effect of unbalanced loads on the voltages.
This was carried out by uncoupling the 2 phase load from each of the three feeders. This 2 phase load was the same for each feeder i.e. the 2 phase load between R and T for each of the three feeders.
This gave approximately 4 % of a neutral voltage imbalance.
This was examined for the R-T, S-T and R-S loads.
The resulting maximum and minimum of each of the three phase voltages from the different scenarios simulated were recorded.
This is illustrated in Figures 1 and 2, by the double lines for each of the voltages.

The voltage set point was also varied, from a low value 10.4 kV to a high value 10.8 kV to determine the impact this could have on the resultant voltages.

The phase voltages that resulted from the simulations were summated to find the neutral voltage on the network where:

Vn = Va + Vb + Vc

This was carried out by using a script inside the EMTP-ATP software called a MODEL, and verified by calculation afterwards.

Results

The three phase voltages and calculated neutral voltage were then plotted along with the logic algorithm settings to determine where the limit of the existing algorithm lay with respect to the detection of different fault impedances.

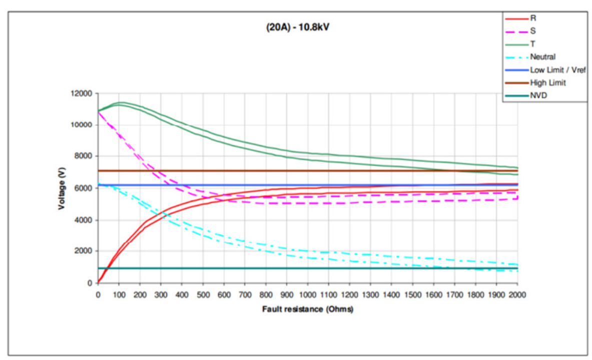

Figure 1 Resultant Voltages for an example 20 A network

From Figure 1 shown above, for an example 20 A network the logic can detect a fault up to a resistance of 1300 Ω. Above this range, the faulted phase rises higher than the low setting of the algorithm.

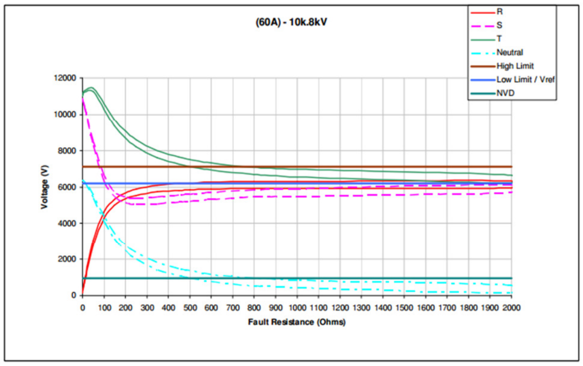

Figure 2 Resultant Voltages for an example 60 A network

The example output for a larger size network of 60 A shows that the detection limit of the algorithm decreases to approximately 350 Ω.
This showed that the higher resistance faults may not be picked up by the existing logic algorithm, even with the altered setting and that the new FPE relays with a newly propose logic may be beneficial in detecting higher fault resistances.
The new logic algorithm was as follows:

If the leading phase is greater than 1.15 per unit (pu)
AND
If the reference phase is less than 1.0 pu
AND
The neutral voltage is greater than 0.15 pu
The lagging phase may be higher than 1.0 pu but not above 1.15 pu.

Using this algorithm the relay has a greater detection range, allowing the reference phase to increase higher than the low setting.

With this algorithm for the example of a small network shown above, the detection limit is 1600 Ω, 300 Ω greater than the altered algorithm for the existing logic.

For the larger network, the new FPE relay can detect faults up to 450 Ω, 100 Ω greater than the altered algorithm for the existing logic.

The limiting detection factor for the new FPE relay is the NVD setting. It is set to detect a fault if there is more than 15 % of NVD on the network. Theoretically this could be decreased to increase sensitivity, but operationally there will always be an amount of NVD on the network, and if this setting is too low, it may spuriously operate.

Testing

Both of these algorithms were tested in house on the new FPE relay, in order to insure they would work as desired.
The algorithm was programmed into the relay by the ESBI Protection Technology Group.
The different phase voltages output from the EMTP-ATP fault simulations were put into a Comtrade file that was then uploaded into a test kit.
These voltages were then applied to the FPE relay to verify that it would detect a fault as predicted, and to verify more accurately the detection limits.

Conclusions

The results of the study showed that the altered algorithm would increase the detection limit of the existing relays presently installed on the Irish 10 kV network.
Resulting from this work, the ESB has decided to adopt the altered algorithm settings

The new FPE relay still must be field tested to verify the benefits found in the results of the study.

Acknowledgements

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