Case Study - Indian Basin Utility Interconnection

Overview

Indian Basin is a Marathon Oil Company processing plant operation located in New Mexico. The plant's electrical distribution is interconnected with the area utility. The plant owns and operates five synchronous generators totaling 3.48 MVA. This generation is a mix of gas turbine driven and diesel driven equipment. A No Export Power agreement exists between the utility and the plant. Normal plant demand is approximately 2.45 MVA. Load control techniques allow onsite generation to maintain critical operations when the utility interconnect is opened for faults or other abnormal conditions. The utility interconnect provides a source of electrical energy when required, and increases reliability of the plant distribution system. This case study will review the present power system protection equipment used at the utility interconnect as well as how directional overcurrent protection was applied inside the plant distribution system to improve system selectivity. Methods used to monitor protection quality and reduce risk of unwarranted outages will be presented. Logical next steps for improvement and conclusions derived complete the material presented.

Distribution System Layout

A simplified one-line diagram is provided in Figure No. 1. The utility source is composed of a 1000KVA 12470 – 480vac transformer connected grounded wye on the 12.47kv side and delta connected on the plant 480vac distribution side. Transformer percent impedance is 2.5% on the 1000kva base. A 1600amp, 480vac power circuit breaker #352 connects the plant's main distribution bus to the 480vac utility source transformer. Three 800kw 0.8 power factor gas turbine generators are direct connected to the 480v main distribution bus via three 1600amp breakers (#152, #252 and #452). Automatic load control schemes, including VAR controls, are employed in these gas turbine generators. The plant's main distribution system is predominantly high resistance grounded. The portions of the distribution system that are solidly grounded are separately derived sources via grounded secondary wye transformers. The bulk of the plant load is served from this 480vac main distribution bus via ten feeders. These loads are motor control centers, building and process loads along with plant miscellaneous loads. This portion of the plant distribution system is considered to be critical to plant operations.

A 1600amp, 480vac power circuit breaker #552 connects the 480vac main distribution bus to a 1500KVA 480 – 4160vac transformer connected delta-delta. Transformer impendence is 3.8% on the 1500kva base. Two 540kw 0.8 power factor diesel generators are direct connected to the 4160vac distribution system via two 1200amp breakers 52G1 and 52G2. Speed and voltage regulation controls for these diesel generators are fixed and not automatic. This portion of the distribution system is also predominantly high resistance grounded. Again, the portions of the distribution system that are solidly grounded are separately derived sources via grounded secondary wye transformers. Two large motors, 500hp and 800hp, feed from the 4160v feeders along with a small miscellaneous load.

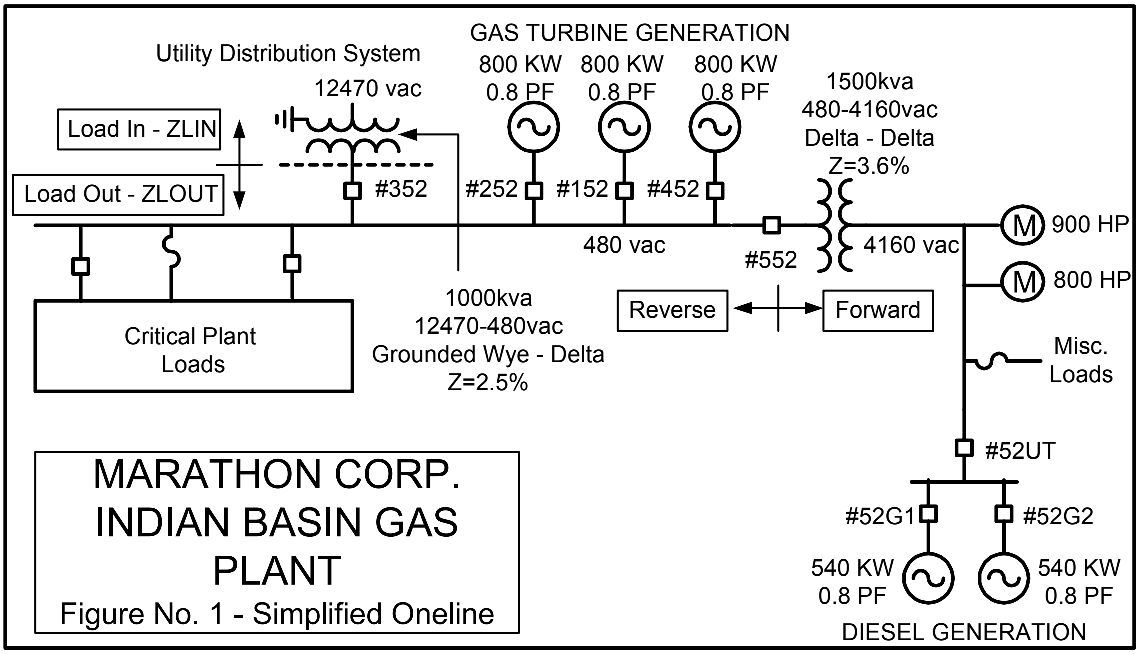

Figure No. 1

Advantages of Utility Source Transformer Connection

The 12470 – 480 vac grounded wye delta transformer configuration provides advantages to both the plant distribution system and the utility distribution system. The grounded wye primary benefits the utility by maintaining a solidly grounded system, even if the plant generation feeds a portion of the utility distribution system for a short period of time prior to tripping the #352 interconnect breaker. This scenario occurs when the utilities distribution circuit protection interrupts the distribution circuit and the #352 interconnect breaker remains closed until islanding protection, under voltage and/or under frequency trips the #352 interconnect breaker. Although this period is designed to be short, maintaining a solidly grounded system (X / R ratio of 3 or less) is necessary to prevent arrestor damage on the utility distribution system. Figure 2 below shows that when a ground fault occurs and the utilities distribution circuit protection trips to interrupt the fault, the ground fault is not cleared until the plant interconnect breaker #352 is opened. The utility distribution feeder now being energized from the plant generation via the interconnect remains solidly grounded by the grounded wye transformer connection. The 9kv arrestors are subjected to 12.47/1.732 kv or 80% of nominal voltage rating as long as a neutral shift does not occur. If an ungrounded wye or delta configuration was used on the utility distribution feeder side of the interconnect transformer, the 9kv rated arrestor would be subjected to approximately 12.47 kv or 138% of nominal voltage rating since the ground fault is maintained by the plant generation.

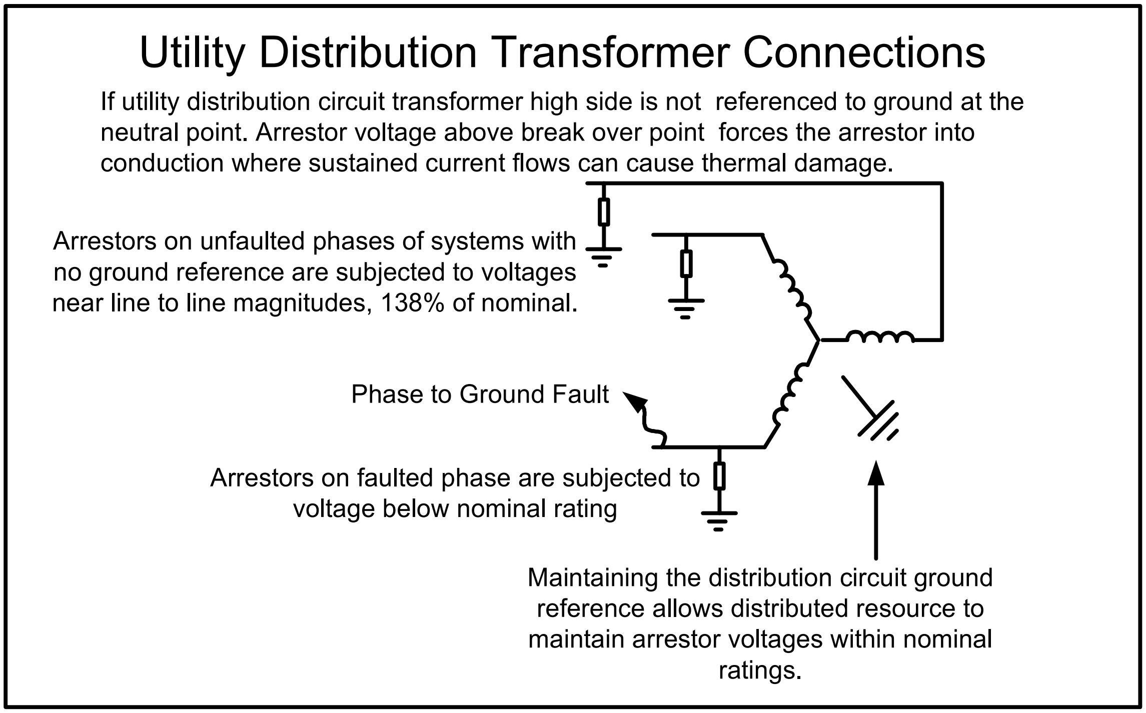

Figure No. 2

Zero sequence isolation is provided by the 480vac delta connected winding, which benefits the plant distribution system by allowing the use of high resistance grounding. The zero sequence isolation benefits the utility by eliminating plant generation contributions to distribution system ground faults. The utility and plant do not need to coordinate utility distribution ground fault protection with plant distribution ground fault protection.

Utility Interconnection Protection

A SEL-351 multi-function microprocessor based relay is utilized to provide interconnect protection. Besides providing the necessary protection and control functions, this system incorporates valuable functionality such as event analysis, sequential event reports and programmable display messaging. The plant engineering group uses these functions to not only monitor and record system disturbances, but to gauge protection quality as well as provide operator information based on system status. These techniques will be discussed later in this case study.

Source side open delta connected potentials are utilized by the protection system. Single level definite time phase-phase under voltage and phase-phase over voltage protection is provided by the protection system. Under voltage pickup settings are set at 94% of nominal and over voltage pickup settings are set at 132.5% of nominal. Definite delay time settings for both over and under voltage tripping are set for two seconds. Single level definite time under and over frequency protection is provided by the protection system. Under frequency pickup settings are set at 59.25hz and over frequency pickup settings are set to 60.25hz. Both over and under frequency definite time delay settings are set for 5.0 cycles. Reverse power detection with definite time tripping is provided by a unique load encroachment element. This load encroachment element detects balanced load flow from the plant to the utility based on positive sequence impedance calculations. CT connections are wired such that the reverse direction is defined as load flow from the plant distribution system to the utility distribution system. Settings for the load encroachment element are reverse minimum load impedance (ZLR), maximum positive load angle reverse (PLAR) and maximum negative load angle reverse (NLAR). When the positive sequence impedance falls within the region defined by these settings, ZIN is asserted. The ZIN element is then used to start a programmable timer which will trip the #352 interconnect breaker in 4 seconds. See Figure No. 3 below for a graphical representation of the load encroachment element. A major advantage of using the 4-second time delay is that load regulation of the plant's generation is not instantaneous and often short periods of reverse power flow occur when large plant loads are shed quickly. Numerous unnecessary trips of the #352 interconnect breaker are prevented by this approach. The time delay is coordinated such that distribution system reclosing can occur without the possibility of unsynchronized distribution system equipment closing.

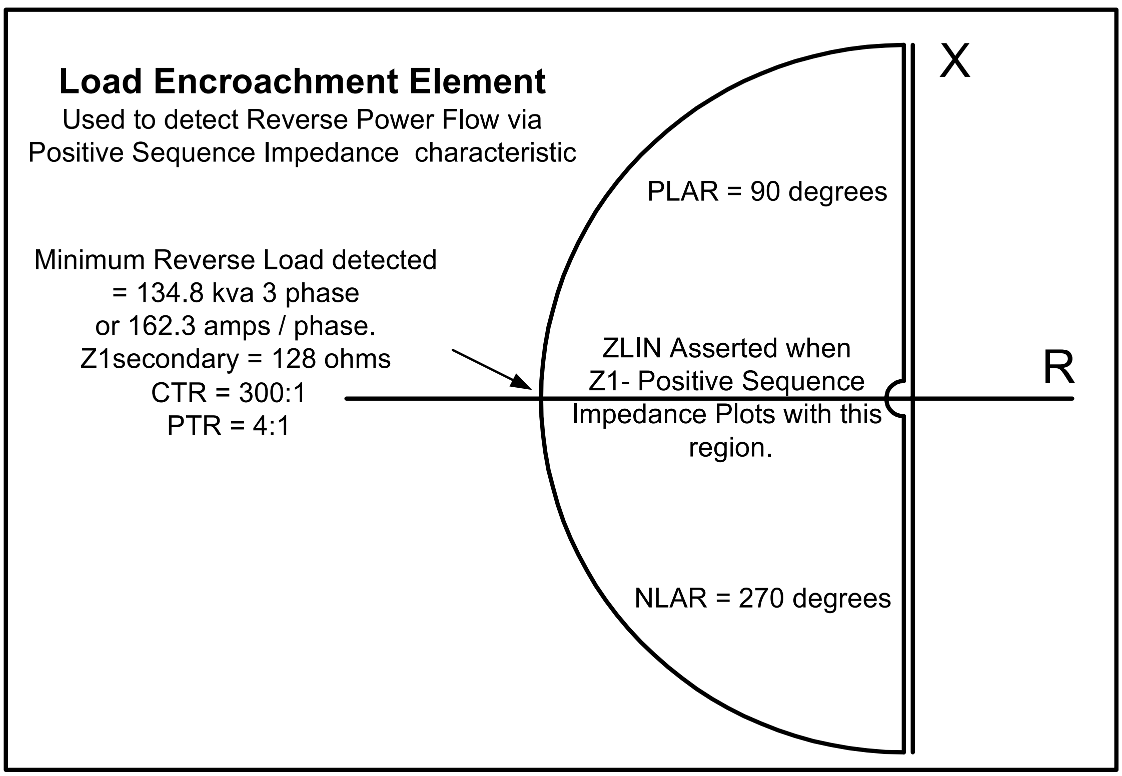

Figure No. 3

Speed matching, voltage regulation, and synchronization controls are employed by generation protection and control relays. A single layer of electromechanical check synchronization protection is utilized on the #352 interconnect breaker. No out of step protection is presently in service.

The interconnection protection as it exists has successfully opened the #352 interconnect breaker during utility disturbances numerous times. Under frequency and under voltage tripping are the predominant elements that initiate #352 breaker tripping during utility distribution disturbances. The load encroachment element has also operated during distribution system light load periods. Analysis of #352 interconnect breaker operations is routinely carried out to detect unnecessary or incorrect operation of the interconnect breaker. Analysis of these operations to date confirms the #352 interconnect breaker will operate properly for utility system disturbances. One additional setting is necessary when applying under frequency interconnect protection. Under voltage supervision settings within the under frequency element should be reviewed and are often lowered such that the under frequency element is not disabled by severe under voltage conditions.

Recommended Enhancements to Interconnection Protection

The protection system can provide additional features to improve monitoring and prevent #352 interconnect breaker closing when the utility distribution system is de-energized or out of synch with the plant distribution system. Utilization of an additional output contact programmed to prevent closing of the #352 interconnect breaker when the utility distribution system is de-energized or out of synch would provide an additional layer of close control protection. This programmable output contact should also be programmed to allow a definite delay time beyond distribution system restoration prior to closing the #352 interconnect breaker. This contact would remain open as long as the utility distribution system is in an off nominal voltage and frequency state. The contact would close when the utility distribution voltage and frequency return to normal and the specified time delay has expired. This type of close interlock control is prevalent in emerging standards. The driving force is preventing inadvertent utility distribution system energization for personnel safety reasons. See Figure 4 for proposed relay logic.

The interconnection protection equipment relies heavily on proper utility system voltage measurements. For this reason, the loss of potential indication element within the protection system should be provided to operation's personnel in the form of a interconnect protection system abnormal alarm. This loss of potential element detects abnormal potentials at the relay and can be utilized to block operation of protection elements. The loss of potential elements operates as follows. When a ten percent drop in positive sequence voltage is detected, with no corresponding change in positive sequence or zero sequence current, a loss of potential status is asserted. Loss of potential status assertion is latched if this condition persists longer than 60 cycles. The loss of potential status is automatically reset when positive sequence voltage rises above fifty volts secondary and the calculated value of the system negative sequence voltage is less than five volts secondary. When a potential fuse blows, circuit breaker trips or wiring failures occur, the loss of potential status can be programmed to an output contact to drive the interconnection protection abnormal alarm. In the case of interconnection protection, where critical process equipment will be maintained in service when the interconnect breaker is open, the loss of potential status should not prevent interconnect breaker tripping. In cases where the interconnect breaker needs to remain closed to maintain the critical process, loss of potential status can be used to prevent nuisance tripping caused by potential circuit abnormalities.

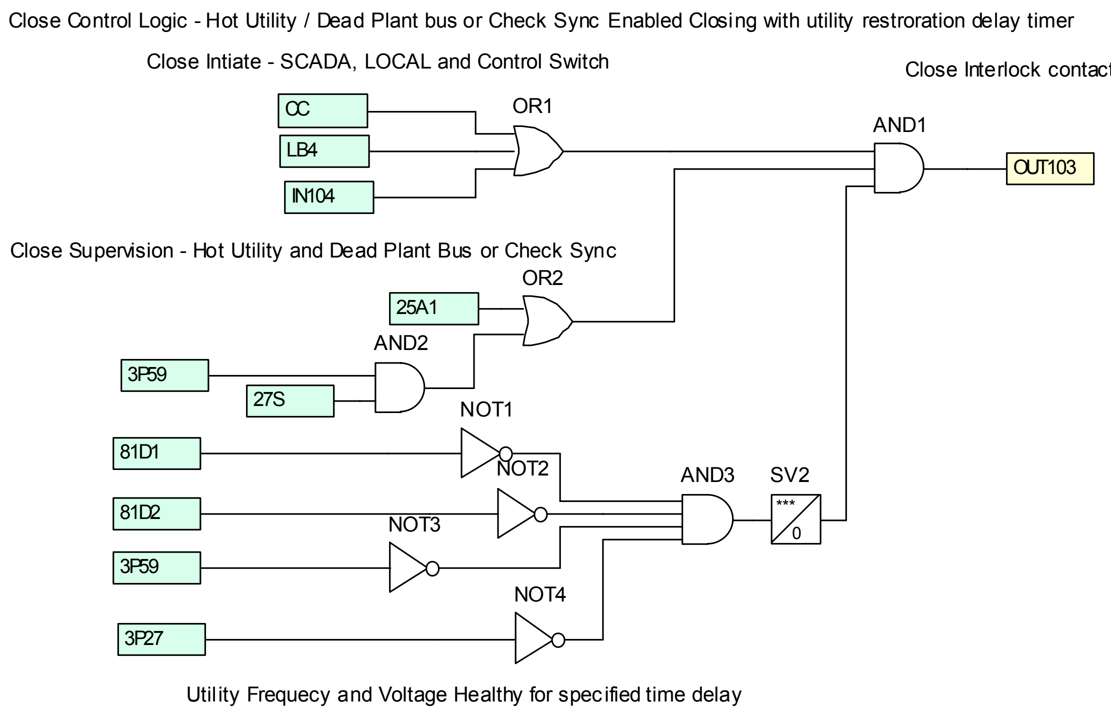

Figure No. 4

Plant Distribution 480 – 4160vac Tie Protection

The tie breaker #552 which connects the 480vac winding of the 480-4160vac step up transformer is operated normally closed and allows the two 540kw 0.8 power factor diesel generators to support the plant's main 480vac distribution bus. These generation resources provide the plant with future capability for expansion and are needed for generation redundancy requirements. Tie protection setting criteria is as follows:

- Provide fast low set overcurrent protection that is not sensitive to loading and secure for disturbances on the utility distribution system.

- Provide additional overcurrent protection for balanced fault conditions, which is less sensitive and secure during motor starting operations on the 4160vac system.

A SEL-351 multi-function microprocessor based relay is utilized to provide this tie breaker protection and control scheme. This protection package provides various levels of overcurrent protection. The fast low set protection specified in the criteria above is provided by a definite time directional negative sequence element. Relay connections are such that the forward direction is defined as current flowing into the 4160vac system. The definite time delay is set at 2 cycles to avoid tripping on negative sequence transients. These transients can be caused by unbalanced load conditions detected during breaker opening and closing operations. This directional negative sequence element will operate for unbalance faults in the forward direction only. It can be set below load current levels and is secure during unbalanced faults on the utility distribution system since these faults would be in the reverse direction. Both the 480vac and the 4160vac systems are predominantly high resistance grounded with ground detection and alarming equipment; therefore, no residual ground elements are utilized. The fast high set protection specified in the criteria above is a combination of a non-directional definite time overcurrent element and a non-directional extremely inverse time overcurrent element. This combination will operate for balanced fault conditions and is secure during motor starting in-rush. This tie protection system provides the following key advantages to the 480vac main plant distribution bus.

- Maintains close tie continuity with the 480vac plant main distribution bus throughout disturbances on the utility distribution system.
- Maintains close tie continuity with the 480vac plant main distribution system during motor starting operations on the 4160vac plant distribution system.
- Provides fast clearing of unbalanced faults located on the 4160vac system that minimizes adverse effects to the 480vac plant main distribution system.

Recommended Enhancements to Tie Protection

The multi-functional microprocessor based protection system incorporated in this tie protection can again be programmed to provide a close interlock contact which would prevent #552 breaker closing if the 4160vac distribution is energized or out of synch. This additional close interlock feature would again apply a second layer of check synch protection. The directional overcurrent elements utilize potentials to derive polarizing quantities. For this reason, loss of potential status should be programmed to provide a tie protection system abnormal alarm.

Protection Quality Measurements

Both the interconnection and tie protection systems incorporate sequential event reports. These sequential event reports record time tagged protection system element status. Since the multi-functional microprocessor based relay systems have multiple levels of protection, the unused levels of overcurrent protection are used for monitoring via these sequential event reports. These additional layers of over current protection are not programmed to initiate tripping. By analyzing the sequential event reports after plant distribution system and utility distribution system disturbances, measures of protection quality can be assessed even if no operations resulted from the disturbance. This technique is being utilized by engineering personnel at the plant and has given engineers much information on the response of the interconnect and tie protection systems to disturbances in both the utility distribution system and plant distribution system. One example of this analysis is that prior to implementing the directional negative sequence protection logic in the tie system protection scheme, the directional negative sequence settings were applied to the relay and monitored with the sequential event report prior to enabling the element in the tripping logic. This allowed protection engineers at the plant time to review the performance of the directional negative sequence settings during plant operations and utility distribution system disturbances prior to committing the relay settings into the tripping logic. Other examples of monitoring provided by the sequential event report was to evaluate the plant generation response during load shedding. The load encroachment element is monitored to provide information on duration of reverse power flow during plant load shed operations.

Event Analysis

Event reports, which contain much greater detail of the system parameters with both pre-fault and post-fault data, are automatically initiated and recorded in both the interconnection and tie protection systems. These reports can also be initiated by protection elements even if tripping is not initiated. These event reports provide vital information to plant engineering when the interconnect breaker protection system initiates tripping or the tie breaker protection system initiates tripping. Information obtained from these event reports include time of occurrence, voltage, frequency and relay element status prior to and during the disturbance, as well as relay settings in effect during the disturbance. The data obtained from the event can be used to replicate pre-fault and post-fault waveforms with relay element statuses provided. Phasor plots of voltage, currents and sequence quantities can be graphically obtained for each sample of data acquired by the protection systems. See Figure 5 and 6 below for examples of these wave form captures and phasor plots.

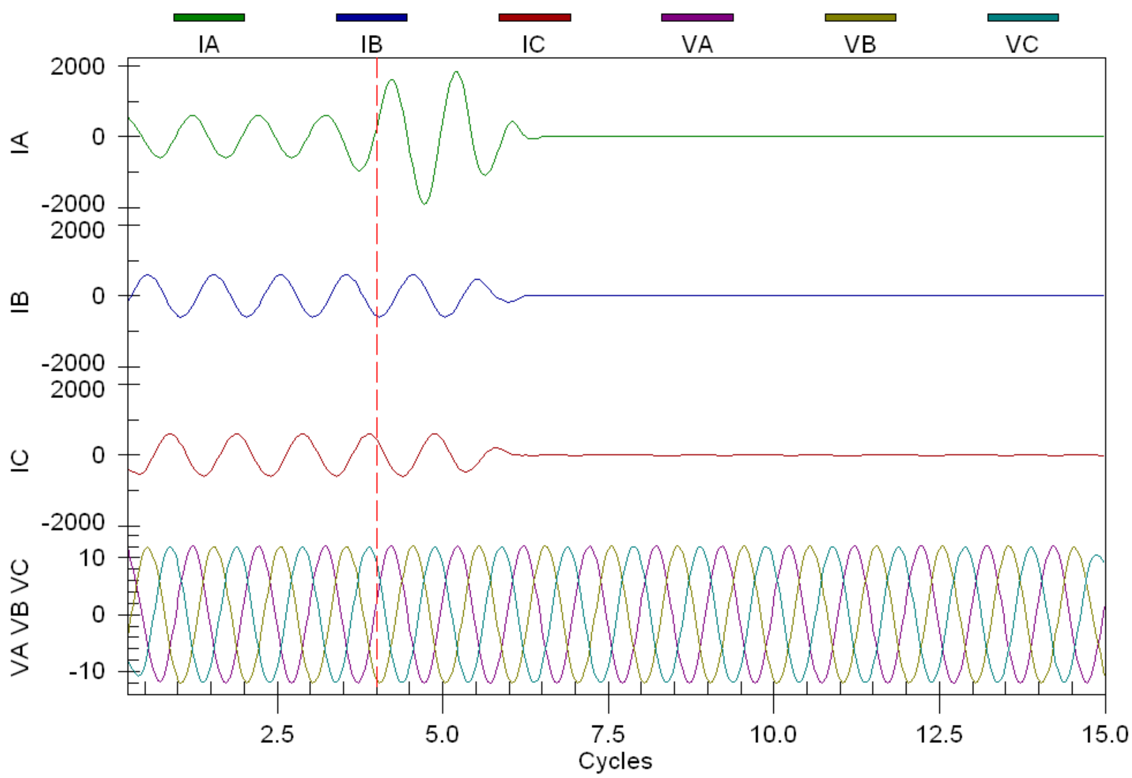

Figure No. 5

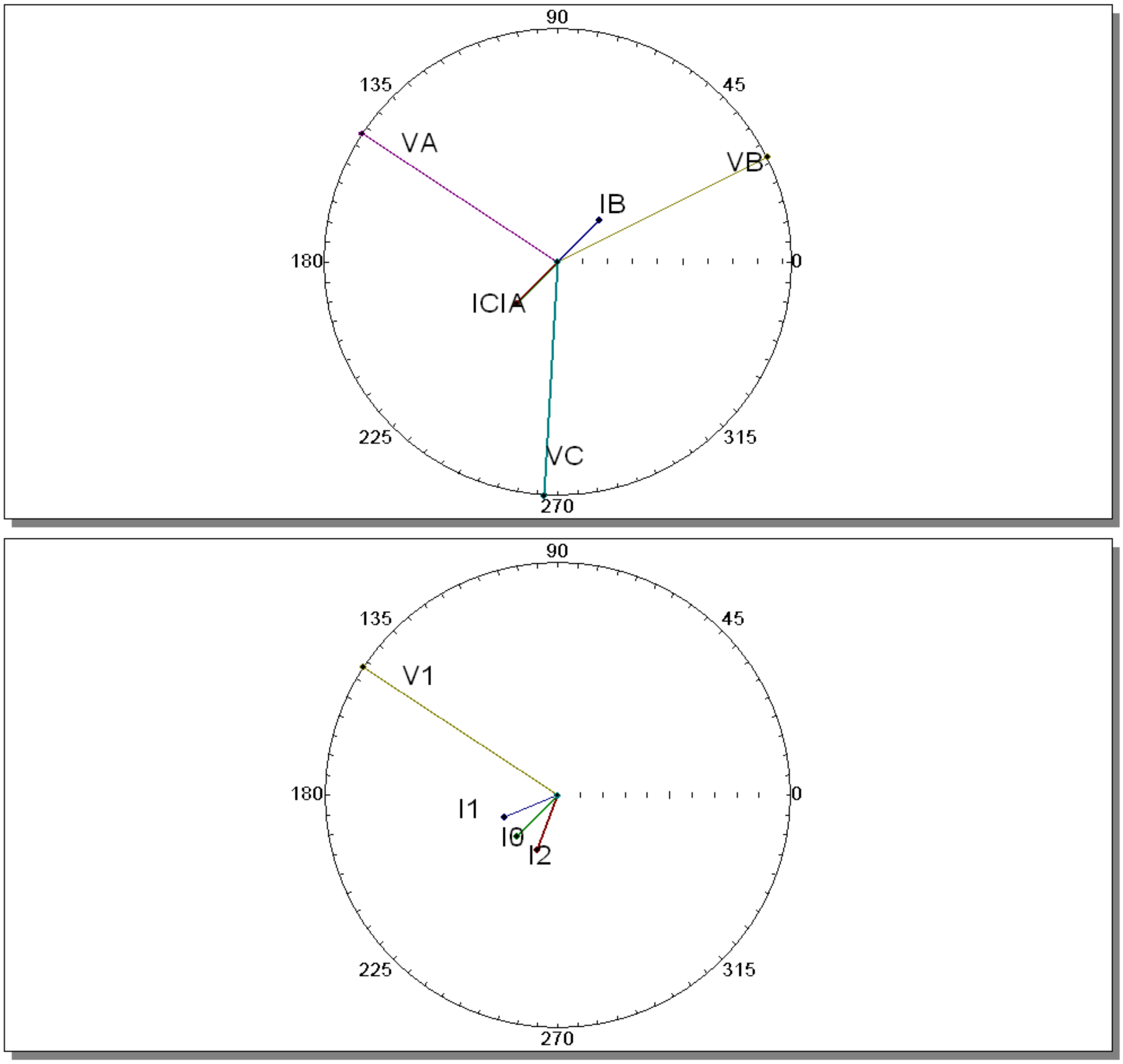

Figure No. 6

Display Messaging

Both the interconnect and tie protection systems aid operating personnel by providing display messages initiated by protection system element status. These display messages provide informative text that enhances protection system targets. An example of the display message programming is as follows: An under frequency initiated trip of the #352 interconnect breaker asserts a display message point which adds the following display text, UNDER FREQ TRIP, to the rotating display. These messages provide quick indication of type of operation to plant personnel.

Conclusions

This case study shows that interconnection protection is well suited to today's multi function microprocessor based relays. For most disturbances on the utility distribution system, operation of the interconnect breaker is initiated by the islanding elements, under frequency and/or under voltage. Additional reverse power protection is warranted if distributed resource generation equipment size matches closely with utility distribution system light load levels. Reverse power protection that is set extremely sensitive with fast or no time delays, increases nuisance interconnect protection operation. Consider generator load control response time when applying reverse power protection. Where possible, monitor the relay protection system to insure that vital input parameters are not out of range due to protection system abnormalities. For critical protection such as out of synch close control, employ additional layers of control where possible. Often a review of performance is necessary once an interconnection protection system is placed in service. This performance review should include methods of monitoring protection quality. Finally, provide local information to improve interconnection protection system operation and troubleshooting.