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# Negative Sequence Impedance Measurement for Islanding Detection In Presence of Distributed Generation

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K E Y W O R D S: fault Negative Sequence Impedance, Distributed Generation (DG), islanding detection, intentional-islanding, Active method, short-circuit.

**ABSTRACT:** Distributed generation (DG), similar to other generators require electrical protection against system short-circuit and unusual conditions. Adding DG to the electric power distribution systems, can reduce the reliability, protection, system stability and power quality to consumers. The challenges associated with DG, protecttion against the unscheduled islanding, is an important issue. It is essential that the islands are immediately detected and the DG is disconnected from the distribution network or taking it under control. According to distribution utility Standards, the island must be detected in less than 2 seconds. In this paper a new method for detecting active synchronous type generator island DG, based on negative sequence impedance measurement is introduced. A negative sequence impedance islanding detection (NSIID) method is an improvement in the impedance measurement techniques for the detection of an island due to the negligible non detection zone and specifically large threshold window. Finally The algorithm for implementing this network protecting approach will be presented. In this paper, simulations have been done in Digsilent and results have been analyzed.

## Introduction

Small localized power sources, commonly known as “Distributed Generation” (DG), have become a popular alternative to bulk electric power generation [1]. There are many reasons for the growing popularity of DG; however, on top of DG tending to be more renewable, DG can serve as a cost effective alternative to major system upgrades for peak shaving or enhancing load capacity margins [2].

Islanding is a condition in which a micro-grid or a portion of the power grid, which contains both load and distributed generation (DG), is isolated from the remainder of the utility system and continues to operate[3]. The island state is intentional or unintentional. In this paper, the purpose of the island is kind of unintentionally.

The IEEE society has produced a standard for Distributed Generation IEEE 1547, [4] [5], that highlights the IPP’s distributed generator requirements. One of the requirements for islanding detection states that if an island condition were to occur, the distributed generator should detect and disconnect itself from the network within two seconds of the island state occurring. Apart from published standards and specialized industry requirements, islanding conditions are technically undesirable. There exists many islanding detection methods that can be fundamentally split into two basic categories: communication and local where local detection can then be split into two more sub headings of active and passive detection schemes [6].

The most reliable and also often the most difficult to implement islanding detection scheme is through direct communication between the distributed generators and the utility. Though the trivial case for this method is extremely reliable, the practical implementation of transfer trip or power line signaling can be in flexible, complex and expensive to implement for higher penetration of distributed generators and in other more complex systems. As a result, more cost effective methods of local islanding detection are preferred. Local detection means that the Independent Power Producers are responsible for detecting and disconnecting their generator(s) when an island condition occurs independently and without direct input from the local utility.

Due to its negligible impact on power quality, a passive islanding detection method is desired. Passive islanding detection monitors the distributed generator terminals for changes in the voltage, current or frequency to estimate the system island state. Unfortunately, passive techniques have sensitivity limitations; hence, active islanding detection methods are being proposed in combination with passive methods [7] [8]. Active detection methods proposed in available literature, consist of a signal or disturbance being injected into the network by the DG or near to the DG and the resulting reaction is then measured and compared to the preset threshold.

Reactive power export error detection method, impedance measurement method, slip-mode frequency shift algorithm (SMS), active frequency drift (AFD), active frequency drift with positive feedback (AFDPF), automatic phase-shift (APS) and adaptive logic phase shift (ALPS) are a few examples of active islanding detection techniques. The problems with these techniques are that they introduce perturbations in the system and detection time is slow as a result of extra time needed to analyze the system response of the perturbations. Furthermore, the perturbations are injected at predefined intervals even though it is unnecessary during most operating conditions. Also, if islanding occurs during an interval, then it has to wait for next perturbation to be applied before it can be detected, which further elongates the detection time. Applications of active techniques are limited to the DG type and/or load, i.e. reactive power export error detection method cannot be used when the DG has to operate at the unity power factor and methods based on phase shift are mostly useful for inverter based DGs. Also, AFD is very effective for purely resistive loads but it may fail for other loads. Active methods based on impedance measurement introduce high frequency signals, AFD injects a distorted current waveform, and SMS, AFDPF, APS and ALPS shifts the phase of output current. This will often lower the quality of power. Therefore, there is a need to develop an efficient methodology to detect islanding of the distribution system with DG, without adverse effects to the system[3].

T he proposed methodology is explained in detail in Section II and it is tested in a radial distribution system, which is presented in Section III. The methodology is simulated in DigSILENT PowerFactory 14. Different events have been simulated and the results are presented in Section 5. Section 6 concludes the paper. The purpose of this paper is to obtain the ranges of ultimate impedance for Negative sequence impedance islanding detection ( NSIID ) relay.

***Study System***

Figure 1 shows a single-line diagram of the system used to investigate typical micro-grid operational scenarios. The basic system configuration and parameters were extracted from the benchmark system of the IEEE Standard 399-1997 [9], with some modifications to allow for autonomous micro-grid operation. The system is composed of a 13.8-kV, three-feeder distribution subsystem which is connected to a large network through a 69-kV radial line. The 13.8-kV distribution substation is equipped with a three-phase 1.5-MVAr, fixed shunt-capacitor bank. The 13.8-kV substation bus-bar is radially connected to the main grid through the substation transformer and a 69-kV line. The network at the end of the 69-kV line is represented by a 69-kV, 1000-MVA short-circuit capacity bus. A combination of linear and nonlinear loads(L1 to L5) are supplied through three radial feeders of the subsystem. Loads L1 to L4 are composed of linear RL branches. Load L5 is a three-phase diode-rectifier load. The aggregate of L4 and L5 constitutes a sensitive load within the distribution subsystem.

The system also includes two DG units, i.e., DG1 (5-MVA) and DG2 (2.5-MVA) on feeders F1 and F3 respectively DG1 is a synchronous rotating machine equipped with excitation and governor control systems. It may represent either a diesel-generator or a gas-turbine-generator unit. DG2 utilizes a voltage-sourced converter (VSC) as the interface medium between its source and the power system. DG2 Represents a dispatchable source with adequate capacity to meet the real/reactive power commands, within pre specified limits, subsequent to disturbances. Such a dispatchable source may also include energy storage interfaced at the converter dc bus. DG2 provides control on its output real and reactive power components independently.

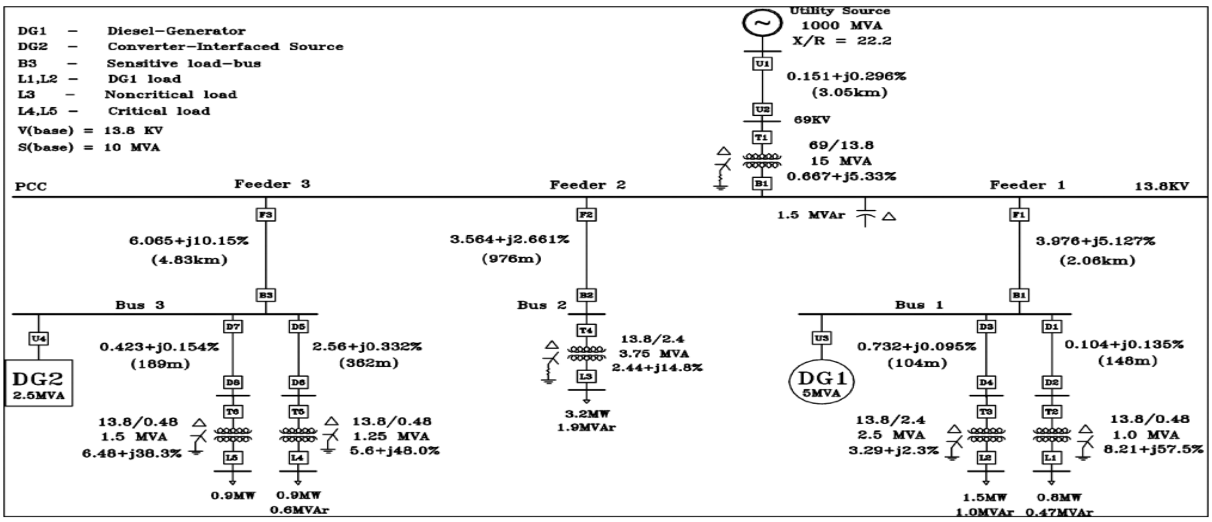

Figure 1. Single-line diagram of the study system.

**Proposed Methodology**

The negative sequence impedance islanding detection (NSIID) method is an improvement on previous impedance measurement techniques for islanding detection due to its small non detection zone and distinctly large threshold window which have challenged previous impedance based islanding detection techniques.

The islanding detection method presented in the paper, NSIID, takes the theoretically accurate concept of impedance measurement and extends it into the symmetrical component impedance domain, using the existence of naturally and artificially produced unbalanced conditions. To evaluate this method, we use Figure 2. (DG system is a radial feed). The method employs the assumption that the impedance of an islanded network is much greater than a utility connected network as seen in Equation 1. The variables with a subscript '2' in Equation 1 indicate negative sequence components. The negative sequence impedance is calculated using Equation 2 where V2 is the negative sequence voltage at the point of measurement and I2 is the negative sequence current at the point of measurement.

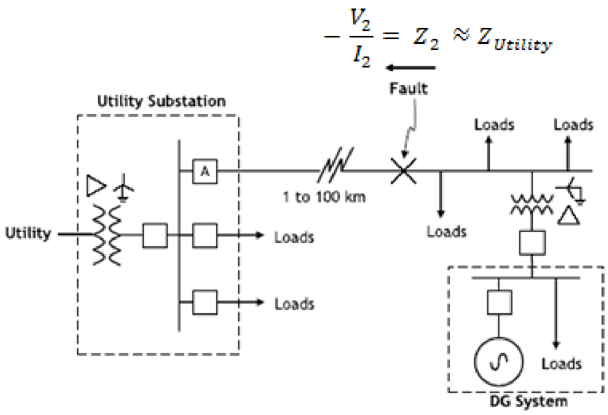


Figure 2. Negative Sequence Impedance Measurement Islanding Detection Concept

Z2−Island >> Z2−Utility−Connected (1)

Z2−Th´ evenin ≈ −V2I2 (2)

The algorithm for naturally occurring negative sequence currents can be seen in Figure 3. The algorithm starts with setting an initial threshold impedance ($Z_2$) from either measuring negative sequence impedance directly or with known network information from the local utility. Then negative sequence impedance islanding detection (NSIID) relay can start its islanding detection scanning by measuring the negative sequence impedance continuously. The input voltages and currents locations are the most important considerations when implementing this algorithm. To reduce errors, a count of three positive readings must be made before the islanding detection breaker will open. This initial three positive readings can be any number that allows for the impedance change to be detected with in the current IEEE standard of two seconds. So if $Z_{MAX} > Z_2 > Z_{MIN}$ , the island state has occurred and breaker A is opened.

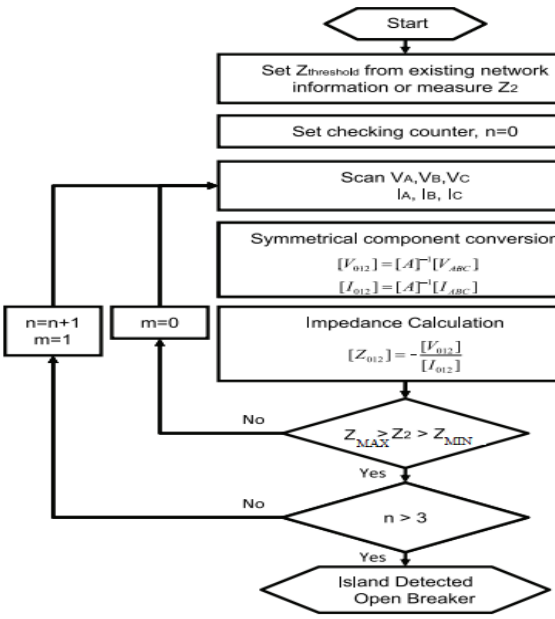


Figure 3. Natural Negative Sequence Impedance Islanding Detection Algorithm

***System parameters***

The system parameters are given in Tables 1.

Table 1. Distributed generations specification

| DG1 Specifications $S_b$=5MVA ,$V_b$=13.8kV | | | |
|---|---|---|---|
| $R_a$ | 0.0052 (pu) | $X_{ls}$ | 0.2 (pu) |
| $X_d$ | 2.86 (pu) | $X_q$ | 2.0 (pu) |
| $X_d$’ | 0.7 (pu) | $X_q$’ | 0.85 (pu) |
| $X_d$” | 0.22 (pu) | $X_q$” | 0.2 (pu) |
| $T_{do}$’ | 3.4 (s) | $T_{do}$” | 0.01(s) |
| $T_{qo”}$ | 0.05(s) | H | 2.9 (s) |
| DG2 Specifications | | | |
| Rated Voltage | | 13.8 kV | |
| Rated Power | | 2.5 MVA | |
| Switching Frequency | | 1260 HZ | |
| Tie Impedance ($R_f$ + $jX_f$) | | 0.01 + j0.15 (p.u) | |

**Simulation And Results**

In this paper, island state is detected by measuring the negative sequence impedance continuously. Unbalanced loads can increase the accuracy of negative sequence impedance islanding detection (NSIID). So unbalanced load connected to the DG, is the most appropriate load to detect island state. It is necessary to mention that in this case just load 4 is unbalanced. In the first part it is assumed that no short-circuit has occurred in the system, in the second part effect of applying a capacitor then influence of short circuit in the third part and finally consequences of inductive machine would be analyzed in the last part. The recommended algorithm is able to identify islanding at a fraction of hundredths of seconds. In conclusion ultimate threshold impedance is presented by the following assumption: except L3 all other loads connected to DG have been studied and calculated one by one like above mentioned L4.

***No short-circuit condition***

In grid-connected, breaker “B1” is in close position & while islanding is detected it will change to open position. it is necessary to detect the island state in less than 2 seconds. In this condition( No short circuit ) when beaker “B1” becomes open, the negative sequence impedance will increase from 0.2013 pu to 0.771 pu in less than 0.02 s.

***Effect of applying a capacitor***

In this section, we Applied capacitors on PCC bus, bus 1 and bus 3 then results will be analyzed. Negative sequence impedances(Z2) are listed in Table 2.

Table 2. Negative Sequences (in pu)

| Locatin of capacitor | Stat | $V_2$\| (V) | \|$I_2$\|(A) | \|$Z_2$\| (pu) |
|---|---|---|---|---|
| PCC | Islanded | 5.300 | 282.560 | 0.8115 |
| PCC | Utiliy Connected | 1.300 | 279.600 | 0.2017 |
| Bus 1 | Islanded | 5.040 | 283.167 | 0.7724 |
| Bus 1 | Utility Connected | 1.300 | 280.320 | 0.2010 |
| Bus 3 | Islanded | 5.042 | 282.600 | 0.7744 |
| Bus 3 | Utility Connected | 1.300 | 279.760 | 0.2013 |

According to table 2, the Intervals of changes in Island state and Utility Connected are as the following ranges.
Impedance intervals of Islanding (in pu):
[0.77 – 0.82]
Impedance intervals of Utility Connected (in pu):
[0.20 – 0.21]

***Influence of short circuit***

In this section, various short circuits occur in different parts of the grid. Negative sequence impedances (Z2) are listed in Table 3.

Table 3. Negative Sequence impedances (in pu)

| Types and locations of short circuits | | Negative sequence impedances |
|---|---|---|
| 3 Phase short circuit | Line U1-U2 | 0.2007 |
| | Line F1-B1 | 0.2005 |
| | Line F2-B2 | 0.2006 |
| | Line F3-B3 | 0.2007 |
| | PCC | 5.68 |
| 2 Phase short circuit | Line U1-U2 | 0.2007 |
| | Line F1-B1 | 0.2005 |
| | Line F2-B2 | 0.2006 |
| | Line F3-B3 | 0.2007 |
| | PCC | 14.36 |
| 2 Phase short circuit to ground | Line U1-U2 | 0.2007 |
| | Line F1-B1 | 0.2005 |
| | Line F2-B2 | 0.2006 |
| | Line F3-B3 | 0.2007 |
| | PCC | 14.34 |
| 1 Phase short circuit | Line U1-U2 | 0.2007 |
| | Line F1-B1 | 0.2005 |
| | Line F2-B2 | 0.2006 |
| | Line F3-B3 | 0.2007 |
| | PCC | 12 |

According to the table 3, the Intervals of changes in short circuit condition are as the following ranges.

Impedance intervals of short circuit (in pu):
([0.2 – 0.21] & [5.6 – 14.5])

***Consequences of inductive machine***

In this part, we applied inductive machines at four locations 1- Bus-bar L1, 2- Bus-bar L2, 3- Bus-bar L3, 4- Bus-bar L5 then consequences of inductive machines will be presented. Negative sequence impedances (Z2) are listed in Table 4.

Table 4. Negative Sequence impedances (in pu)

| Location of inductive machine | Negative sequence impedances |
|---|---|
| Busbar L1 | 0.1993 |
| Busbar L2 | 0.1980 |
| Busbar L3 | 0.1983 |
| Busbar L5 | 0.1973 |

According to the table 4, Intervals of changes for inductive machines are as the following ranges.
Impedance intervals of inductive machines (in pu): [0.19 – 0.2]

According to the subjects listed in the previous sections, the intervals of changes in the island state and non-island state are as follows. It should be mentioned that non-island state includes various situations like Utility Connected, short-circuit, inductive machines and applying a capacitor.
Impedance intervals of island state:
[0.77 – 0.82]
Impedance intervals of non-island state:
([0.19 – 0.21] & [5.6 – 14.5])
So the range of impedance threshold for detection of the island state is:[0.77 - 0.82]

Negative sequence impedance islanding detection ( NSIID ) relay is used by the DG to detect the opening of circuit breaker 'B1' causing an island. With defining the ranges mentioned above for NSIID relay, it will not consider other conditions like short circuit as an island state.

**Conclusion**

The negative sequence impedance islanding detection method (NSIID) is an improvement on previous impedance measurement techniques for islanding detection due to its small non detection zone and distinctly large threshold window which have challenged previous impedance based islanding detection techniques. The proposed method is much faster than the other active methods. And need accurate measuring devices to calculate the negative sequence components. This method has a good performance in terms of connecting to the network and ability to distinguish between conditions like short circuit and island state. Based on the predefined assumption in simulation section, the ranges of ultimate impedance threshold (in pu) would be: [0.3 -2.4]

However the ranges of ultimate impedance for other conditions like Utility Connected, short-circuit, inductive machines and applying a capacitor are as the following ranges.

Impedance intervals of Utility Connected (in pu):
[0.0131 – 0.2170]
Impedance intervals of short circuit (in pu):
([0.0450 – 0.2763] & [5.1100 – 33.4200])
Impedance intervals of inductive machines (in pu):
[0.1144 – 0.2170]

The above results makes it clear that when we wants to obtain the ranges of ultimate impedance threshold for the negative sequence impedance islanding detection ( NSIID ) relay, we should analyze all states that are likely to occur.

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