Special Considerations for Distribution Feeder Protection Coordination

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SYNOPSIS
This paper discusses special considerations for the proper coordination of feeder relays via the examination of some of the more onerous applications.

Multiple Circuits Sharing Same Structures

The first example is the protection of multiple distribution circuits sharing the same set of structures as shown in Figure 1. A cross country fault could occur due to a tree limb that falls across the outer phase on a pair of three-phase overhead circuits running along the same set of distribution poles.

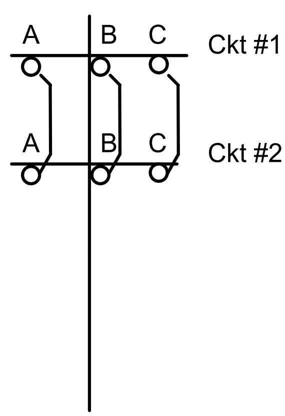

Figure 1 – Three Phase Fault on Double Circuit Distribution Line

A three-phase, cross-country fault is examined to show some of the considerations necessary how to properly coordinate the feeder relays protecting the two circuits.

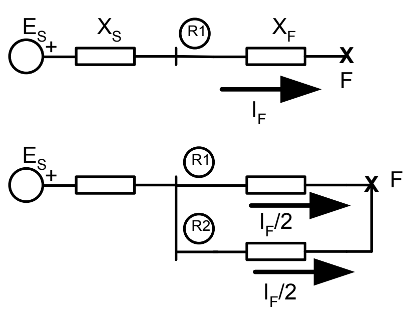

Figure 2 – Double Circuit Distribution Fault Analysis

E_S is the system voltage (100 volts secondary line-to-ground). X_F (10 Ω secondary) is the reactance of the feeder up to the point of the fault. I_F is the fault current flowing in the feeder. The table below shows the fault current magnitude for both a single feeder (I_F) and a cross country fault involving both (I_F'). X_F is held constant while the system reactance (X_S) is varied.

Table 1 – Cross Country Fault Current Magnitudes

X_S	I_F	I_F'	I_F/I_F'
1 Ω	9.1 amps	8.33 amps	1.1
2 Ω	8.33 amps	7.1 amps	1.2
5 Ω	6.67 amps	5 amps	1.3
10 Ω	5 amps	3.33 amps	1.5
15 Ω	4 amps	2.5 amps	1.6

The fault current magnitude in the feeder for a cross country fault decreases as the source impedance increases. Therefore it is possible the overcurrent protection will not coordinate properly with upstream protection as illustrated in Figure 3.

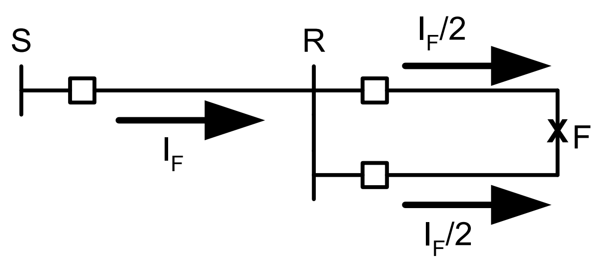

Figure 3 – Double Circuit Distribution Fault Analysis

Peer-to-peer communication allows relays to share status in real time. Therefore it is possible to program the two feeder relays at substation R such that if both simultaneously detect a fault they can properly adjust the pickup settings for coordinated overcurrent elements.

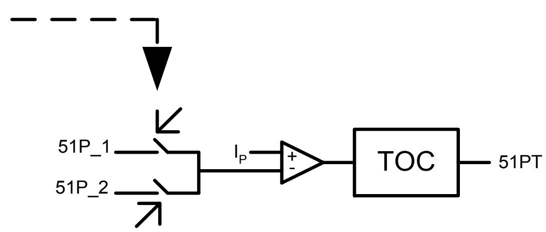

Figure 4 – Enhanced Coordination via Peer-to-Peer Communication

51P_1 is the normal pickup setting for the phase time overcurrent element. 51P_2 is a lower pickup setting and only used when a cross country fault has been detected. I_P is the maximum phase current. TOC is the time overcurrent characteristic. 51PT is the output.

Single-Pole Tripping

Single-pole tripping is popular now for some three-phase distribution circuits since much of the load is single phase (for example a large residential area). Special considerations are required to properly account for unbalance during the open pole prior to reclose which can adversely affect directional elements and ground overcurrent protection. Figure 5 shows the angular relationship between V_1 versus I_1 and V_2 versus I_2 for a single phase-to-ground fault and phase-to-phase fault on a radial feeder. The subscript 1 denote positive-sequence quantities and the subscript 2 denotes negative-sequence quantities. The fault location is in the forward direction with respect to the feeder relay.

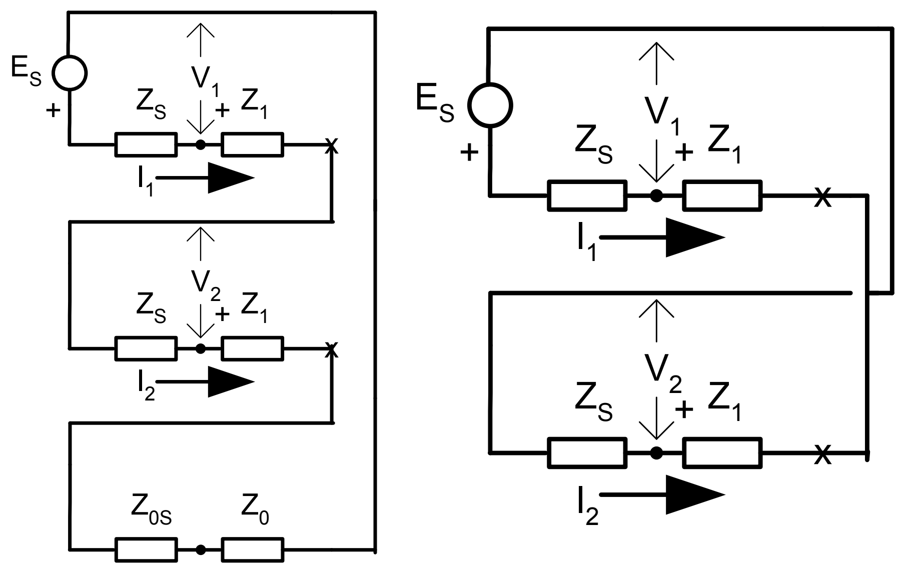

Figure 5A – Symmetrical Component Diagrams for Single Phase-to-Ground and Phase-to-Phase Feeder Faults

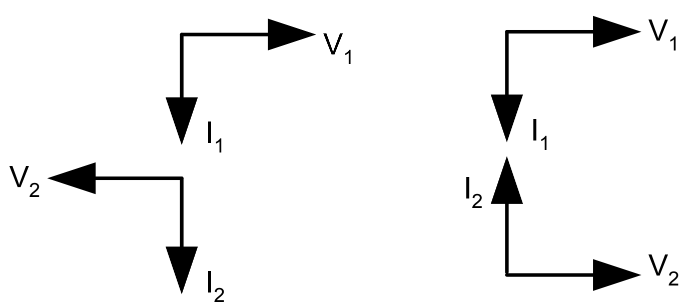

Figure 5B – Symmetrical Component Voltage and Current Phase Relationships

E_S = Equivalent Source

Z_S = Equivalent Positive-Sequence Source Impedance

Z_{0S} = Equivalent Zero-Sequence Source Impedance

Z_1 = Positive-Sequence Feeder Impedance

Z_0 = Zero-Sequence Feeder Impedance

It is possible that during an open pole the phase relationship between V_2 and I_2 is the same or close to that for a single phase phase-to-ground fault in the forward direction. If the load current is high enough that the unbalance current in the two healthy phases exceeds the pickup of a directional overcurrent element then unwanted tripping can occur. The same can also hold true for V_0 and I_0 measured by the feeder relay. One solution is to block directional elements during a single pole open condition. The pickup of the directional overcurrent elements should be set above this type of unbalance if possible.

Single pole tripping can also lead to heavy inrush current when the open pole is reclosed, such as the case for residential load with a heavy concentration of air conditioning (i.e., motor load). *The inrush current looks like ground fault current since it is flowing in one phase and often the voltage also momentarily collapses*. Special steps such as the detection of hot load inrush must be employed to prevent nuisance trips.

Fast Bus Tripping Schemes

The fast bus tripping scheme is applied for bus work in distribution substations and works on the basic principle of a directional comparison blocking scheme. If the fault is located on a feeder then the feeder relay sends a blocking signal via an overcurrent element (50B) to halt the fast bust trip, however if the fault is on the bus there is no blocking signal and a fast bus trip (50T) occurs. *There are many special considerations that are required to ensure this scheme is both reliable and secure otherwise there is always the possibility of an unwanted trip occurring during an external fault*. Figure 6 illustrates a distribution substation with three overhead feeders. The transformer bank is connected delta-wye.

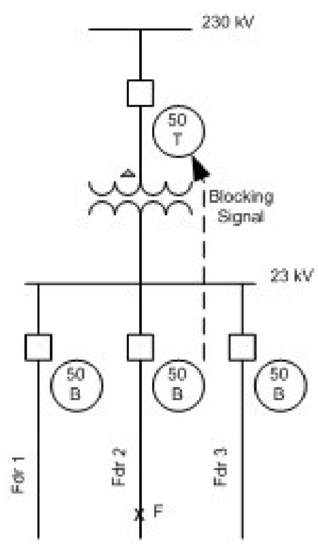

Figure 6 – Distribution Bus Bar Blocking Scheme – Fast Bus Trip

<u>Directional Supervision</u>

Some customers use directional elements to supervise the overcurrent elements if there is any ground sources connected to the feeders (e.g., distributed generation). Figure 7 illustrates such a system. Should a ground occur on the bus then supervision of the feeder relay overcurrent element via a forward looking directional element prevents unwanted blocking and the fault is quickly cleared.

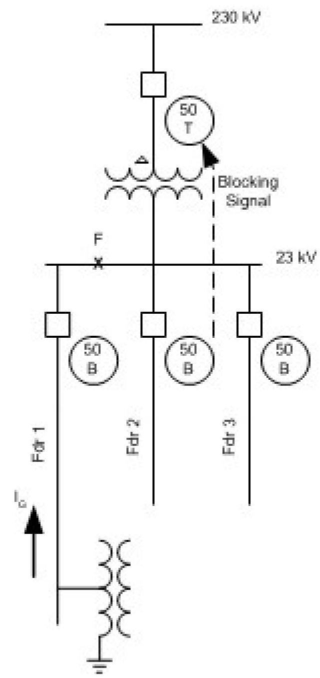

Figure 7 – Ground Source Connected to Distribution Feeder

Modern numerical feeder relays can utilize multiple polarizing quantities such as negative- or zero-sequence voltage. The feeder overcurrent elements should be supervised simultaneously by directional elements that operate for any fault type. If there is only one active directional element then there is the possibility the blocking signal will momentarily drop out during an evolving fault. For example consider the case of a phase-to-phase fault that evolves into a three-phase fault such as shown in Figure 8.

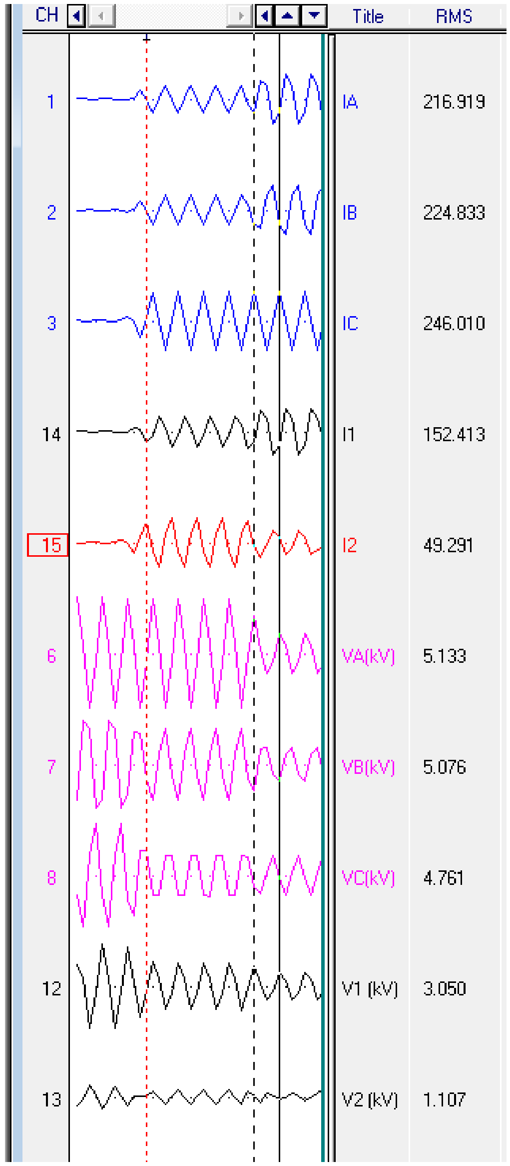

Figure 8 – Evolving Fault, Phase-to-Phase to Three Phase

Negative-sequence voltage and current measured by the feeder drops to zero when the fault evolves into the third phase. If the supervisory directional element requires at least one processing interval to switch from negative-sequence to positive-sequence voltage then the blocking signal drops out and an unwanted bus trip can occur during an external fault. If on the other hand both the positive- and negative-sequence directional elements are active then the protection scheme will remain stable and ride through the transition.

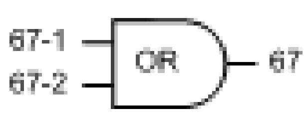

Figure 9 – Multiple Simultaneous Polarization

Overcurrent Pickup Coordination

If there are looped feeders as illustrated in Figure 10 then the pickup setting for 50T must be properly coordinated versus 50B. The feeder relays will see less fault current due to the distribution so the 50B pickup must be set more sensitive, otherwise unwanted tripping can occur for remote faults.

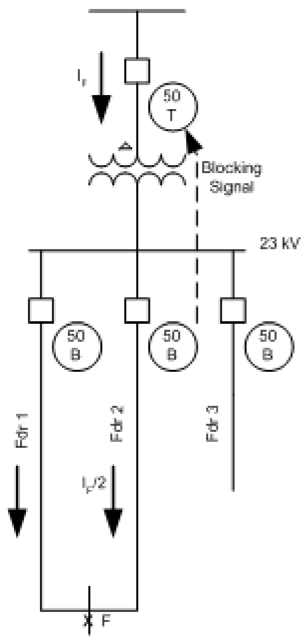

Figure 10 – Looped Distribution System

CONCLUSIONS

Special considerations are required for looped distribution feeders with sources at both ends, otherwise unwanted tripping and miscoordination can occur. If single pole tripping is employed then it may be necessary to block directional elements during the open pole prior to reclose. Fast bus tripping schemes appear deceptively simple to implement but also require many special considerations to make secure.

ABOUT THE AUTHOR

Steve Turner, IEEE Senior Member, is a Senior Applications Engineer at Beckwith Electric Company. His previous experience includes work as an application engineer with GEC Alstom, and an application engineer in the international market for SEL, focusing on transmission line protection applications. Steve worked for Duke Energy (formerly Progress Energy), where he developed a patent for double-ended fault location on overhead transmission lines.

Steve has a BSEE and MSEE from Virginia Tech. He has presented at numerous conferences including Georgia Tech Protective Relay Conference, Western Protective Relay Conference, ECNE and Doble User Groups, as well as various international conferences.