APPLICATION NOTE

Focused Directional Overcurrent Elements (67P, Q and N) for DER Interconnection Protection

Abstract

This Application Note describes the use of *focused* directional overcurrent elements (67P, 67Q, and 67N) for Distributed Energy Resource (DER) Interconnection Protection As shown in Figure 1, the DER Interconnection Protection may be employed at the point-of-common coupling (PCC) to trip (deenergize) the PCC or point-of-connection (PoC), or in the case of inverter-based DER, cease to energize. Directional protection as applied in up-line interrupters (feeder breakers and reclosers) is not addressed in this Application Note.

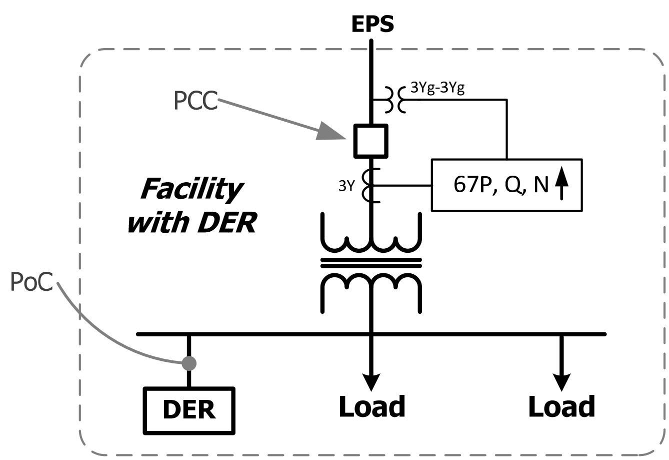

Figure 1: Use of 67 P, Q and N Elements at the PCC for DER Interconnection Protection

Differing from *traditional* directional overcurrent elements that employ a 180° forward/reverse directional decision, the *focused directional overcurrent* concept employs a *tunable* angle characteristic that can be set to detect single and multiphase inductive faults, such as those found on overhead distribution feeder circuits, while ignoring load and normal VAR output of active-VAR DER units.

For detection of fault backfeed into Utility distribution systems (Electric Power System or EPS) by conventional (rotating machine based) DER and inverter-based DER, *focused directional overcurrent* improves both *sensitivity for increased dependability* and *selectivity for additional security.*

Introduction

Normally faults in the EPS are cleared by the up-line interrupter protection (feeder breaker or recloser). In cases where the DER normally exports power across the PCC to the EPS, transfer trip systems have been employed to ensure removal of the DER from the faulted EPS. The transfer trip is initiated by the up-line interrupter, with the signal sent to down-line DER as shown in Figure 2. With the feeder now de-energized, the EPS may implement a reclose cycle without concern for an energized DER remaining on the feeder. However, the use of transfer trip systems comes with high capital cost as well as high operational costs, and may not be 100% reliable.

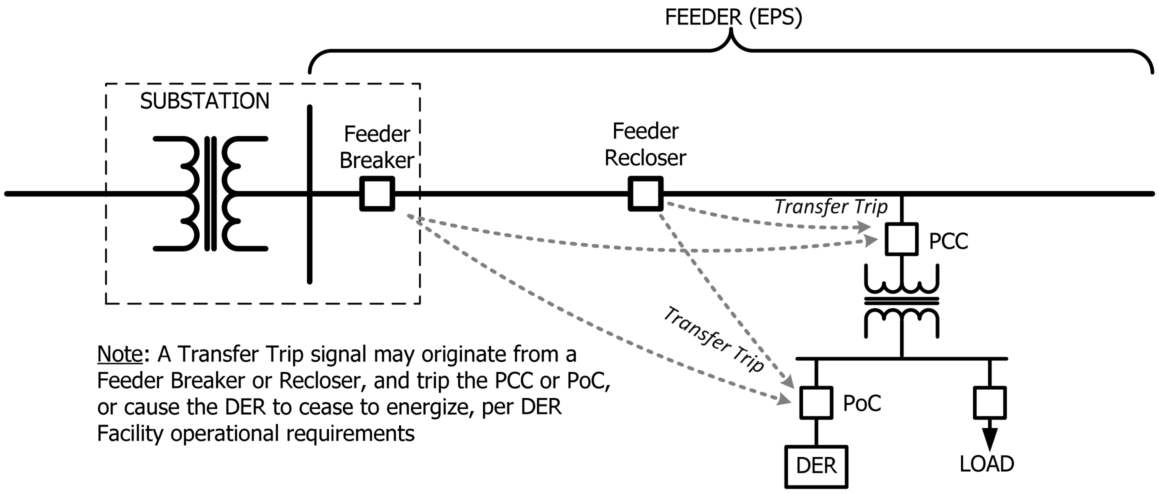

Figure 2- Typical Transfer Trip for DER

If the DER remains energized and supplying fault current during the EPS reclosing cycle, the fault may not be extinguished and the DER and/or DER facility's loads may be damaged by the EPS up-line interrupter out-of-phase closing between the DER facility and the EPS. Up-line interrupter closed/tripped timing and DER energized/de-energized timing are shown in Figure 3.

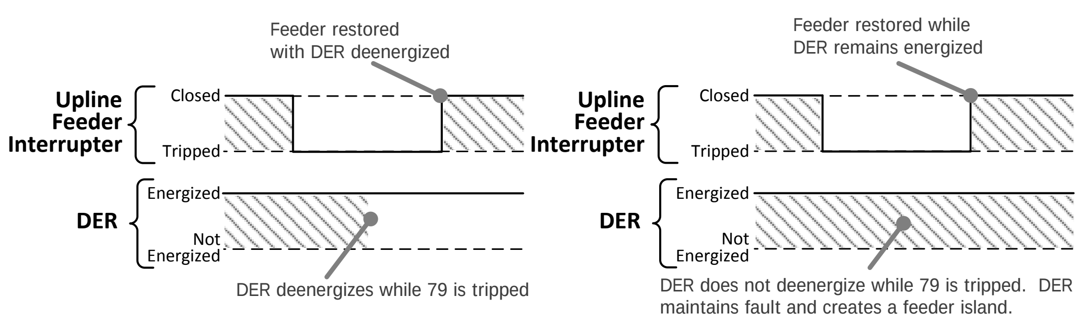

Figure 3: Feeder Reclosing Sequence with DER De-energized and Remaining Energized

Traditional Directionalization

For DER Interconnection Protection, directionalization has been used as a security enhancement to control phase and ground overcurrent elements. When used at the PCC, directionalization to the EPS effectively blinds the overcurrent elements for load and faults in the DER's facility, thereby increasing the DER Interconnection Protection security. If employing *traditional* 180° forward/reverse directional control, as shown in Figure 3, the overcurrent elements are subject to tripping on the DER's real power output when the DER is exporting power to the EPS.

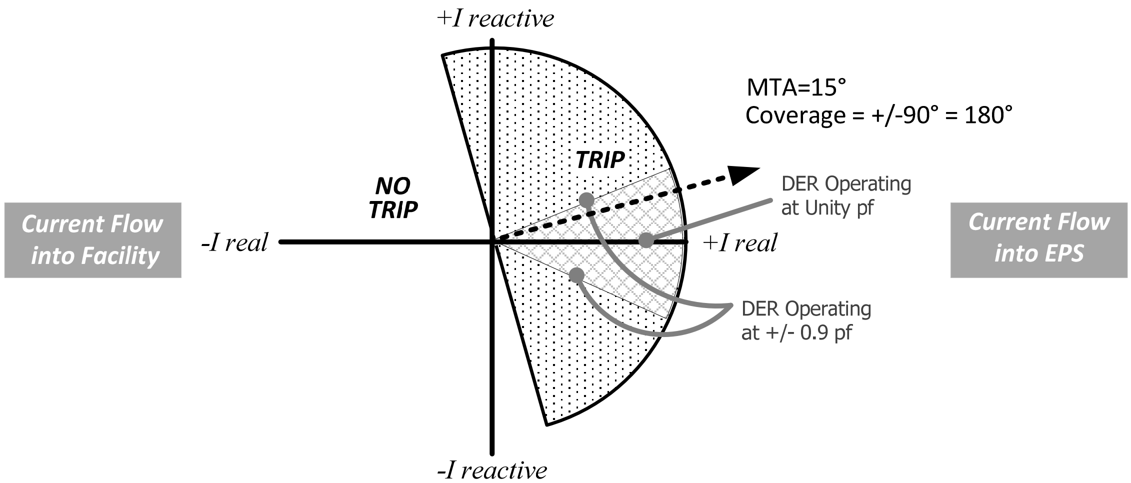

Figure 3: Traditional 180° Forward/Reverse Directional Control for Overcurrent Elements (MTA = 15°)

Figure 4 illustrates the effect of increasing the MTA from 15° to 115° so the forward, real power flow region is ignored. However, this exposes the overcurrent element to trip on load flow and faults in the facility (reverse load area). Thus, increasing the MTA in an attempt to blind normal export current is not a feasible solution with traditional 180° directional overcurrent elements.

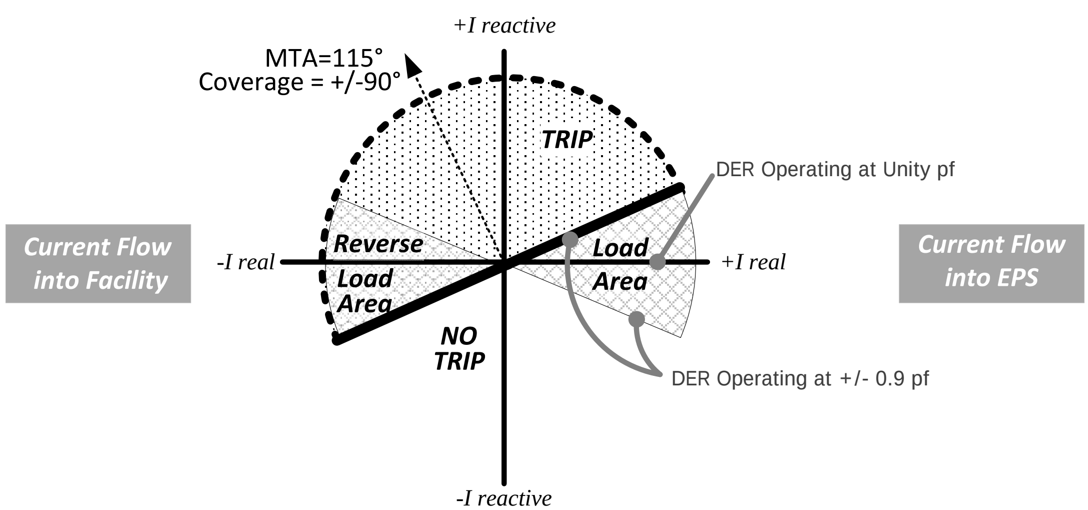

Figure 4: Traditional 180° Forward/Reverse Directional Control for Overcurrent Elements (MTA = 115°)

To avoid tripping on normal DER export power output to the EPS, the overcurrent elements must be set above the DER's rated output current. Inverters typically develop fault currents of 1.1-1.3x rated current. For an inverter-based DER, this overcurrent pickup value with margin is typically 1.2–1.4x the DER's rated output current, as shown in Figure 5. This tactic, however, decreases sensitivity to detect DER fault infeed into the EPS, as this current value is essentially the same as rated output with margin for overload. If the inverter-based DER is supplied by some variable source, such as a PV array, as the PV output decreases below rated (i.e., PV with low irradiance) the output current for both load and faulted EPS conditions also decreases below rated, making fault detection even more difficult.

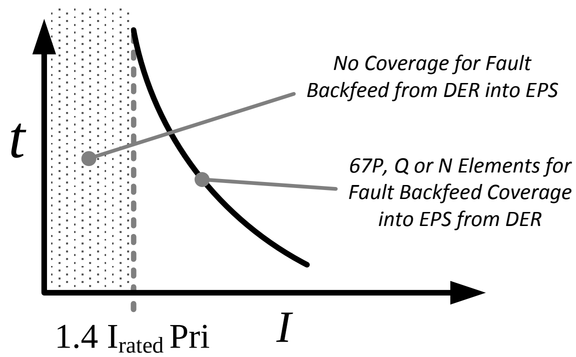

Figure 5: Setting Overcurrent Elements above DER Rated Current and Fault Current Levels

Focused Directional Overcurrent Concepts

Focused directional overcurrent (FDO), as shown in Figure 5, allows the directional characteristic of the overcurrent element to be *tunable* to a region other than the traditional 180° forward/reverse decision. For example, the overcurrent element response angle may be restricted to 45° forward, plus or minus 10°, for an effective response angle of 35° to 55°, seen in Figure 5 below.

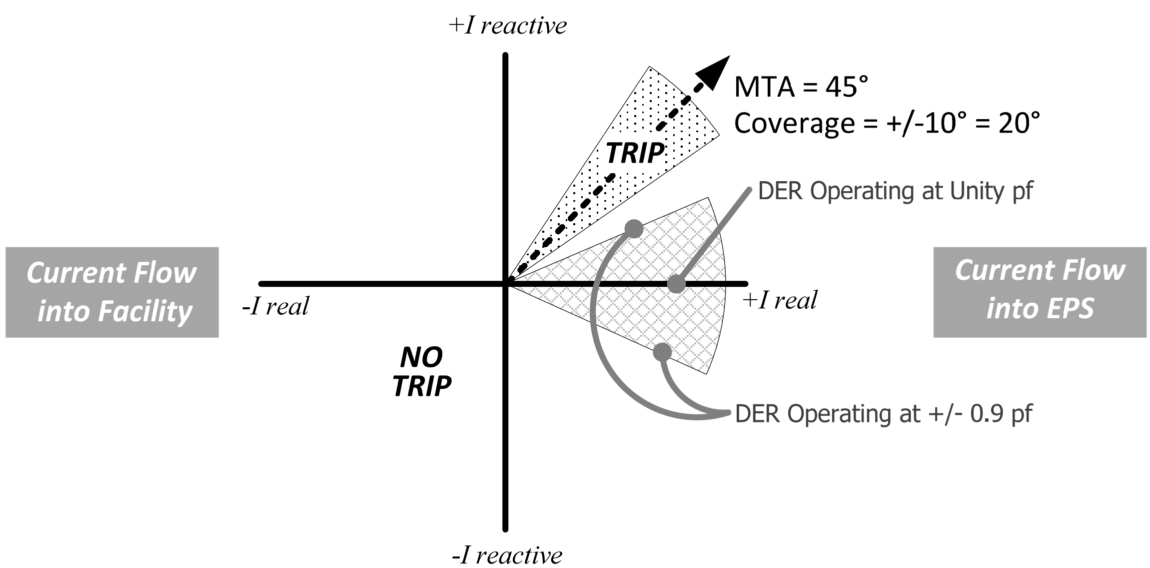

Figure 5- Focused Directional Overcurrent Set to 35° to 55° Forward

FDO elements may be employed with definite time characteristics to coordinate with transmission protection for transmission fault ride-through, as transmission protection typically uses definite time characteristics.

FDO elements allow settings as low as 0.15A secondary, as seen in Figure 6, which greatly improve the sensitivity of the overcurrent elements.

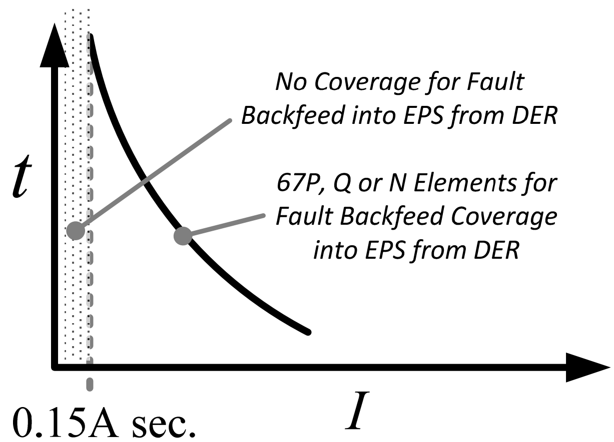

Figure 6- Sensitive Pickup Settings using a Focused Directional Overcurrent Element Employing an Inverse Time Characteristic

The actual minimum primary current level detectable for DER Interconnection Protection would depend on the applied CT ratio. An example is with the DER Interconnection Protection using a 500:5 CT, and by employing a setting of 0.15 secondary amps for the FDO element, a sensitivity of 15A primary amps would be obtained.

Figure 7 uses the most sensitive FDO pickup setting with a definite time characteristic to coordinate with transmission protection and allow ride-through.

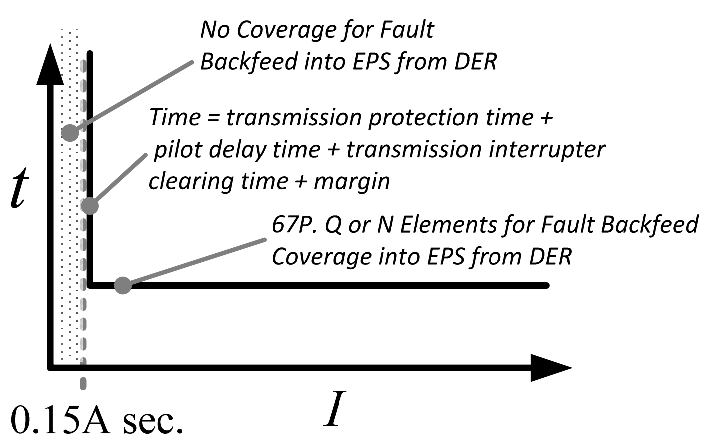

Figure 7- Sensitive Pickup Settings using a Focused Directional Overcurrent Element Employing a Definite Time Characteristic

Load Encroachment Blinding Shortcomings

Load encroachment blinding (LEB) is effective at ignoring inverter-based DER output current at or near unity power factor. As LEB typically employs the quotient of positive sequence voltage to positive sequence current (V_1/I_1) to arrive at positive sequence impedance (Z_1) for overcurrent blinding purposes, a three-phase symmetrical load event is assumed. In the case of non-three-phase shunt faults (e.g. phase-to-ground, phase-to-phase and phase-to-phase-to-ground faults), LEB is ineffective. During a non-three-phase shunt fault, LEB will not have any effect on the overcurrent elements. If the overcurrent elements are set at or below the DER's rated output and the DER's output current on the unfaulted phase(s) is in the load region (near unity pf) and exceeds the overcurrent setting, an undesired trip will result. Figure 8 below illustrates this point. Phases B and C would trip if the overcurrent settings were lower than the DER rated output value. For this reason, LEB is not a proxy for FDO.

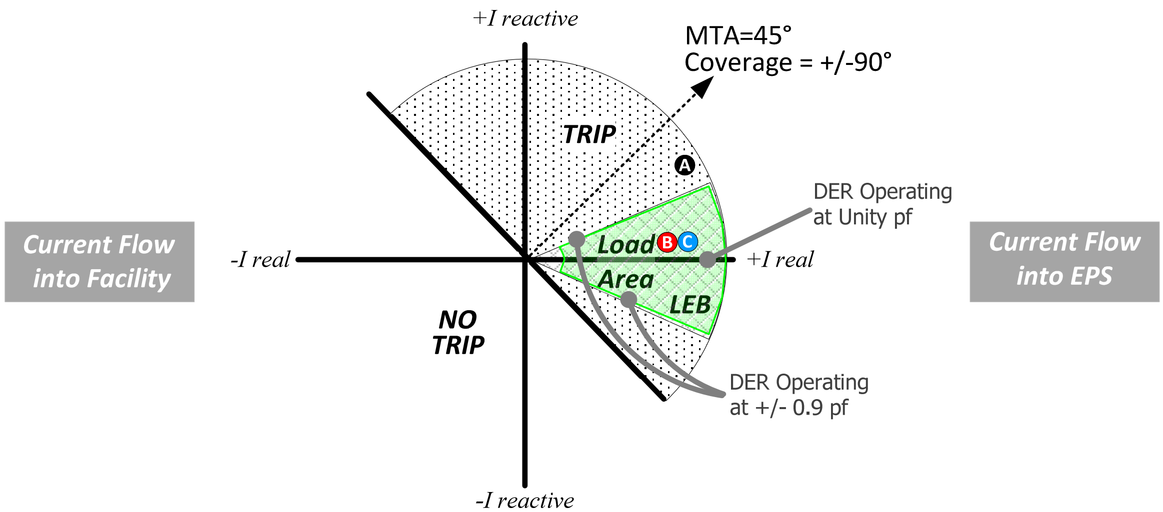

Figure 8- LEB with a Ground Fault on Phase A. Phases B and C are at Rated Load Values

Application Considerations and Limitations for Inverter-Based DER

An inverter, at its terminals, depending on the technology, might only provide positive sequence current which can affect the polarization of an FDO element. Additionally, transformer winding type and grounding at the PCC and EPS energization status at the DER Interconnection Protection, play pivotal roles in directional polarization and application of FDO.

Ground Faults (67N):

In order to apply FDO for ground faults, the element must be able to polarize which *requires* that the interconnection transformer winding at the Utility-side of the point-of-common coupling be grounded wye (See Figure 8).

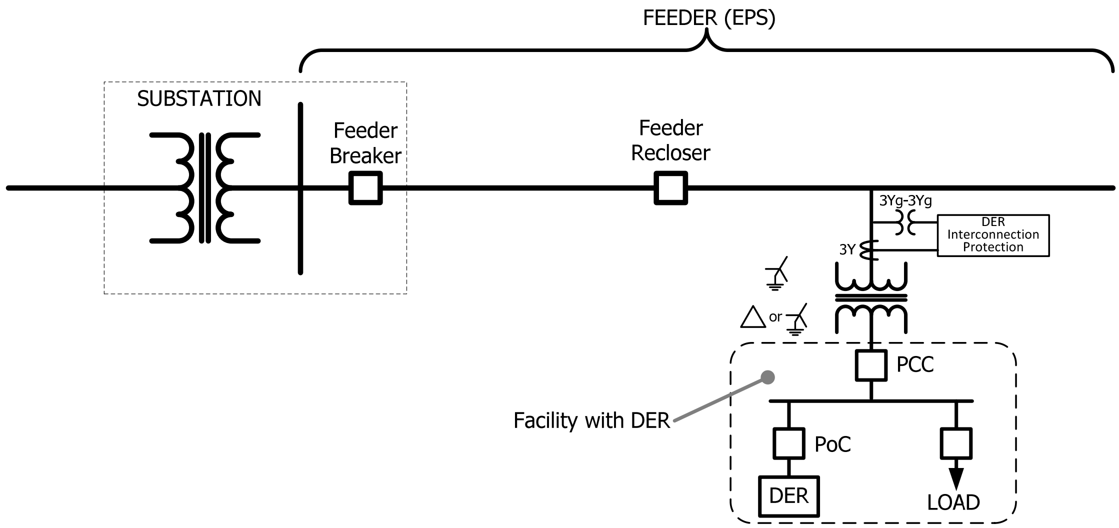

Figure 9 - One line diagram of a DER interconnection with an EPS-side grounded-wye interconnection transformer

If the interconnection transformer winding facing the EPS is delta or otherwise ungrounded, with a single phase-to-ground fault on the distribution feeder appreciable ground current is not available to measure. This is not a shortcoming of the FDO approach, but a characteristic of an ungrounded-source supplied system. With ungrounded sources, one would use $3V_0$ voltage detection for ground faults. Note that for FDO 67N protection and $3V_0$ voltage protection <u>both</u> require 3Yg VTs on the utility-side of the interconnection transformer (3Yg-3Yg for FDO 67N or $3V_0$ by calculation or 3Yg-Broken Delta for $3V_0$ measurement). An exception is with a 3Yg-3Yg Interconnection Transformer, a 3Yg-3Yg VT may be applied on the low-side (DER facility side).

If the 67N element cannot polarize, it will not allow a 67N trip, remaining secure.

Phase-to-Phase Faults (67Q):

As a negative sequence polarized directional element is employed for phase-to-phase fault directional determination, 67Q will work with rotating machine based DER, or mixtures of rotating machine and inverter based DER in a given facility, but may not work with 100% inverter based DER. Inverters may not produce negative sequence current and therefore a negative sequence voltage drop might not occur, and therefore negative sequence voltage (V_2) may not be available to polarize.

In most cases, the 67Q will be able to function if the Utility is still connected to the feeder and a phase-to-phase fault is present. With FDO 67Q applied at the DER Interconnection Protection, the substation source will allow V_2 to be produced by the phase-to-phase faults. The V_2 would, in most cases, be measurable at the DER PCC and therefore V_2 polarization would be available during the time the feeder was supplied from the substation. To maintain the V_2 polarizing source and ensure the DER facility is tripped, the 67Q used at the DER Interconnection Protection would need to be coordinated to trip slightly faster than the up-line feeder relaying or recloser protection.

If the 67Q element cannot polarize, it will not allow a 67Q trip, remaining secure.

3 Phase Faults (67P):

The directional element can employ a positive sequence voltage polarization, which inverters as well as other DER types produce on a 3 phase fault. If the inverters are of the newer "smart type" that can produce VARs for fault ride-though, the V_1 angle will change to the faulted line angle and the FDO 67P will function.

If the 67P element cannot polarize, it will not allow a 67P trip, remaining secure.

Other Considerations:

- FDO will always work for rotating-machine based DER, as the rotating machines can produce all sequence quantities for a fault (fault type dependent): positive (for 67P), negative (for 67Q) and zero (for 67N). The only limitation is the 67N with ungrounded EPS-facing interconnection transformer windings, similar to the inverter-based DER application discussion.
- FDO is not intended for high-impedance fault detection characterized by primary ground faults with a highly resistive component and current values of 10A or less. High-impedance fault detection requires specialized methods.

Conclusions

1. FDO is a method that allows greater dependability (the ability to trip when you should) and security (do not trip when you should not) as the use of the focused angle allows low-set overcurrent elements to be applied.

2. The FDO setting can be less than inverter full rated power. This is extremely important as fault currents produced by inverters are typically only 1.1-1.3 pu of rated output current. Furthermore, at times of low power output, e.g. low sunlight, the inverter output is already reduced. FDO can usually be set adequately low such that coordination for low output power conditions are not required.
    a. As very low fault current may be securely detected with FDO elements, the likelihood of an undetectable fault backfeed situation from DER to the EPS decreases. This is because if there is an extremely low current supplying a fault (less than a very low pickup setting), then this low current would typically not be able to hold up the feeder voltage on the islanded feeder. Therefore, the DER Interconnection Protection would typically trip on an undervoltage condition.
    b. This allows decreased dependence on transfer trip for DERs that normally export power to the EPS.

3. If the FDO elements cannot polarize for <u>any</u> reason (system conditions prohibit polarizing), the element has the ability to use a threshold in the directional element that will <u>block</u> the overcurrent from picking-up and tripping. The FDO approach remains secure if it cannot polarize, yet it offers the opportunity to provide sensitive fault back-feed protection for inverter-based DER systems.

4. Load encroachment blinding does not block unfaulted phase(s) with current in the load region from tripping on non-three-phase shunt faults (phase-to-ground, phase-to-phase and phase-to-phase-to ground). FDO blocks the unfaulted phase(s) from nuisance tripping, and allows tripping of faulted phase(s) on the feeder angle with currents at, or well below rated DER output.

References

[1] Beckwith Electric, *M-7679 Recloser Control Instruction Book*, 2016

[2] Beckwith Electric, *M-7651A D-PAC Feeder Relay Instruction Book*, 2016

[3] *C37.230, IEEE Guide for Protective Relay Applications to Distribution Lines*, IEEE Power System Relaying Committee, Second Edition, 2007

[4] *Protective Relaying, Principles and Applications, 3rd Edition*; J. Lewis Blackburn and Thomas J. Domin; CRC Press; 2007, ISBN 1-57444-716-5

[5] *IEEE 1547-2018, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*, Standards Coordinating Committee 21 (Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage)

Annex: Screenprints of 67N Element in M-7651A and M-7679