DIRECT TRANSFER TRIP REQUIREMENTS FOR LARGE INVERTER DER INTERCONNECTING TO THE LIPA DISTRIBUTION SYSTEM

EXECUTIVE SUMMARY

PSEG-Long Island (PSEG-LI) presently requires implementation of direct transfer trip (DTT) functionality on inverter-interfaced DER facilities connected to the LIPA distribution system and rated 1 MW or greater. PV project developers have raised objections to this requirement on the premise that the active anti-islanding (AAI) functionality of their inverters eliminates the need for DTT. The speed of island detection, however, is deemed insufficient to coordinate with the "instantaneous" reclosing implemented on LIPA feeders. This reclosing practice is critical for public safety and customer satisfaction in the densely-populated area that the LIPA system serves. Alternative approaches to provide reclosing coordination have been determined to be infeasible due to the physical design of LIPA substations. Therefore, PSEG-LI concludes that the DTT requirement is justified and must be retained.

BACKGROUND

Distribution feeders must be de-energized by opening of their circuit breakers in response to faults, for elimination of dangerous conditions (e.g., line down, not creating a detectable fault), for circuit maintenance, or for system reconfiguration. Conventional distribution systems have been designed with the expectation that there would not be any sources of energization connected to the feeder after opening of the normal feeder source at the substation. Interconnection of distributed energy resources (DER) to the feeders, with sufficient aggregate capacity to support the connected load, creates the potential for the distribution feeders to remain energized after the feeder breaker is opened. This is commonly termed "islanding", where utility assets and other customers are energized solely by DER.

This continued energization creates possible issues of public and worker safety, as well as power quality. However, the most significant issue is the possibility of the feeder breaker reclosing when the DER-fed island and the utility source voltages are out of phase. The potential consequences of out-of-phase reclosing are discussed later in this document.

PSEG-Long Island (PSEG-LI), as the operator of the Long Island Power Authority system, has a standing requirement that DER facilities rated 1 MW and above must have direct transfer trip (DTT) implemented so that these facilities can be removed from the distribution system when the feeder breaker opens. This requirement is imposed on all types of DER, including DER facilities composed of inverters tested and certified according to IEEE 1547.1 and UL-1741 standards. PV project developers have raised objections to this requirement on the premise that the active anti-islanding (AAI) functionality of the inverters eliminates the need for DTT because the inverters have proven the ability to detect islands under prescribed test conditions where inverter output and load demand are closely balanced.

THE CASE FOR INSTANTANEOUS RECLOSING

A majority of overhead distribution system short circuit faults are "temporary" in nature.[1] In this context, temporary means that if the circuit is de-energized for a period, and then the feeder breaker is closed again, the fault will no longer be present and the circuit will be returned to reliable service. Temporary faults can be the result of a flashover across an open-air gap (e.g., across an overhead line insulator) caused by a transient overvoltage such as a lightning strike. Deenergization of the circuit allows the fault arc path to deionize and regain its insulation strength. Other temporary faults are caused by an object, such as a swaying tree branch or an animal that bridges the gap between energized conductors and a grounded object for a moment before falling or burning away.

Distribution circuit reliability is greatly increased by implementing automatic circuit reclosing. Typical reclosing sequences are a short reclosing delay after the initial fault detection, and increasing delays for several subsequent reclosing attempts. Most of the time, faults are eliminated before the final stage of the sequence where the circuit breaker opens permanently (called a "lockout"). When implemented, the SAIFI (system-average interruption frequency index) reliability metric for a utility is substantially increased as most faults result in no customer outages at all (by industry standards, the brief reclosing delay is termed a temporary interruption and is not considered an outage).

Reclosing practices differ among utilities and regions, depending on factors such as the distribution voltages used, lightning frequency, expectations of customers, and the nature of the service territory. One parameter of a reclosing sequence that varies widely is the delay from initial breaker opening until the first reclose attempt. Many utilities use a so-called "instantaneous" first reclose, which is actually a delay of approximately 200 milliseconds. Instantaneous reclosing has proven highly effective for some utilities, and is widely used in service territories having elevated lightning vulnerability. Instantaneous reclosing is also more effective at the 15 kV-class distribution voltage used on the LIPA system, compared to higher distribution voltages. An IEEE survey reports that reclosing delays of less than one second are used by over 50% of utilities operating 15 kV-class distribution systems. [2]One reference reports a first-reclose success rate exceeding 80% using an instantaneous setting.[3] On the Pacific Coast, where much of the solar industry is based and has been focused, lightning is very rare. Utilities in this region often use much longer first reclose delays, on the order of several seconds, because most of the temporary faults they experience are caused by branches or animals.

Where instantaneous reclosing is successful, the impact of a distribution fault is barely perceptible to the public. Experience has shown that consumer devices such as digital clocks and controls ride through the very brief power interruption without disruption to their performance.[4] Motor-driven loads keep spinning on inertia. This greatly increases customer power quality and also is important for public safety. An outage of a traffic light for several

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[1] Short, T., "Electric Power Distribution Handbook", CRC Press, New York, 2004.

[2] *Ibid.*

[3] "Applied Protective Relaying", Westinghouse Electric Corporation, 1982.

[4] Short, T., *op. cit.*

seconds can lead to chaos and collisions (despite the rarely observed NYS law that states inoperative traffic lights automatically require four-way stopping by all traffic). Street lights will go out and take an extended period to restart if power is interrupted for several seconds, but will not do so for a brief interruption of only a fraction of a second).

The LIPA service territory has unique characteristics compared to upstate NY utilities. The lightning ground flash density is greater on Long Island than much of Upstate, meaning a greater proportion of distribution faults are lightning-induced flashovers which are usually "healed" by a fractional-second reclosing delay. Long Island is also much more exposed to coastal storms. LIPA customers are particularly demanding with regard to electric service reliability and quality. Long Island is an urban and densely-suburban area, with severe highway traffic congestion, where power interruptions can have a greater societal and public safety impact compared to upstate areas which may be more resilient and tolerant of interruptions. Therefore, PSEG-LI deems it unacceptable and imprudent, on the basis of customer power quality and public safety considerations, to change its present distribution circuit reclosing schemes.

Requirements of Standards

It is widely known that IEEE Std 1547™-2003 requires DER to cease energization of the utility feeder within two seconds after islanding occurs. Less attention appears to be devoted to Clause 4.2.2 of IEEE 1547 which states "The DR [DER] shall cease to energize the Area EPS [utility] circuit to which it is connected prior to reclosure by the AreaEPS." This effectively imposes a limit on islanding duration that is the lesser of the utility feeder reclosing delay and the two-second ceiling, unless some other means are applied to prevent feeder reclosing to an energized island. Although this requirement seems rather explicit, some apparently either ignore this reclosing coordination requirement or consider it to be ambiguous.

IEEE 1547 is now undergoing revision, and is expected to be adopted by 2018 or before. The current near-final drafts of this revised standard more explicitly define the requirement for reclosing coordination, and state clearly that either islanding must be detected within the existing reclosing delay, the reclosing delay lengthened by the utility, or means be implemented to block reclosing into an energized island.

Limitations of Standardized AAI Testing

Most inverter-interfaced DER, such as PV, use AAI schemes to detect islands and initiate DER tripping. These AAI schemes are tested in accordance with IEEE Std 1547.1™-2005 and UL-1741. These standards prescribe a test circuit composed of a load composed of parallel resistor, capacitor, and inductor that is tuned to 60 Hz, having a power demand matched to the DER output. The island detection test is performed using one inverter along with this synthetic load.

Actual utility loads consist of an array of customer devices having complex characteristics, including significant amounts of motor load. Loads that are purely resistive include electric water heaters, clothes dryers, kitchen ranges, and incandescent lights, which are just a fraction of the total load. The portion of pure-resistance loads is decreasing as incandescent lighting is phased out, and an increasing amount of load is electronically controlled with widely varying characteristics that are not well defined. It is estimated that LIPA loads during summer daytime hours, when PV output is also high, may consist of up to 50% to 70% motor load. This is of significance as the technical literature documents tests demonstrating that motor loads can perpetuate islanding to a substantially greater degree than purely resistive loads.[5]

Real utility distribution circuits tend to have DER from a range of manufacturers connected, each of which uses their own proprietary AAI schemes. The technical literature indicates that islanding detection effectiveness tends to decrease when diverse DER designs operate together.[6],[7]

The discrepancies between standardized DER tests and realistic system conditions are important because even the two-second islanding duration limit may not be certain in practice. PSEG-LI does not believe that there is a significant risk that a DER island could persist indefinitely, but it does believe that it would be imprudent to use reclosing times as short as two seconds on feeders where there is enough DER penetration to potentially support an island. A time margin is deemed necessary, so the shortest reclosing delays that can safely be used might be three to five seconds.

Consequences of Reclosing into an Energized Island

Small changes in the frequency of a DER-sourced island will cause the island's voltage to rapidly fall out of phase with the grid. If a feeder circuit breaker is reclosed when the grid and island are out of phase, the resulting transient can be damaging to utility and other-customer equipment and disruptive to system reliability. Unlike synchronous generators, it is recognized that inverters are self-protected and are not particularly vulnerable to the out-of-phase reclose. The reclose event, however, can cause very high transient overvoltages, transient torques on motor drive trains, and high inrush currents that cause nuisance operation of fuses and other over-current protective devices.[8] The transient overvoltages can damage sensitive customer equipment and may fail utility surge arresters, with the latter potentially resulting in a circuit outage.

Because of the potential impacts, the possibility of an out-of-phase reclose event must not be considered acceptable, even under highly infrequent circumstances.

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[5] H. Igarashi, T. Sato, K. Miyamoto and K. Kurokawa, "Power Generation Confirmation of Induction Motors and Influence on Islanding Detection Devices", Electrical Engineering in Japan, vol. 171, no. 4, 8-18, 2010

[6] Hoke, A., *et al.*, "Experimental Evaluation of PV Inverter Anti-Islanding with Grid Support Functions in Multi-Inverter Island Scenarios', National Renewable Energy Laboratory, Report NREL/TP-5D00-66732, 2016.

[7] Pazos, F., *et al.*, "Failure Analysis of Inverter Based Anti-Islanding Systems In Photovoltaic Islanding Events", 22nd International Conference on Electricity Distribution, Stockholm, 10-13 June 2013.

[8] Walling, R., *et al.*, "Summary of Distributed Resources Impact on Power Delivery Systems", IEEE Transactions on Power Delivery, Vol. 23, No. 3, July, 2008

Probability and Duration of Islanding

There has been much discussion regarding the probability of circuit conditions capable of sustaining an island. A widely-cited International Energy Agency report concludes that the probability of a sustained island is insignificantly small.[9] However, this study only considers islands persisting greater than five seconds to be of significance.

Most AAI schemes use some form of positive feedback that drives an islanded system beyond voltage or frequency tripping thresholds. The time required to reach the tripping thresholds is dependent on the excess or deficiency of real or reactive power in the islanded subsystem. Therefore, the duration that an island persists is a function of the degree of balance between the sum of real and reactive power outputs of the DER with the real and reactive power demand of the island's loads, net of real and reactive power attributed to losses and reactive power compensation (e.g., capacitor banks). Where the allowable island duration is very short, such as where coordination with very short feeder circuit breaker reclosing times is necessary, AAI schemes may not succeed for much greater degrees of power imbalance. Therefore, probabilistic studies based on power balance criteria required for much run-on times are not relevant.

Review of published studies and test results indicate that typical run-on times for inverters with AAI are much longer than 200 milliseconds, particularly where dissimilar inverter designs are operating together. The revision of IEEE 1547 undergoing development is almost certain to require disturbance ride-through functionality in order to mitigate the potential degradation of bulk grid security by ever increasing DER penetration.[10] The wider voltage and frequency trip settings necessary to allow this ride-through functionality inherently lengthens the response time of AAI schemes.[11] It is therefore concluded that AAI schemes are not capable of coordination with short feeder reclosing delay times; i.e. these schemes do not provide acceptable prevention of out-of-phase reclosing.

Voltage-Supervised Reclosing

PSEG-LI's opinion is that coordination with reclosing is the critical issue. A means of preventing circuit breakers from reclosing into an energized island would allow AAI functionality to substitute for DTT. Reclosing into an energized island can be blocked by a relay scheme called voltage-supervised reclosing, otherwise known as "undervoltage permissive" or "overvoltage blocking". This consists installing a potential transformer on the feeder side of the breaker, on each phase, and connecting the secondary of the PTs to voltage relays. The voltage relay contacts are in series with the reclosing relay's contacts, and do not allow reclosing to occur when there is voltage above a certain threshold on the feeder.

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[9] Cullen, N., Thornycroft, J., Collinson, A., "Risk Analysis of Islanding of Photovoltaic Power Systems within Low Voltage Distribution Networks", International Energy Agency Report IEA PVPS T5-08, 2002.

[10] NERC Integration of Variable Generation Task Force, "Performance of Distributed Energy Resources During and After System Disturbance Voltage and Frequency Ride-Through Requirements", National Electric Reliability Corporation, 2013.

[11] Hoke, A., *op. cit.*

Conceptually, this provides the necessary prevention of out-of-step reclosing. However, the design of LIPA distribution substations makes implementing voltage-supervised reclosing schemes practically infeasible. LIPA substations use outdoor metal-clad switchgear, which are modular units including a draw-out circuit breaker, instrument transformers, and protective relays, all in a single metallic enclosure. Figure 1 shows a typical metal-clad switchgear. This switchgear does not have PTs on the feeder side of the breaker that can sense feeder voltage. It is infeasible to retrofit the switchgear with PTs as there is no space allowed for accommodating these devices. Underground cables ("express feeder" or "feeder get-away") connecting the feeder to the switchgear are terminated within the enclosures. The first available location where PTs can feasibly be installed are where the cables connect to the overhead feeders, usually some distance from the substation. The PT secondary leads would have to be run to the substation, or transduced and communicated to the substation over a data link. There may also be inadequate provisions to add the voltage relays to the modular switchgear unit. For the reasons stated, voltage-supervised reclosing is deemed to be an infeasible solution for LIPA substations.

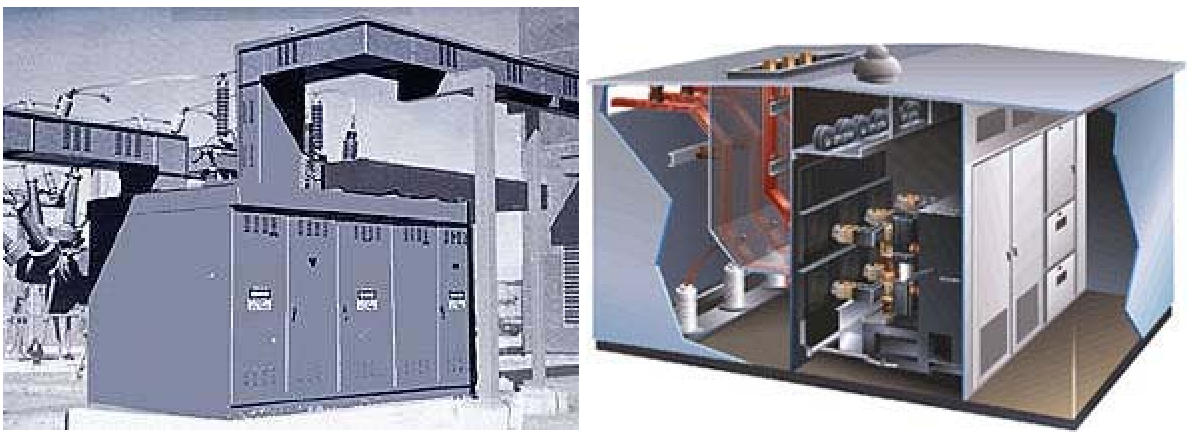

Figure 1 – Photo and cutaway illustration of typical outdoor metal-clad switchgear. (Source: OSHA.Gov)

DTT Requirement

Instantaneous feeder reclosing has substantial benefits to LIPA customers and the public at large. Inverter AAI schemes are inadequate to coordinate with short-delay feeder breaker reclosing, thus posing risk of damage to utility and customer equipment as a result of out-of-phase reclosing. Voltage-supervised reclosing would be a satisfactory solution if it were not for practical implementation issues specific to LIPA distribution substation design. Therefore, PSEG-LI has no choice but to continue to require DTT for large DER facilities.

The issues of islanding and reclosing are related to the aggregate rating DER on the feeder, and not to the rating of any particular DER facility. However, the imposition of DTT on small DER, such as residential and small commercial rooftop PV, is impractical and poses undue costs on these small projects. Even where an individual large DER facility does not have sufficient rating to alone pose a risk of short-term islanding, this large facility combined with small DER may reach the critical aggregate rating threshold, either now or in the foreseeable future considering the economic and policy-driven proliferation of DER. A DER rating threshold of 1 MW has been determined to be both an economically-tolerable cost to facilities of this size and a rating that can easily put the typical LIPA feeder well towards the DER penetration where short-term islanding can be expected.