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Islanding Discovery/Detection in Distributed Generation Using Fuzzy Rule-Based Classifier

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Abstract:

Distributed generation (DG) on the distribution system provides many potential benefits like peak shaving, fuel switching, improved power quality and reliability, increased efficiency, and improved environmental performance. Impacts are steady state voltage rise, increase the fault level, power quality, islanding. One of the problems is an islanding. Islanding refers to the condition in which a distributed generator (DG) continues to power a location even though electrical grid power from the electric utility is no longer present. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. For that reason, distributed generators must detect islanding and immediately stop producing power; this is referred to as anti-islanding. So many islanding detection techniques are available, each one having their own advantages and drawbacks. A fuzzy rule-based islanding detection technique is implemented in this project. The initial classification model is developed using decision tree (DT) which is a crisp algorithm. This algorithm is transformed into a fuzzy rule base by developing fuzzy membership functions (MFs) from the DT classification boundaries.

Keywords:

Distributed Generation, Decision tree, fuzzy rule, islanding detection, similarity measure.

Introduction:

Distributed generation, also distributed energy, on-site generation (OSG) or district/decentralized energy is generated or stored by a variety of small, grid-connected devices referred to as distributed energy resources (DER) or distributed energy resource systems. Conventional power stations, such as coal-fired, gas and nuclear powered plants, as well as hydroelectric dams and large-scale solar power stations, are centralized and often require electricity to be transmitted over long distances. By contrast, DER systems are decentralized, modular and more flexible technologies, that are located close to the load they serve, albeit having capacities of only 10 megawatts (MW) or less. DER systems typically use renewable energy sources, including small hydro, biomass, biogas, solar power, wind power, and geothermal power, and increasingly play an important role for the electric power distribution system. A grid-connected device for electricity storage can also be classified as a DER system, and is often called a distributed energy storage system (DESS). By means of an interface, DER systems can be managed and coordinated within a smart grid. Distributed generation and storage enables collection of energy from many sources and may lower environmental impacts and improve security of supply.

Integration with the grid:

For reasons of reliability, distributed generation resources would be interconnected to the same transmission grid as central stations. Various technical and economic issues occur in the integration of these resources into a grid. Technical problems arise in the areas of power quality, voltage stability, harmonics, reliability, protection, and control.[31] Behavior of protective devices on the grid must be examined for all combinations of distributed and central station generation.[32] A large scale deployment of distributed generation may affect grid-wide functions such as frequency control and allocation of reserves.[33] As a result smart grid functions, virtual power plants [34] [35] [36] and grid energy storage such as power to gas stations are added to the grid. Each distributed generation resource has its own integration issues. Solar PV and wind power both have intermittent and unpredictable generation, so they create many stability issues for voltage and frequency. These voltage issues affect mechanical grid equipment, such as load tap changers, which respond too often and wear out much more quickly than utilities anticipated. Also, without any form of energy storage during times of high solar generation, companies must rapidly increase generation around the time of sunset to compensate for the loss of solar generation. This high ramp rate produces what the industry terms the "duck curve" that is a major concern for grid operators in the future. Storage can fix these issues if it can be implemented. Flywheels have shown to provide excellent frequency regulation. Short term use batteries, at a large enough scale of use, can help to flatten the duck curve and prevent generator use fluctuation and can help to maintain voltage profile. However, cost is a major limiting factor for energy storage as each technique is prohibitively expensive to produce at scale and comparatively not energy dense compared to liquid fossil fuels. Finally, another necessary method of aiding in integration of photovoltaics for proper distributed generation is in the use of intelligent hybrid inverters.

Technical challenges

Distributed generation (DG) is not without problems. DG faces a series of integration challenges, but one of the more significant overall problems is that the electrical distribution and transmission infrastructure has been designed in a configuration where few high power generation stations that are often distant from their consumers, ”push” electrical power onto the many smaller consumers.

DECISION TREE:

A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. It is one way to display an algorithm. Decision trees are commonly used in operations research, specifically in decision analysis, to help identify a strategy most likely to reach a goal. Another use of decision trees is as a descriptive means for calculating conditional probabilities. When the decisions or consequences are modeled by computational verb, then we call the decision tree a computational verb decision tree.

ISLANDING PROTECTION FOR DISTRIBUTED GENERATION:

This thesis presents a novel method of islanding detection for the protection of distributed generator fed systems that has been tested on power distribution busses of 25 kV and less. Recent interest in distributed generator installation into low voltage busses near electrical consumers has created some new challenges for protection engineers that are different from traditional radially based protection methodologies. Therefore, typical protection configurations need to be re-thought such as re-closures out-of-step monitoring, impedance relay protection zones with the detection of unplanned islanding of distributed generator systems. The condition of islanding, defined as when a section of the non utility generation system is isolated from the main utility system, is often considered undesirable because of the potential damage to existing equipment, utility liability concerns, reduction of power reliability and power quality.

Current islanding detection methods typically monitor over/under voltage and over/under frequency conditions passively and actively; however, each method has an ideal sensitivity operating condition and a non-sensitive operating condition with varying degrees of power quality corruption called the non detection zone (NDZ). The islanding detection method developed in this thesis 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. Specific applications, where this islanding detection method improves beyond existing islanding detection methods, are explored where a generalized solution allows the protection engineer to determine when this method can be used most effectively. To start, this thesis begins with a brief introduction to power systems in North America and the motivation for the use of distributed generation. Further chapters then detail the background and specifics of this technique.

ISLANDING :

Islanding is the situation in which a distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by DG connected to it. As shown in the figure. Traditionally, a distribution system doesn't have any active power generating source in it and it doesn't get power in case of a fault in transmission line upstream but with DG, this presumption is no longer valid. Current practice is that almost all utilities require DG to be disconnected from the grid as soon as possible in case of islanding. IEEE 929-1988 standard requires the disconnection of DG once it is islanded .Islanding can be intentional or Non intentional. During maintenance service on the utility grid, the shut down of the utility grid may cause islanding of generators. As the loss of the grid is voluntary the islanding is known. Non-intentional islanding, caused by accidental shut down of the grid is of more interest. As there are various issues with unintentional islanding. IEEE 1547-2003 standard stipulates a maximum delay of 2 seconds for detection of an unintentional island and all DGs ceasing to energize the distribution system,

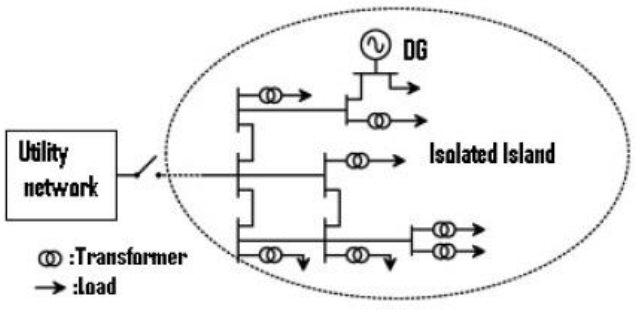

Figure 1.4: Scenario of Islanding operation

ISSUES WITH ISLANDING:

Although there are some benefits of islanding operation there are some drawbacks as well. Some of them are as follows:

- Line worker safety can be threatened by DG sources feeding a system after primary sources have been opened and tagged out.
- The voltage and frequency may not be maintained within a standard permissible level. Islanded system may be inadequately grounded by the DG interconnection.
- Instantaneous reclosing could result in out of phase reclosing of DG. As a result of which large mechanical torques and currents are created that can damage the generators or prime movers [26] Also, transients are created, which are potentially damaging to utility and other customer equipment. Out of phase reclosing, if occurs at a voltage peak, will generate a very severe capacitive switching transient and in a lightly damped system, the crest over-voltage can approach three times rated voltage.
- Various risks resulting from this include the degradation of the electric components as a consequence of voltage& frequency drifts.

Due to these reasons, it is very important to detect the islanding quickly and accurately.

UTILITY PERSPECTIVE OF DISTRIBUTED GENERATOR NETWORK ISLANDING

Utilities have a more pragmatic point of view of distributed generation islanding. Their goal is to improve the distribution level (25 kV and below) customer service reliability especially in regions where the reliability is below customer's needs. It is believed that customer reliability could improve with the addition of DG sources and that the DG may be able to sell electricity back to the utility.

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However, without complex studies and frequent expensive system upgrades DG islanding is not allowed. Some examples of these studies are: real and reactive power profile and control, planning for islanding, minimum/ maximum feeder loading, islanding load profile, minimum/maximum voltage profile, protection sensitivity and DG inertia. One more specific example is how substation auto-reclosers of circuit breakers and main line reclosers may be disabled and other protection devices may need to be removed to allow proper coordination of utility sources and DG sources. Maintenance times might also increase as utility workers will not only need to lockout the utility lines but they will need to take additional time to lockout all the installed DG lines. Some of the required installation studies of an Independent power producer must complete to be able to island are:

1. Inadvertent islanding and planned islanding study

2. Reliability study

3. Power quality study

4. Utility equipment upgrades assessment

5. Safety and protection reviews

6. Commercial benefit study.

Clearly the costs of designing a DG to be capable of islanding or to simply be installed into the main utility owned network requires extensive and costly engineering and business reviews which may be outside the financial range of smaller DG suppliers.

DT TRANSFORMATION INTO THE FUZZY RULE BASE:

The DT is transformed to a fuzzy rule base by developing the fuzzy membership functions [20] from the partition boundaries of the DT. From the DT boundaries, rectangular MFs are developed for each independent variable. For illustration, consider

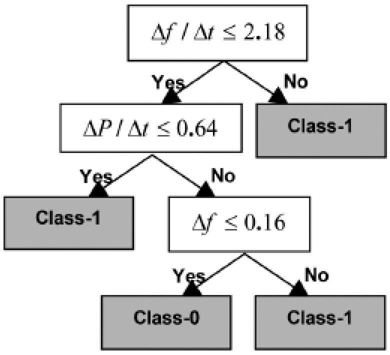

Fig. 2. DT-based islanding detection. Class-1 means islanding and class-0 means nonislanding.

the DT classification boundaries shown in Fig. 3(a). The associated trapezoidal fuzzy MFs [Fig. 3(b) and (c)] are developed for variables X_1 and X_2 as follows:

$$A_1 = \mu\{X_1, [0, 0, a, a]\}$$
$$A_2 = \mu\{X_1, [a, a, c, c]\}$$
$$B_1 = \mu\{X_2, [0, 0, b, b]\}$$
$$B_2 = \mu\{X_2, [b, b, d, d]\}$$

Where

$$\mu_j(X_j; a, b, c, d) = \max\left(0, \min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right)\right). \quad (1)$$

From the fuzzy MFs, a simple rule base can be generated for classes 1 and 2 as follows:

If X_1 is A_1 and X_2 is B_1, then Class$-1(C-1)$
If X_1 is A_2 and X_2 is B_2, then Class$-2(C-2)$.

From the aforementioned DT-fuzzy transformation technique, the resulting DT output (Fig. 2) is converted to the corresponding fuzzy rule base. The most significant features $\Delta f/\Delta t$, $\Delta P/\Delta t$, Δf are considered as , and , respectively. Depending upon the values of the above three variables, the classification boundaries are decided for islanding detection. Thus, when is greater than 2.18, then the class is “1”. If is less than 2.18 and less than 0.64, then the class “1”. If is greater than 0.64 and less than 0.1664, then class “0”, otherwise class “1”. From the DT boundaries, trapezoidal MFs are developed for each variable.

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The fuzzy MFs developed for variable are and , for are , , and for are , . Per the above formulations, the rectangular MFs are derived. As

$$A_1 = \mu\{X_1, [2.18, 2.18, 34.0, 34.0]\}$$
$$A_2 = \mu\{X_1, [-9.5, -9.5, 2.18, 2.18]\}$$
$$B_1 = \mu\{X_2, [0.64, 0.64, 19.0, 19.0]\}$$
$$B_2 = \mu\{X_2, [-0.5, -0.5, 19.0, 19.0]\}$$
$$B_3 = \mu\{X_2, [-0.5, -0.5, 0.64, 0.64]\}$$
$$C_1 = \mu\{X_3, [0.16, 0.16, 0.6, 0.6]\}$$
$$C_2 = \mu\{X_3, [-0.05, -0.05, 0.16, 0.16]\}.$$

The fuzzy MFs generated from the DT classification boundaries are rectangular in nature. But to further add fuzziness to the membership functions, the rectangular boundaries are skewed to a certain extent by heuristic tuning. The coordinates of the trapezoidal fuzzy MFs are decided after testing on several values around the initial values resulting from DT. Thus, the final fuzz MFs are

$$A_1 = \mu\{X_1, [2.18, 2.3, 30.0, 34.0]\}$$
$$A_2 = \mu\{X_1, [-9.5, -8.5, 1.95, 2.18]\}$$
$$B_1 = \mu\{X_2, [0.64, 0.60, 18.0, 19.0]\}$$
$$B_2 = \mu\{X_2, [-0.5, -0.4, 18.0, 19.0]\}$$
$$B_3 = \mu\{X_2, [-0.5, -0.4, 0.55, 0.64]\}$$
$$C_1 = \mu\{X_3, [0.16, 0.2, 0.5, 0.6]\}$$
$$C_2 = \mu\{X_3, [-0.05, -0.03, 0.12, 0.16]\}.$$

The corresponding fuzzy rule base is developed for each classification category and given as follows:

$R1:$ If X_1 is A_1 and X_2 is B_2, then Class−1

$R2:$ If X_1 is A_2 and X_2 is B_3, then Class−1

$R3:$ If X_1 is A_2 and X_2 is B_1 and X_3 is C_1, then Class−1

$R4:$ If X_1 is A_2 and X_2 is B_1 and X_3 is C_2, then Class−0.

In fuzzy rule-based models acquired from numerical data, redundancy may be present in the form of similar fuzzy sets that represent compatible concepts. This results in an unnecessarily complex and less transparent linguistic description of the system. By using a measure of similarity [21], a rule base simplification method is proposed that reduces the number of fuzzy sets in the model.

Similar fuzzy sets are merged to create a common fuzzy set to replace them in the rule base. If the redundancy in the model is high, merging similar fuzzy sets might result in equal rules that also can be merged, thereby reducing the number of rules as well. The similarity measure based on the set-theoretic operations of intersection and union, can be expressed as follows:

$$S(A, B) = \frac{A \cap B}{A \cup B} \quad (2)$$

where .denotes the cardinality of a set, and the " " and " " operators represent the intersection and union, respectively. Rewriting this expression in terms of the membership functions gives

$$S(A, B) = \frac{\sum_{j=1}^{m} [\mu_A(x_j) \wedge \mu_B(x_j)]}{\sum_{j=1}^{m} [\mu_A(x_j) \vee \mu_B(x_j)]} \quad (3)$$

In a discrete universe,

$X = \{x_j, j = 1, 2, \ldots, m\}$, and "$\wedge$" are the minimum and maximum operators, respectively

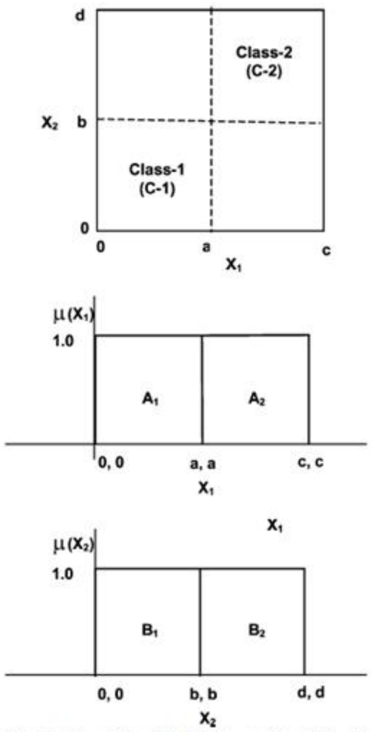

Fig. 3. (a) Decision boundaries of the DT between X_1 and X_2. (b) Fuzzy MF of X_1. (c) Fuzzy MF of X_2.

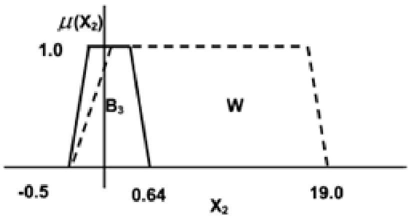

Fig. 4. Fuzzy MFs of X_2 after merging.

merged with a similarity measure of 0.9152 to provide another common fuzzy memberships function $W = \mu\{X_2, [-0.5, 0.1, 18, 19]\}$, shown in Fig. 4. After merging, there are 6 fuzzy MFs instead of Based on the aforementioned criteria, the fuzzy membership function of set “ B1” and “B2 ” are the originally developed 7 MFs. Depending upon the new fuzzy MFs, the rule base is simplified to

$R1:$ If X_1 is A_1 and X_2 is W, then Class−1

$R2:$ If X_1 is A_2 and X_2 is B_3, then Class−1

$R3:$ If X_1 is A_2 and X_2 is W and X_3 is C_1, then Class−1

$R4:$ If X_1 is A_2 and X_2 is B_1 and X_3 is C_2, then Class−0.

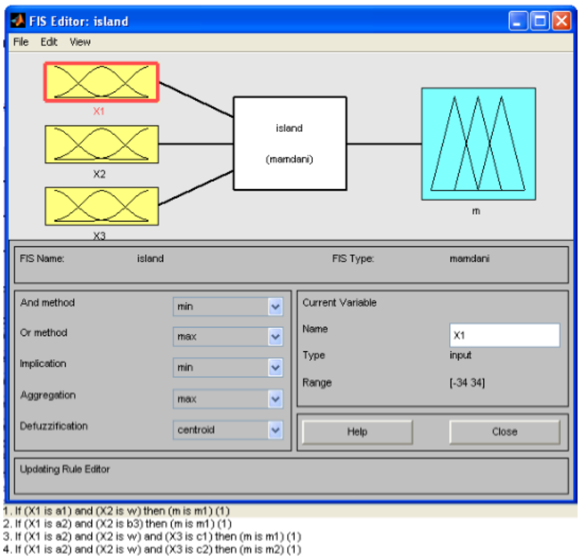

Fig. Fuzzy inference system for islanding detection.

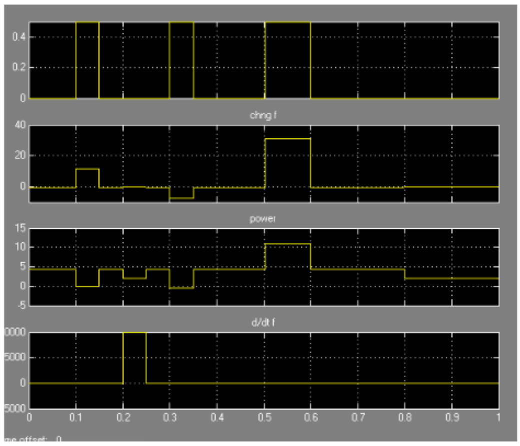

Fig. Output of changing frequency, power, d/dt(f)

CONCLUSION:

Fast and accurate detection of islanding is one of the major challenges in today“s power system with many distribution systems already having significant penetration of DG as there are few issues yet to be resolved with islanding. Islanding detection is also important as islanding operation of distributed system is seen a viable option in the future to improve the reliability and quality of the supply. A fuzzy rule-based passive islanding detection is implemented in this project. The initial classification model is developed using decision tree (DT) which is a crisp algorithm. This algorithm is transformed into a fuzzy rule base by developing fuzzy membership functions (MFs) from the DT classification boundaries.

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