Communications Assisted Islanding Detection

Contrasting Direct Transfer Trip and Phase Comparison Methods

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***Abstract*—A power system island is a part of the power system grid that becomes separated from the larger power system and, depending on the actual load and local generation resource output, may continue to function. Islands may occur as substation breakers are opened and power system faults are cleared, separating local demand and generation from the utility's power system.**

Islanding detection and prevention is an important part of distributed generation (DG). IEEE 1547 – Standard for Interconnecting Distributed Resources with Electric Power Systems, recommends that an island be detected and removed within two seconds of an occurrence. Islanding prevention has several benefits, some of which are safety, generator and consumer equipment protection, and power system stability.

Islanding detection is the most challenging part of power system islanding protection. There are several methods that are used to detect an island condition. These can be generally broken up into three types: passive detection, active detection and communications-assisted detection.

For the purpose of this paper we will focus on communications-assisted detection. Communications-assisted detection has some advantages over passive and active detection methods. There are several different types of passive and active detection but typically each may have a significant non-detection zone (NDZ) or hysteresis in order to compensate for false positives. With communications-assisted schemes, the NDZ can be significantly reduced while still keeping false positives at a minimum.

There are several different types of communications-assisted detection. This paper discusses the advantages and disadvantages of the Breaker Initiated Direct Transfer Trip and Phase Comparison methods. The Phase Comparison method offers some unique advantages over Direct Transfer Trip especially when used in conjunction with complex generator interconnections or when multiple sources of islanding exist. The main benefit of the Phase Comparison method is the simplification of the communications channel required. This greatly reduces cost and complexity while still providing the benefits of a communications-assisted scheme.

***Index Terms*—Anti-islanding, direct transfer trip, phase comparison, communications.**

I. Introduction

A power system island occurs when distributed generation becomes separated from the utility's power system. When this separation occurs it is possible for the generator to continue to supply power to the island independent of the utility, so long as the generator has enough capacity to meet the demands of the load (otherwise the generator would be isolated due to voltage, frequency, or other protection device). Unless appropriate measures are taken, this island condition can remain indefinitely.

II. Unintentional Islanding and Risks

A distinction must be made between intentional islanding and unintentional islanding. A micro-grid, for example, is designed to intentionally separate from and reconnect gracefully to the utility's system when desired. This may be a case of intentional islanding. Unintentional islanding occurs as a result of system protection operations, such as the operation of devices like breakers, disconnect switches, and reclosers. Other events such as system switching operations, environmental issues, and equipment failure may also cause unintentional islanding. This paper will focus on unintentional islanding, and intentional islanding will not be considered further.

When unintentional islanding occurs there are risks to which the utility as well as the public may be exposed. These risks can be categorized as risks to personal safety, power quality and equipment damage.

Personal safety can be affected as the generator may back feed power onto disconnected lines. This poses a risk to utility personnel working on these lines, which they may presume are dead, but also can be a risk to the public in the case of downed live wires within public areas and roadways.

Power quality is also likely to be affected during unintentional islanding. While islanded, any regulation from the grid is lost. As a result power regulation will be reduced, possibly exposing customers to fluctuations in voltage and frequency. As a result of these fluctuations damage can occur with customer and utility equipment connected within the island.

Aside from these risks it is necessary for synchronous generation to be resynchronized to the grid before reconnecting. Without resynchronization damage can occur to the generator. As a result it is beneficial to trip the generation so it can be synchronized again.

For the reasons stated above, IEEE 1547 – Standard for Interconnecting Distributed Resources with Electric Power Systems, recommends that an unintentional island be detected and removed within two seconds of an occurrence [1].

III. Islanding Detection and Prevention

Detecting unintentional islands under all system conditions can prove to be challenging. In an attempt to satisfy all cases, different types of islanding detection methods may be used. Of these methods there are two major categories: local and communications-assisted methods.

A. Local Methods

The purpose of local methods is to detect an island condition with information available at the generator station only and without any external coordination. This benefit is that a minimal amount of equipment is required, simplifying installation and maintenance. Local detection methods can be subcategorized into two categories: passive and active.

1) Passive Methods

Passive local methods use voltage and current measurements from the generator station to determine an island condition. Under/over voltage and frequency relays are commonly used for this purpose. When the demands of the load are expected to exceed the available generation of an island, these methods are effective for islanding detection as the voltage and frequency will not be stable in such cases. When generation and load are closely matched voltage and frequency will be more stable and may cause the passive methods not to trigger when desired. This is known as the non-detection zone (NDZ). In order to reduce the NDZ, passive methods must be set with increased sensitivity in order to detect the island condition. Often, this results in a trade-off between the extent of the NDZ and tripping of the generator during system disturbances not related to any islanding conditions [2]. This will cause loss of generation at a time when the generation may be critically needed [3]. Any false-tripping of this type is undesirable from a generator point of view. Due to the risks of the NDZ, if passive methods are to be used, utilities will commonly require minimum loads to be significantly greater than available distributed generation (DG) levels.

2) Active Methods

Active local methods are similar to passive in that they only require equipment at the generator station (they are local). The islanding detection method however, is altogether different. Active methods repeatedly "test" the system and observe the systems response to these "tests" in order to detect an island. This testing can come in the form of injecting disturbances into the system and checking the response against a predefined result. If the response exceeds a set threshold, then an island is considered "detected". Active methods are better suited than passive methods in cases where load and generation are more closely matched. Although active methods can be successful, concern still exists when multiple DG sources on the same circuit employ active methods [2]. These multiple sources can cause interference with each other, resulting in false positives causing false-tripping. Also, even the best active methods still maintain a certain NDZ. Therefore it may not be possible to detect an island under all system conditions.

B. Communications Assisted Methods

Communications-assisted islanding detection methods do not rely solely on local measurements to determine an island. They coordinate with other devices to determine an island condition. This coordination requires the communication of information between devices for successful operation.

Communications-assisted anti-islanding detection methods offer advantages over local passive and active methods. Although local methods may offer lower equipment and operating costs, communications-assisted methods effectively eliminate the NDZ found in local methods. Since communications-assisted methods rely on external coordination rather than local measurements, the NDZ of local methods is eliminated. Primary islanding detection can then be implemented with the communications method and the local passive methods can be reserved for backup. One of the main benefits in this scheme is that voltage and frequency elements can be set less sensitively, reducing the number of false positives associated with unrelated system disturbances.

There are different types of communications-assisted islanding detection available. The most common is a Direct Transfer Trip (DTT) initiated by an isolation device, e.g. breaker, switch or recloser. Another method is through a Phase Comparison system. Although this is less common, it offers some unique advantages over DTT. Other communications-assisted methods that may exist are outside the scope of this paper.

1) Direct Transfer Trip

DTT islanding detection functions through the sending and receiving of transfer trip signals. The sending of the transfer trip is initiated, or keyed, by an isolating device capable of creating an island condition. This can be a single device such as a substation breaker on a radial distribution line or it can be multiple devices depending on the system topography. Typically, each DTT signal will require its own point-to-point communications circuit, since devices are installed in geographically separate locations. Once the transfer trip signal is received at the generator, the local breaker will be opened and the generator taken off-line. For cases where multiple isolation devices must operate to form an island, special logic schemes must be used to determine the presence of the island.

As with other protection applications using communications, we must consider the core parameters which determine performance of the communications channel. These parameters are security, dependability and latency. Security is defined as the resistance to false operation during adverse conditions such as a poor signal-to-noise ratio or poor bit error rate. Dependability is defined as the ability to operate when desired during adverse conditions. Latency can be defined as the total time between the initiation of the DTT signal at the transmitting equipment and the physical or actual operation at the receiving equipment. Typically security and dependability have an inverse relationship with each other. Measures taken to improve security will often negatively impact dependability. Conversely, measures taken to improve dependability will often negatively impact security. As a result, optimizing security and dependability becomes a balancing act which must be considered when selecting communications channels and parameters. Security is particularly important with any DTT-type signal, including islanding detection. Since a DTT signal can directly cause a trip to occur (it is unsupervised by other elements), a high level of security is needed to prevent false operation and loss of generation. Dependability, although not as critical as security, is still important. The most secure system is one that will never operate - defeating the purpose of the system altogether. When a communication circuit is used as the primary source of islanding detection, dependability becomes somewhat similar to the NDZ as with local detection. If the DTT receiver does not receive the intended transfer trip signal during the unintentional islanding event, the island is effectively not detected [2] and backup methods will be required to intervene. For the reasons stated above, when selecting DTT communication channels and methods, thorough consideration should be given to these communications channel parameters.

There are a number of communications channels that are suitable for DTT islanding detection. These include fiber optic, private or leased digital networks, analog phone line, digital phone line, power line carrier and wireless radio. Factors to be considered in selecting channels include availability, equipment cost, operating cost and reliability. Whichever method is selected, it must conform to the applications security, dependability and latency requirements. For leased channels, service level agreements (SLA) may specify pertinent performance metrics.

The advantages of the DTT islanding detection scheme are independent of the communication method. As described previously, utilizing a communications channel for islanding detection eliminates the NDZ seen in local methods. As a result, voltage and frequency elements can be de-sensitized to greatly reduce false operations during unrelated system disturbances. Another advantage is speed. End to end operating times of less than 10ms are common with most protection-grade channels. Adding one or two additional cycles of delay to increase security will still allow for speeds less than 40ms. Finally, for many applications DTT is a simple solution for islanding detection. Simple radial lines with generation at one end, like that shown in Fig. 1, are the simplest type and make it easy to design, implement and maintain DTT anti-islanding solutions.

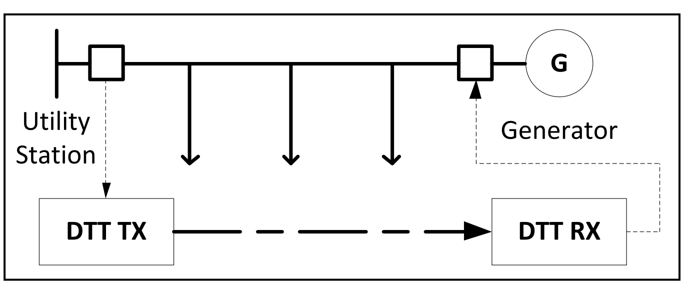

Fig. 1. Radial line Direct Transfer Trip example.

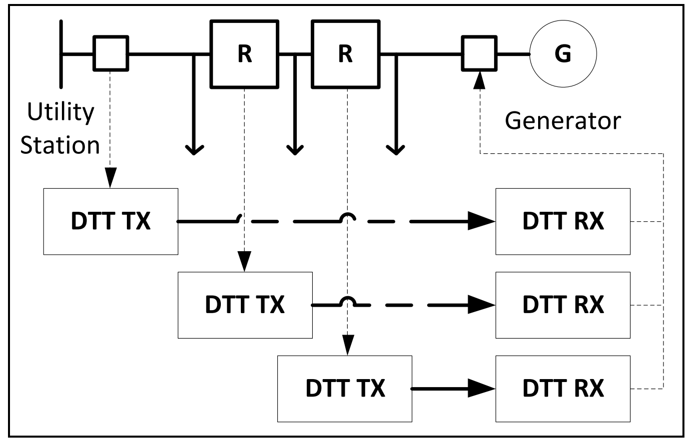

Fig. 2. Direct Transfer Trip example with multiple interruption sources.

The disadvantages of DTT for anti-islanding start with the initial and/or recurring communications costs as with all communications methods. For a single DTT channel this cost may be manageable, but when the number of interrupt devices multiplies and the interconnection topology becomes more complex the number of DTT channels and complexity increases greatly, as in Fig. 2 and Fig. 3. It should be mentioned that some communications methods can help alleviate this complexity and duplication of devices. Single-point to multi-point or multi-point to multi-point communications can help reduce the number of independent communications channels required. For example, using a shared wide-area network (WAN) with IEC 61850-8-1 GOOSE protocol can reduce the number of point-to-point communications circuits. Still, the complex logic required to determine an island for complex topologies remains.

2) Phase Comparison

Phase comparison is an altogether different method of islanding detection. Like DTT it utilizes a communications channel to determine an island condition, but operates on a completely different principle. To detect an island the phase comparison method compares the voltage phase angle at the generator station with the voltage phase angle at the utility source station. While the generator is connected to the utility station there will be little phase angle difference as both will be synchronized and operating at the same power system frequency [3]. When an island is formed, load imbalances will cause a frequency difference between generator and utility and the phase angles will begin to drift apart [3]. At a preset phase angle, typically 90°, the phase comparison system will provide a trip command to prevent the unintentional island from persisting [3].

To perform the phase comparison and islanding detection it is necessary to communicate data about the utility voltage phase to the generator where the comparison takes place. The sending and receiving of the voltage phase is accomplished using a phase comparison transmitter and receiver. This consists of a transmitter that is modulated with the voltage phase frequency and a receiver that detects this modulated signal. With microprocessor-based protection communications equipment and integrated programmable logic the comparison and islanding detection functionality can be achieved in a single device.

Because communications circuits are used to deliver the utility voltage phase information, inherent communications delays occur and must compensated for. Without delay compensation a fair comparison cannot be made. Comparison must be done in a time-aligned manner because any uncompensated delay will appear as a phase shift. Methods used for delay compensation vary for different channel types as the delay characteristics may be different. For example, with pure analog circuits the communications delay will be relatively constant as there are no variable delays associated with packets or path switching, as with some digital communications. With digital communications extra precaution should be taken as communication delays may not be fixed. With direct fiber optic systems this is not a concern, but with multiplexed digital networks, both private and leased, this can occur. For example, path failures may cause digital networks to switch paths to reroute data. These path changes can cause differences in communications delays as the data traverses different routes. To successfully use these types of digital communications, some automatic delay compensation must occur. A common method for performing this compensation is by round trip ping pong measurements. Ping-pong schemes repeatedly measure the round trip latency in the communication circuit. Assuming the channel delay is symmetrical, the one-way delay can be calculated by dividing the round trip time by two. Using the calculated one-way time delay the communication device can compensate for the delay internally. Delay compensation, either automatic or manual, can be done by delaying the local generator voltage phase digitally, in programmable logic such as a timer, to align with the received utility voltage phase.

In some cases it is desired to have backup or manual control of the generator connection to the utility station above and beyond the phase comparison detection system. This is typically possible since the communications channels and terminal equipment used would likely be capable of also providing a DTT signal initiated at the utility station. This could come in the form of an additional transmit function in digital communications or as an additional frequency channel with analog communications. This same capability could also be used in the reverse direction, from generator to utility, for the purpose of delivering breaker status information to the utility for integration into the utility operations system.

With phase comparison islanding detection the time it takes for a trip to occur from the inception of the island will vary according to several factors: the resulting frequency difference between utility and generator at the time of islanding; the difference in the phase angle trip set point; and the security trip delay time. We can define this detection time according to the following equation, Eq. 1.

$$T_D = A_T / \{360 * |(F_S - F_G)|\} + D_S \quad (1)$$

where:

T_D = phase comparison detection time.

A_T = desired trip angle.

F_S = utility system frequency at the time of islanding.

F_G = generator frequency at the time of islanding.

D_S = security trip delay.

In a practical example, when islanded, the generator frequency may fall to 59.5 Hz while the utility station remains at 60.0 Hz. With a trip angle setting of 90° and using Eq. 1 the time it will take for the phases to reach 90° of slip will be 500 ms. Adding a security delay of six cycles, or 100 ms in a 60 Hz system, will give a total detection time of 600 ms. With only a slight load imbalance and the generator frequency falling to 59.8 Hz while the utility station remains at 60.0 Hz, a total detection time of 1.35 seconds can be expected considering the same parameters. This still provides ample time for the breaker to open and prevent continuation of the island within the IEEE 1547 two-second requirement [1].

Requirements for security and dependability are different for phase comparison systems than with DTT systems. As discussed, with DTT there is a need for a high level of security in order to prevent false operation. With phase comparison the information being communicated is a representation of the voltage phase and does not directly cause a trip to occur. It is necessary first for the received voltage phase information to be compared with the local voltage phase and second to meet or exceed the set trip angle. As a result, phase comparison is inherently more secure than a DTT system as there is supervision from other elements, and these must operate together in order to cause a trip condition. In order to further improve security, a security delay may be added to require several consecutive cycles where the measured phase exceeds the set point, typically six, before issuing a trip.

Dependability of the phase comparison communications system is paramount. Since the phase comparison islanding detection system relies on receiving the utility voltage phase information it is necessary to have a high level of dependability. Depending on the communications system, different parameters can be optimized to improve dependability. With analog communications, certain security features such as guard before trip and noise detectors need to be removed or desensitized. For digital communications, changes to consecutive message requirements may be reduced or bit error rate blocking may be relaxed.

Communications options for phase comparison islanding detection vary from DTT. Power line carrier would not be a suitable option as communications would be lost during islanding. Audio leased lines and several digital communications are viable options. As discussed any communications channel with variable delays must utilize a dynamic delay compensation method. It is important to note that audio channels multiplexed onto digital networks may result in variable delays, unlike point-to-point audio circuits. Sometimes it is not obvious whether or not leased phone lines are being transported by digital networks. When utilizing leased phone lines it is important to understand how the line is constructed and if it traverses any other networks, and if so, what types of networks.

Some digital communications such as wireless and packet based have not been thoroughly validated for phase comparison. Some of these may be feasible but additional testing is necessary to determine performance and suitability for the application.

Phase comparison islanding detection, like other communications-assisted methods, does not have the NDZ of local methods and also solves a number of the disadvantages of DTT.

When multiple sources of islanding exist, phase comparison provides a simple approach as it is not necessary to know the individual states of each interruption device. Since islanding is determined by the inherent voltage phase slip it is not necessary to know which device caused the island. Thus the communications requirements are simplified. Regardless of the number of interruption devices only one communications channel is needed for each generator on a circuit. With DTT each interruption device position must be known in order to determine the same island condition, and multiple communication channels may be required.

In Fig. 2 a radial distribution line with two reclosers is shown. In order to know if an island exists, using DTT, the position of the substation breaker, recloser 1 and recloser 2 must be known. When any of these devices open, an island is created. The resulting open operation will initiate a DTT command to be sent to the respective DTT receiver which will isolate the generator at the point of interconnect. In this scenario three DTT transmitters, three receivers, and three communications channels are required to successfully detect all island conditions. In Fig. 3 the same scenario is depicted using phase comparison as the islanding detection method. Since it is no longer necessary to know the position of the individual breaker and reclosers, only one transmitter, one receiver and one communications channel is required. Regardless of which device causes the island a resulting voltage phase drift will occur and be detected.

In cases of complex generator interconnections phase comparison islanding detection helps simplify the communication channel requirements. For looped systems, islanding detection based on breaker, recloser, and switch positions can create the need for complex logic to determine if an island exists. With phase comparison this is not necessary. Regardless of how the island is formed and by what combination of open breakers, the inherent phase drift will occur and be detected.

In Fig. 4 an example loop system is shown. In this scenario the generator is interconnected to the utility source station by means of separate lines and stations. Using DTT as the primary islanding detection method would require breaker position information for each breaker to be known. Since it is not possible to island in this scenario, without a breaker or isolation device from each interconnection being open at the same time, it is necessary to utilize logic to determine if an island exists based on the current breaker status. In this scenario six DTT transmitters, six receivers, and six point-to-point communication channels are needed for full implementation. The cost of this type of system would be many times greater than a phase comparison system. In Fig. 5, with the same scenario, communications-assisted islanding detection can be achieved with one phase comparison transmitter, one receiver and one communications channel.

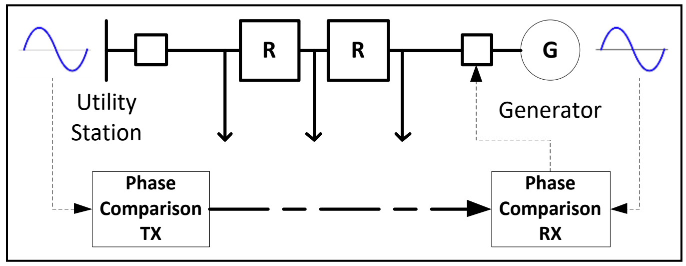

Fig. 3. Phase comparison example with multiple interruption sources.

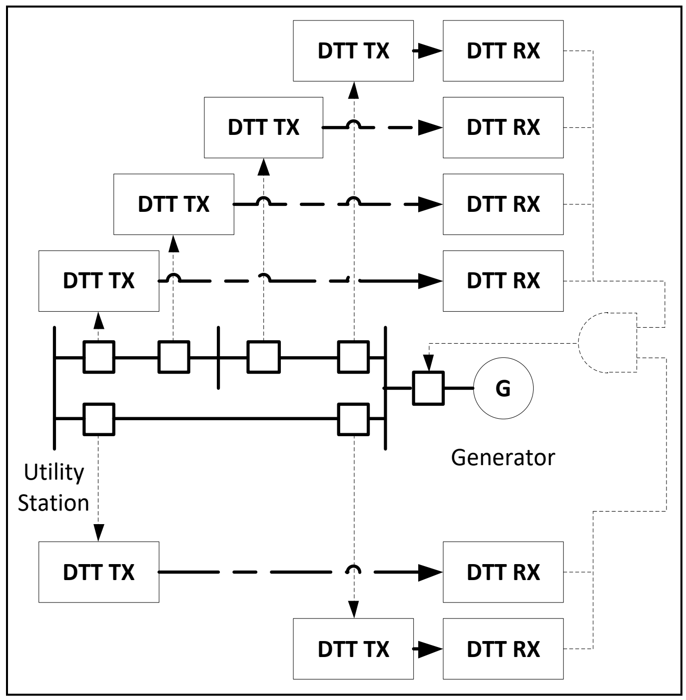

Fig. 4. Direct Transfer Trip loop system example.

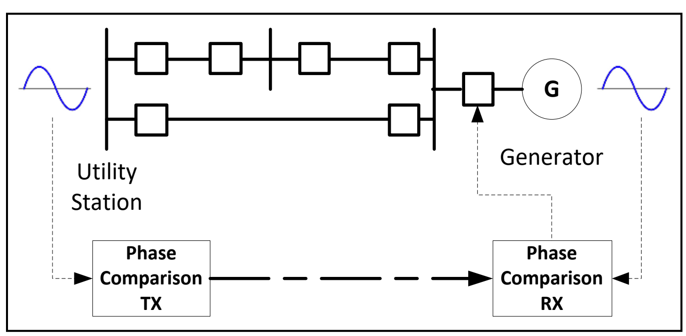

Fig. 5. Phase comparison loop system example.

Another advantage of phase comparison for islanding detection is the adaptability of the phase comparison system for the future. In a situation where DTT may be a simple application with only one substation breaker involved, in the future more complexities could be added with the addition of reclosers or other changes to system topology. With phase comparison these upgrades may not require any changes to the islanding detection system. For DTT, each recloser added requires another transmitter, another receiver, and another point-to-point communication channel. With phase comparison nothing additional is needed and the same islanding detection system still functions as it did before. This has an added benefit when considering non-utility generation. It would be difficult to approach a non-utility generator to expand their islanding detection system when there is little upside from their position. In this way phase comparison islanding detection systems can provide a "future proof" and adaptable method while still achieving the benefits of communications-assisted islanding detection.

As with DTT and other communications-assisted methods, the initial and recurring cost of the communications circuit is a disadvantage. However, phase comparison can significantly reduce the need for additional communications channels in complex systems, both today and into the future. Even in the most simple applications phase comparison will not add any additional communications requirements over DTT.

IV. Conclusion

Unintentional islanding brings a number of risks related to safety, equipment damage and power quality issues. Because of this, unintentional islands are not desired and need to be prevented. In some cases detecting island conditions may be difficult, especially when using local detection methods. These methods are not as robust at detecting islands where generation and load are closely matched. Communications-assisted methods such as DTT have been used effectively for many years but can bring with them considerable costs and design complexities when utilized for applications involving multiple islanding sources and complex interconnections. With the proliferation of DG comes the need for more robust anti-islanding solutions. Phase comparison islanding detection simplifies the detection system requirements by detecting voltage phase shift as a result of frequency change between the generator and the utility. This helps reduce the need for communications channels and equipment by shifting the detection method from breaker, switch or recloser status to simple phase angle comparison. Performing phase comparison over communications channels requires delay compensation for an accurate comparison. Fixed compensation for fixed delay communications easily achievable but will not suffice for variable delay communications. For variable delay, compensation must be dynamic. Microprocessor based protection and communications platforms provide the mechanisms, such as ping-pong measurements, for achieving dynamic delay compensation.

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Biographies

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