AI-Based Islanding Detection for Utilities and Industrials

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SUMMARY

The Islanding Detection Algorithm, or iDA, is a method devised for detecting electrical islands in distribution systems. It is based on a patented technique for transmission-system applications that operates on voltage and current measurements. This paper discusses simulation tests for distribution feeders with Distributed Energy Resources (DERs) in New York and California. The results reveal that, by applying Machine Learning to many conceivable circuit configurations, the grid strength values form two clusters of numbers (one for grid-connected conditions and one for islanding conditions). The two clusters have a separation large enough to set a threshold value for islanding detection. The presented islanding-detection algorithm (iDA) requires only measurements local to the DER location, and thus, avoids the needs for data communications and its associated costs.

KEYWORDS

Distributed Energy Resource (DER), Direct Transfer Trip (DTT), Islanding, Under/Over Voltage, Under/Over Frequency and Impedance, Short-circuit Analysis (SCA).

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1. INTRODUCTION

Unintentional islanding occurs when a Distributed Energy Resource (DER) continues to provide power to a section of the utility grid after the substation has been disconnected from the main grid. The likelihood of islanding is rare in practice, as a stable island would need a perfect balance between load and generation to initially exist and continue to sustain. In most instances, a voltage or frequency problem arising in an unstable island would trigger onboard anti-islanding schemes to disconnect the DER, which are part of the interconnection standard. However, the safety of line workers and the public will continue to be the primary concern, and the utility may require Direct Transfer Trip (DTT) for certain DER installations. DTT is a feeder-level protection scheme, which disconnects the DER if an upstream breaker is opened or a fault is detected. DTT is considered effective and has a long history of use in utility-system protection. However, the cost of a DTT installation can be high as it requires data communications and separate transmitters and receivers for each DER installation. In operation, DTT can become problematic when feeders are reconfigured to accommodate load change or to restore service following an outage.

Recognizing that the cost of DTT can be a barrier to wide adoption of DERs, stakeholders in states with policy that encourage DERs, such as New York and California are looking for new, low-cost techniques for islanding detection. This paper presents a new Artificial Intelligence driven low-cost technique that does not require data communications like DTT and can adapt to changes in circuit topology.

Central to this method is the grid strength seen by the DER. The grid strength depends on the DER location and changes with time because the grid changes continuously. The transition of a distribution circuit from normal (connected to a substation) to islanding (disconnected from the substation) exhibits itself in a significant change in the grid's strength. Tracking a changing grid strength has been successfully done and implemented for high-voltage relay applications [1]. The tracking technique is now migrated to distribution-systems application and can be implemented in relays or smart inverters. This paper reports on Phase 1 tests, which were done via simulating distribution circuits in New York and in California.

Section 2 discusses the review of existing islanding detection methods and their comparison. Section 3 describes the iDA methodology, Section 4 covers the testing of iDA via simulations on distribution feeders in New York and California and Section 5 provides conclusions.

2. REVIEW OF EXISTING ISLANDING DETECTION METHOD

Islanding detection methods based on the location of measurements belong to two categories: (i) Local method and (ii) Remote method. The local method can be further divided into Passive, Active and Hybrid methods. While the local methods can reside at the DER site, the remote methods do not, they are based on the monitoring at the utility level. These methods are further described below [2]:

1. Passive inverter-resident methods rely on the detection of an abnormality in the voltage at the point of common coupling (PCC) between the DER and the utility.

2. Active inverter-resident methods use a variety of methods to cause a disturbance in the PCC voltage that can be detected to prevent islanding.

3. Active methods not resident in the DER also actively attempt to create an abnormal PCC voltage when the utility is disconnected, but the action is taken on the utility side of the PCC. Communications-based methods involve the transmission of data between the DER or system and utility systems, and the data is used by the DER system to determine when to cease or continue operation.

4. Passive methods that are not resident in the DER, such as utility-grade protection hardware for over/under frequency and over/under voltage protection relaying, are the utilities' fall back to assure loads are not damaged by out-of-specification voltage or frequency. These may be required for very large DER installations.

See Table 1 for the comparison of different methods in each of these categories.

Characteristic	Local Method			Remote method	
	Passive	Active	Hybrid	Utility	Communication
Principle of operation	Uses monitoring of local V, I , f	Uses signal injection from DER	Combination of passive and active	Based on specific equipment	Communication Grid and DERs
Non-detection zone	Large	Small	Small	None	None
Response time	Short	Slightly shorter than passive	Longer than active	Fast	Faster
Operation failure	Possible depending on threshold	Possible	Possibility lower than individuals	Possible if parameters sized out	Possible due to ferro-ressonance
Effect on distribution system	None	Voltage fluctuation	Lower than active method	None	None
System cost	Low (minimal hardware)	Medium (additional equipment)	High	Very high	Extremely high
Effectiveness	Depends on consume/supply	Effective even in source/load balance	Very effective	Very effective	Most effective
Multiple DGs operation	Possible	Not possible	Possible	Possible	Possible
Influence by the number of connected inverter	None	Yes	Yes	None	None
Effect on power quality	No degradation	Degraded	Degraded, but lower than active	No degradation	No degradation

Table 1. Comparison of methods

This paper presents a different islanding-detection algorithm (iDA), which is passive and based on local measurements. The details of iDA described in the next section.

3. DESCRIPTION OF iDA

The invention is an algorithm, called Islanding Detection Algorithm (iDA), that processes voltage and current measured at the point of interconnection, i.e., the location where the Distributed Generation (DG)/DER is connected to the distribution circuit. The premise behind the iDA is that there is a fundamental difference in network impedances, or "Thevenin," when a distribution circuit transitions from being grid-connected to being island-operated. Essentially, (a) when the distribution circuit is part of a grid, the Thevenin impedance of the external world as seen by the DG/DER is small, but (b) when the distribution circuit is isolated from the grid, the Thevenin impedance is large.

Making the iDA work in practice involves two things:
1. A reliable way to track the Thevenin impedance based on local measurements of voltage and current. We adopt the technique described in U.S. Patent No. 6,249,719 and US Patent 6,219,591 for use in distribution circuits.
2. A distinction between "small" and "large" Thevenin impedance values. Before the iDA is deployed in the field, analysts use a computer model of the underlying distribution circuit and simulate all conceivable conditions (islanding vs grid-connected) to build the two ranges, "small" vs "large."

For the prospective DG/DER owners, the iDA technique lowers the equipment cost when compared to methods that are based on data communications (remote methods in Table 1). The iDA complements the existing local, passive methods that cannot detect stable islands.

4. SIMULATION DESCRIPTION AND RESULTS

The simulation studies were performed on several sample feeders in New York and California to test the iDA algorithm. The simulation results of one sample feeder for each state is discussed in this paper. Two sets of simulation cases were studied. The first set consists of grid-connected cases, and the second set consists of islanding cases. Grid-connected cases include normal and a number of switching event configurations. These events may result in different configurations for the feeder and thus different Thevenin impedance seen by the same DER. With the islanding cases, a stable island was formed, as iDA is more of interest for stable islands, i.e., the balance of local generation and local load at the moment of islanding. For unbalance islands, a voltage or frequency problem may arise and would trigger onboard anti-islanding schemes to disconnect the DER. With stable islands, these schemes may not help in detect the islanding condition.

Sample Feeder#1

Figure 1 shows a layout of sample feeder#1. The substation P is a normal source of supply for this feeder, wherein a fault or loss of the normal supply for this feeder there are a number of alternate switching configurations which can restore the supply source from nearby substation feeders 44258 and 34552. An example of islanding is given in Figure 1, following the disconnection from the substation P, two stable islands were formed (highlighted in dotted circles, colored red and blue). Each island has several DERs in operation. The candidate location of DER is pointed out with symbol 'X' and in the second island two candidate locations of DER were chosen, point 'Y' and 'Z'.

In processing the first set, both the SCA and iDA methods are used to compare the results of the observed Thevenin impedances. (They should be similar!). Figure 2 compares the Thevenin impedance seen by the DER at point 'X', 'Y', and 'Z'. With the second set, the SCA is used first, and the iDA is used only if the separation between the two impedance clusters is found to be insufficient (see Figure 3).
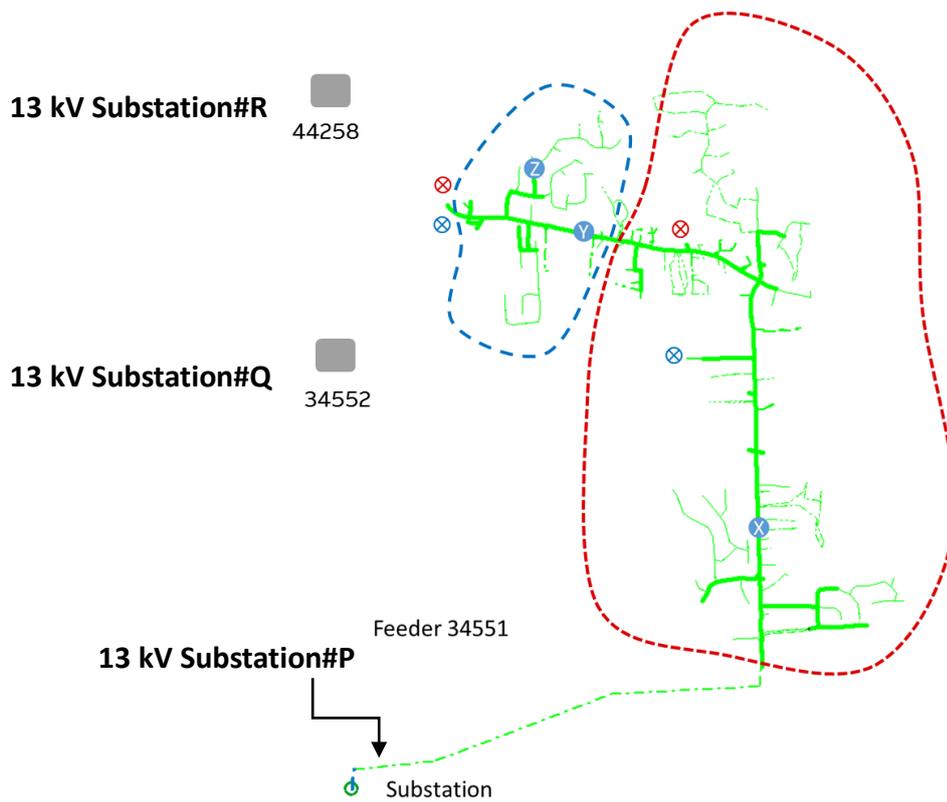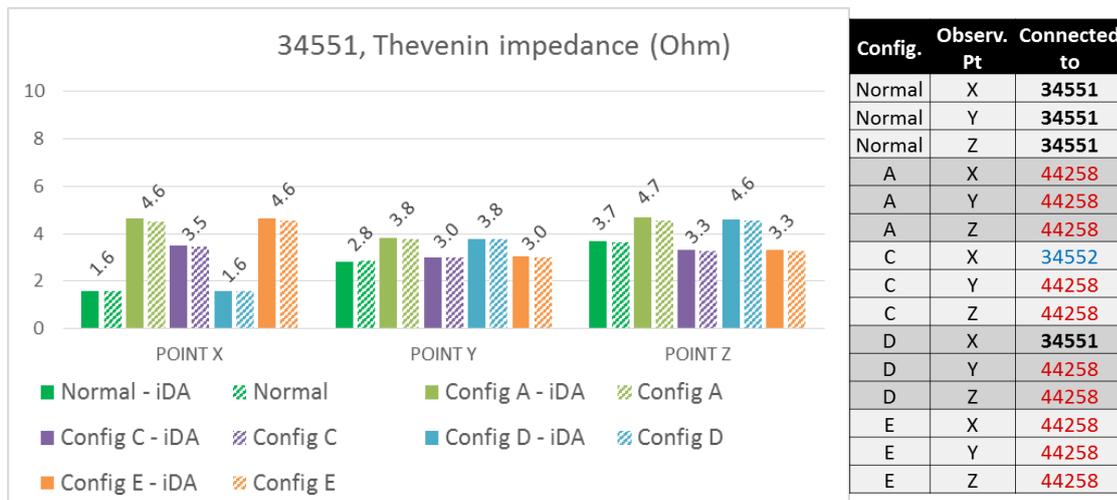
Figure 2. Lay-out of sample feeder#1

Config.	Observ. Pt	Connected to
Normal	X	34551
Normal	Y	34551
Normal	Z	34551
A	X	44258
A	Y	44258
A	Z	44258
C	X	34552
C	Y	44258
C	Z	44258
D	X	34551
D	Y	44258
D	Z	44258
E	X	44258
E	Y	44258
E	Z	44258

Figure 2. Compare the results of the Thevenin impedances during grid connection (SCA vs. iDA)

Thevenin Impedance (Grid connected vs islanding):

Figure 3 shows the results for the three observations points 'X', 'Y', and 'Z' of Feeder 34551. The cluster of low-value bars is for grid-connected cases and is the same in Figure 2. The cluster of high-value bars is for the islanding. Note that for islanding values, two values are shown: one based on the use of SCA (Short Circuit Analysis) and one on iDA. The SCA value is less than the iDA counterpart, as expected, since the SCA overestimate the strength of inverter-based sources. Note that the iDA-based value is not computed for point 'X', as it belongs to an unstable island.

Because the separation is large for the two clusters of values, the impedance threshold for Feeder 34551 is trivial to choose. One candidate is 10 Ohms, for all three sites 'X', 'Y', and 'Z'.
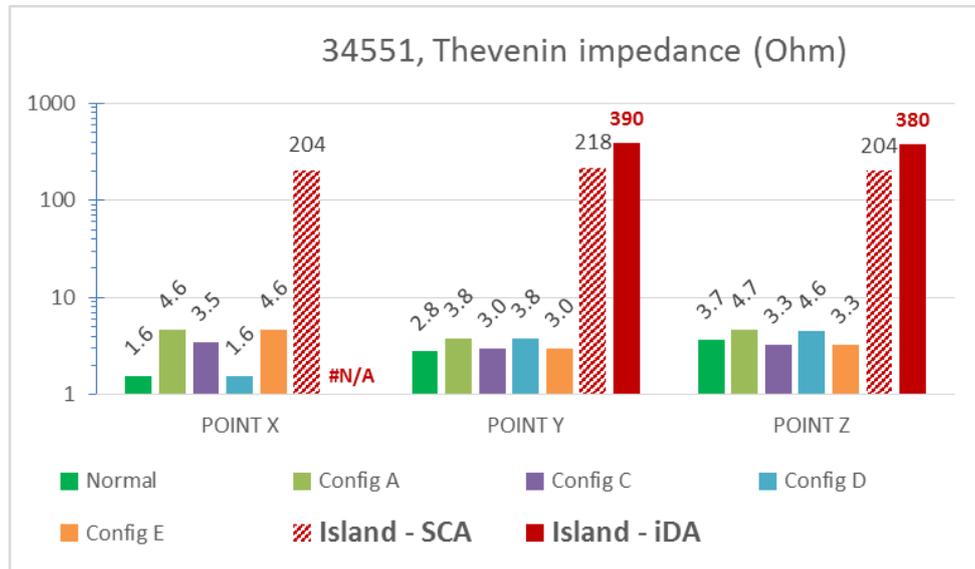

Figure 3. Compare the results of the Thevenin impedances (Grid-connected vs. Island)

Sample Feeder#2

The layout of the sample feeder#2 is given in Figure 4. The largest DERs on this feeder, denoted by circles, form roughly four clusters. Four locations are chosen as representatives for their clusters: 'X', 'Y', and 'Z' are Photovoltaic sources; 'AA' is a synchronous generator. In all simulation models used in this study, Feeder A has the most details as it is the focus of the study; Feeder B is represented in aggregated format:

- Feeder A has all details of the main and laterals (colored orange in Figure 4), as in the provided CYMDIST model.
- Feeder B represented only the portion shown in the green color of the feeder. This is because the feeder has only one DER, dwarfed by the total load on the feeder; thus, to have a combined, stable island with feeder A, only a portion of feeder B will be retained.

Thevenin Impedance (Grid connected vs islanding):

Figure 5 shows the results for the four observations points 'X', 'Y', 'Z', and 'AA' of Feeder A. The cluster of low-value bars is for grid-connected cases and the cluster of high-value bars is for the islanding. Note that for both grid-connected and islanding, three values are shown: one based on the use of SCA and second and third on iDA. In set 1, all DERs are online, while in set 2 one synchronous generator offline.

As expected, the SCA value is less than the iDA counterpart. The locations that are closer to the substation (Y and AA) see a clear jump in Thevenin impedance than the locations that are far away from the substation (X and Z).

Because the separation is large for the two clusters of values, locations that are closer to the substation, the impedance threshold for location 'Y' and 'AA' can be set at 5 Ohms and 4 Ohms, respectively. Location 'X' and 'Z' are marginal, can set a threshold of 12 Ohms and 14 Ohms respectively.
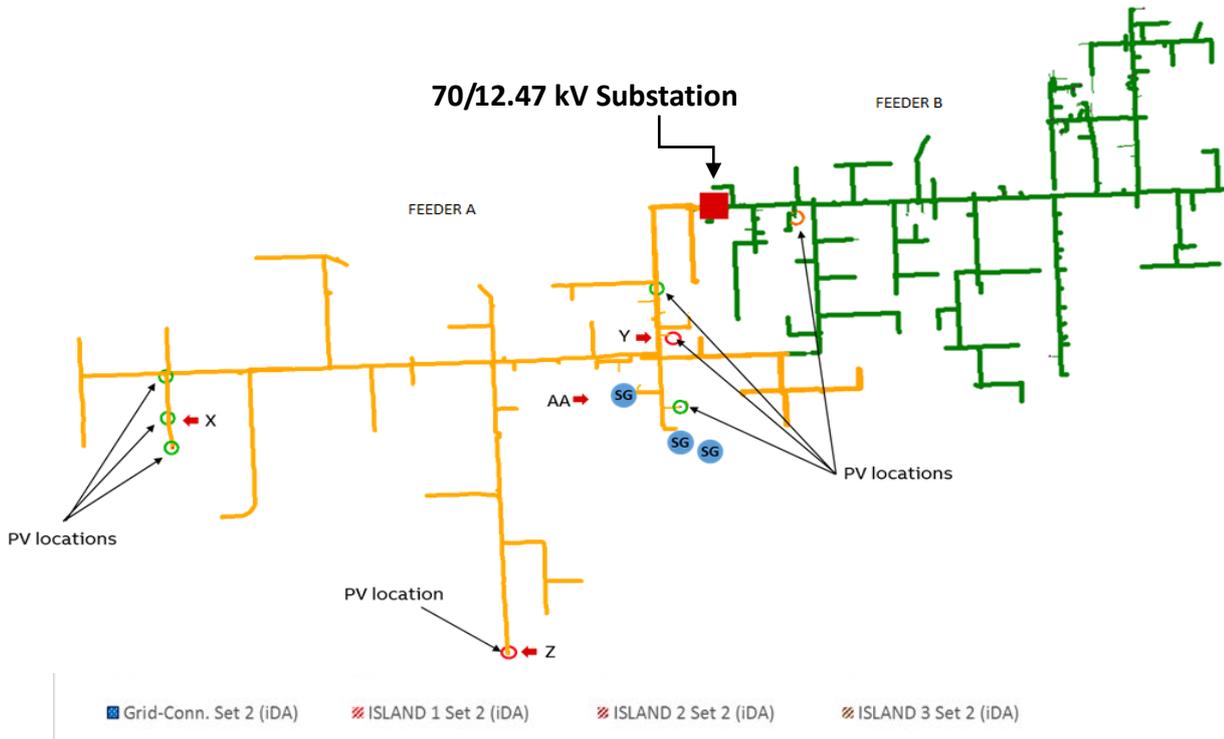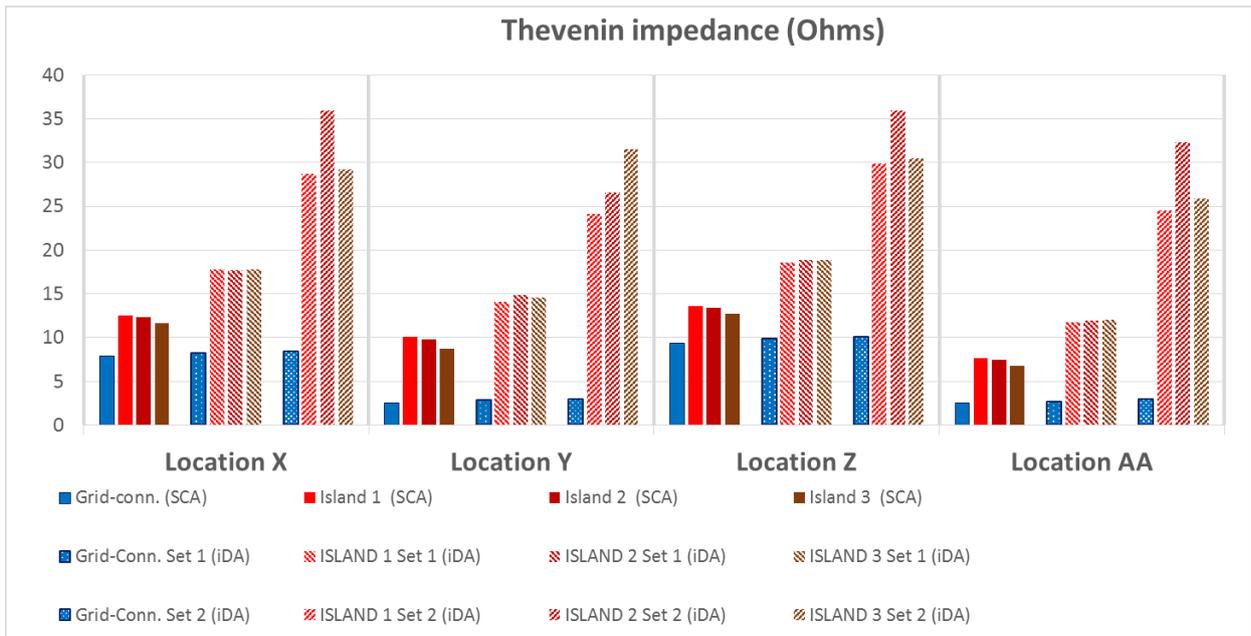

Figure 4 Layout of sample feeder#2

Figure 5. Compare the results of the Thevenin impedances (Grid-connected vs. Island)

5. CONCLUSION

The results reveal that, by applying Machine Learning to many conceivable circuit configurations, the grid strength values form two clusters of numbers (one for grid-connected conditions and one for islanding conditions). The two clusters have a separation large enough to set a threshold value for islanding detection. The presented Islanding Detection Algorithm (iDA) requires only measurements local to the DER location, and thus, avoids the needs for data communications and its associated costs. Encouraged by the results, the research team will carry out further phases of the investigation (to test with field data and to implement in actual devices), which will be disclosed in future publications. The goal of the work is to introduce the iDA as a new add-on for relays and smart inverters and to make it a standard feature for DER protection and control functions.

In the grid-connected case, the two techniques yield similar results; this is because the capacity of the bulk-power grid dwarfs the capacity of the DERs on the feeder. However, in islanding configurations, the role of DERs becomes central. The SCA gives a smaller Thevenin value, as the SCA overestimates the strength of inverter-based equipment. The ABB patented technique, used by iDA to track the impedance, inherently recognizes the inverter dynamics in the measurements, and therefore, properly computes the Thevenin value. This is an important aspect in a test deployment of the algorithm on the physical feeder.

One additional outcome of the study is a faster method for setting impedance threshold for the jump from grid-connected to islanding. We find that the SCA can be used for screening, thanks to its simple modelling and fast computation. The screening is to gauge the separation between two clusters of numbers: grid-connected impedance values versus islanding values. If this separation is found to be sufficient, a threshold can be set. Otherwise, a dynamic simulation is needed to find the true separation before setting a threshold.

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