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Intelligent Passive Anti-Islanding Protection for Doubly Fed Induction Generators

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Abstract

The integration of wind generation units into power system introduces several issues including islanding operation. Therefore, the system should be protected from islanding phenomenon by a fast and reliable islanding detection method. In this paper an intelligent anti-islanding protection approach is proposed to detect islanding states for Doubly Fed Induction Generator (DFIG) units. Different features based on rate of change of voltage, frequency, active power and reactive power at DG bus are employed to construct feature vectors. Because of intermittency of wind power, different generating states for DFIG unit are assumed. Probable events are simulated under system operating states to construct classification data set. Decision tree algorithm due to its high classification speed, implication simplicity and high accuracy, is used to classify instances. The proposed method is tested on typical distribution system including DFIG and different loads. The studies showed that this method succeeds in DFIG anti-islanding protection with high accuracy and negligible false trips. Because of high detection speed of decision tree algorithm, the proposed method is capable to protect the system from asynchronous reconnection of auto-reclosers.

Keywords: Anti-islanding, distributed generation, intelligent learning algorithms, wind generation.

Introduction

Growth of environmental concerns, limitation in fossil fuel resources and need for sustainable energy resources has led to fast development of renewable energy systems. Among different renewable energy sources, wind energy is expanding rapidly due to low operation cost, zero CO_2 emission and high efficiency and Doubly Fed Induction Generators (DFIGs) has become one the most favorable alternatives in wind power market[1]. Nowadays, wind generation units from several kilowatts to several megawatts of rated power have been connected to distribution system in the context of distributed generation. This kind of generation has many advantages such as increasing reliability and decreasing the transmission and distributed loss. Hence distributed generation has recently gained a lot of momentum in the power industry[2]; however, there are some new challenges related to connecting distributed generation units to the grid. One of the most important challenges is to detect unplanned islanding of distributed generation systems[3].

Islanding is defined in IEEE standard as "a condition in which a portion of an area electric power system (EPS) is energized solely by one or more local EPSs through the associated points of common coupling (PCCs) while that portion of the area EPS is electrically separated from the rest of the area EPS[4]".

Islanding condition is an undesirable situation because it will create a shock hazard for utility personnel. Islanding operation also may cause damage to the network equipments and consumers in the case of out-of-phase reconnection of the grid by the auto-reclosers due to phase difference between the grid and island voltage. Other islanding condition drawbacks include lack of grounding, change in fault power, uncoordinated protection, voltage and frequency control problem and power quality degradation[5-6]. Due to these issues, IEEE Standard recommended disconnection of the DGs in the island[4,7]. Islanding detection techniques were categorized into local and communication-based or remote techniques which are depicted in figure 1.

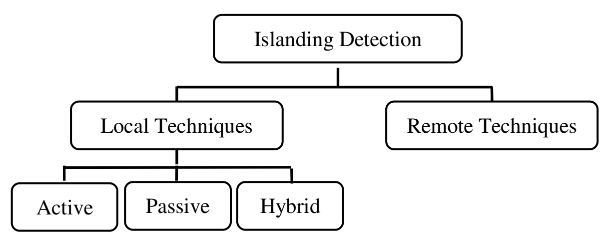

Figure-1
Islanding detection methods

Communication-based techniques use a continuous signal that is sent from utility to the downstream DGs[8]. These techniques are expensive compared to the local islanding detection methods at the present time[9]. Local techniques can be grouped into active and passive islanding detection methods. Active methods are based on deliberately injecting some sort of disturbances into the grid and monitoring its response. When the utility is disconnected and an island is formed, injected disturbances cause abnormal condition that is detectible as islanding condition[10]. Generally power quality degradation is the major concerns about active islanding detection methods. Systems with high penetration rate of distributed generation that use active islanding methods, may face serious power quality problems. Several active methods have been proposed in literature including active frequency drift[10], slip-mode frequency shift[11], Sandia frequency shift[12], etc. Passive islanding detection methods make decision based on measurement of system parameters such as like voltage amplitude, frequency or phase. These methods basically rely on detection of abnormalities when the utility is disconnected and island is formed. Passive methods do not inject any disturbance into the distribution system so the power quality is not degraded. Several passive islanding detection techniques have been developed in recent years. Rate of change of frequency[13], rate of change of voltage[14], vector surge relays[15], voltage unbalance variation and total harmonic distortion[16], and rate of change of phase angle difference[17] are examples of proposed passive methods. In the state with balance in power between load and, the islanding phenomenon will result in negligible deviation in electrical parameters and passive methods fail to detect the islanding and non-detection zone is one of the significant concerns about the passive islanding detection methods.

In the recent decades, intelligent algorithms have been used in different fields[18-20]. Intelligent data mining approach have been employed for passive islanding detection[21-23]. In El-Arroudi et al[21] decision tree algorithm is used to threshold setting of islanding relays. Four features were used to train the classifiers. A set of features including gradient of electric parameters and total harmonic distortion is used to classify the data set in El-Arroudi Kh et al[22]. In Najy W.K.A. et al[23] a statistical signal processing algorithm is utilized to extract features from voltage and frequency waveform. Accuracy of this technique is acceptable but the delay of statistic processing section makes this technique slower than other islanding detection methods.

In this paper an intelligent islanding detection technique for doubly fed induction generator is proposed. Decision tree algorithm is used to classify instances. The proposed islanding detection scheme can be successfully used in anti-islanding protection of DFIG units.

Material and Methods

DFIG Model: Rapid development of wind energy usage has been closely related to advancement of wind turbine and control systems. Doubly Fed Induction Generators (DFIGs) have received much attention for wind energy conversion in the recent years. The term "doubly fed" refers to the fact that rotor and stator voltages are applied separately from rotor side converter and the grid, respectively[1]. A common used model for DFIG is shown in figure 2.

In this model, the stator is connected to the low voltage balanced three-phase grid. Back-to-back PWM converters consist of a converter connected to rotor called "rotor side converter" and a converter connected to the grid called "grid side converter". These two converters are controlled independently of each other. The rotor side converter provides proper rotor excitation and the grid side converter controls the power flow between the AC side and DC bus. This converter allows the DFIG to be operated in both sub-synchronous and over-synchronous speeds[24]. In sub-synchronous condition, power flows from the rotor to the grid, whereas in over-synchronous condition, power flows in opposite direction. In both conditions, power direction in stator side, is from stator to the grid.

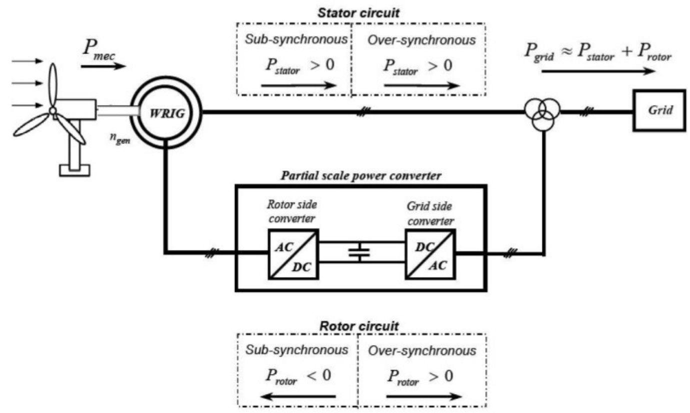

Figure-2
Doubly fed induction generator model

The Concept of Intelligent Anti-Islanding Protection: Intelligent anti-islanding protection uses data that is provided by locally monitoring the connection bus of the DG. The monitoring can be done via sampling voltage and current signal at the DG bus. A feature calculation block transforms the sampling data into proper features and constructs an n-dimensional feature vector. These vectors are inputs for an intelligent classification algorithm which is able to create classifiers with islanding detection capability. The general passive anti-islanding protection procedure is depicted in figure 3.

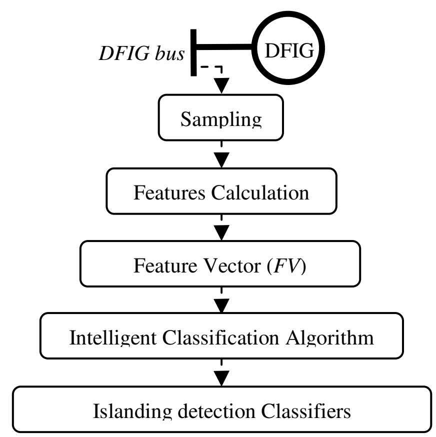

Figure-3
Intelligent Anti-Islanding Protection

Diverse features can be extracted by monitoring the grid to build an n-dimensional feature vector. Feature vector and class for i^{th} instance are:

$$FV^i = [f_1^i, f_2^i, \cdots, f_n^i] \quad (1)$$

$$c^i \in \{-1, 1\} \quad (2)$$

Where f^i_n is the n^{th} feature for the i^{th} instance and c^i is class of i^{th} instance (-1 for non-islanding and 1 for islanding). Islanding detection classifiers are trained by labeled feature vectors called "training data set". The classifiers are tested on a set of non-labeled feature vectors called "test data set". Therefore, the main objective of data intelligent islanding detection methods is to classify testing feature vectors as "islanding" or "non-islanding" classes. Figure 4 illustrates training and testing procedure for islanding detection.

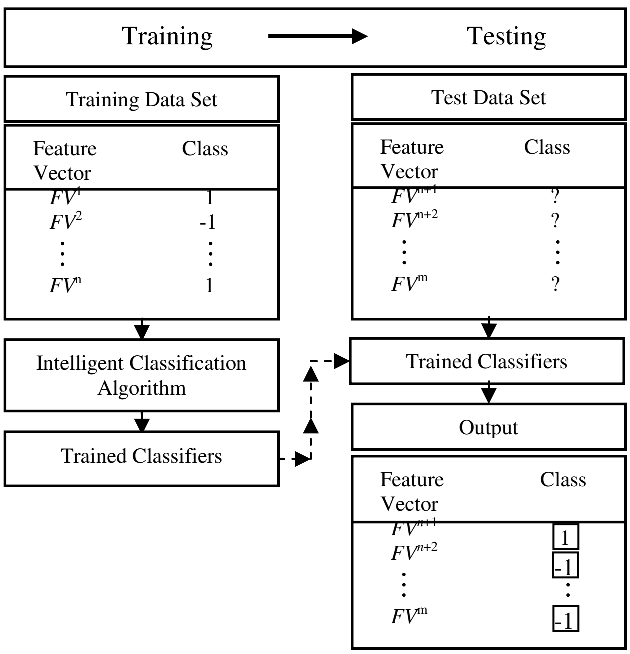

Figure-4
Training and testing the islanding detection classifiers

Decision Tree Classification Algorithm: In this paper, decision tree approach[25-26] is used for classification the input feature vectors as weak classifier. Decision tree algorithm is capable to break down complex decision making process into union of several simpler decisions thus the results are easier to interpret[25]. In the first step of decision tree, entire space is considered as a root node. An initial split is made using a predictor variable, segmenting the root node into two child nodes. These child nodes are chosen among all possible child nodes and contain the purest data. Splits can then be made from the child nodes. A leaf (terminal) node is one where no more splits are made[27]. Predictions are made based on the make-up of leaf nodes. To use a decision tree to make a prediction, the split decisions are followed until a leaf node is reached.

Intelligent Anti-Islanding Protection Data Set: Intelligent anti-islanding protection requires a data set which is composed of feature vectors. Anti-islanding protection features are defined based on mean variation of an electrical parameter over a predefined time interval. Rate of change of electrical parameter 'p_i' which is chosen as i^{th} feature, can be expressed as:

$$f_i(t) = \frac{\Delta p_i(t)}{\Delta t} = \frac{p_i(t+\Delta t) - p_i(t)}{\Delta t} \quad (3)$$

In this paper a four-dimensional feature vector is applied in order to detect islanding condition for DFIG anti-islanding protection. The elements of the feature vector are:

$$f_1(t) = \frac{\Delta P_{DFIG}(t)}{\Delta t} \quad (4)$$

$$f_2(t) = \frac{\Delta Q_{DFIG}(t)}{\Delta t} \quad (5)$$

$$f_3(t) = \frac{\Delta f_{DFIG\ bus}(t)}{\Delta t} \quad (6)$$

$$f_4(t) = \frac{\Delta V_{DFIG\ bus}(t)}{\Delta t} \quad (7)$$

Where P_{DFIG} and Q_{DFIG} are DFIG active and reactive output power, respectively. $f_{DFIG\ bus}$, and $V_{DFIG\ bus}$ are electrical frequency and voltage amplitude at the DFIG bus, respectively.

The intermittency of wind power as well as load variation should be taken into account for data set construction in order to increase classification accuracy. Different system operating states are considered in order to train islanding detection classifier. Produced power of DFIG as well as loads are divided into discrete states. Combination of these states can be used to build operating states of the system.

Diverse events may occur in the grid and each has a specific signature on feature vector. List of events can be extracted from different sources such as standards, testing practices, system topology studies, failure rate of transformers and lines, historical fault reports, etc. Each event should be simulated under abovementioned system operating states.

Results and Discussion

Figure 5 shows single-line diagram of a 13.8 KV distribution system used to demonstrate the proposed islanding detection algorithm. The studied system consists of a DFIG unit, connected to bus 4 and three loads connected to bus 3. Rated values for distribution system of figure 5 are given in appendix. The simulation studies are carried out using PSCAD/EMTDC software.

System Operating States: To cover probable operating states, different wind generation and system loading states are assumed. Three states for wind generation and three loading states are assumed in order to construct the classification data set. Combination of generation and loading states, results in 9 (=3*3) operating states.

System Events: Different events are defined to be simulated under aforementioned states and are listed in table 1. Event number 1, 2, 3, 4 and 5 simulate non-islanding condition. Short circuit (event number 5) is cleared after 5 ms without any circuit breaker operation, so this event should not be classified as an islanding event. Event number 6, 7, 8, 9 and 10 simulate islanding condition.

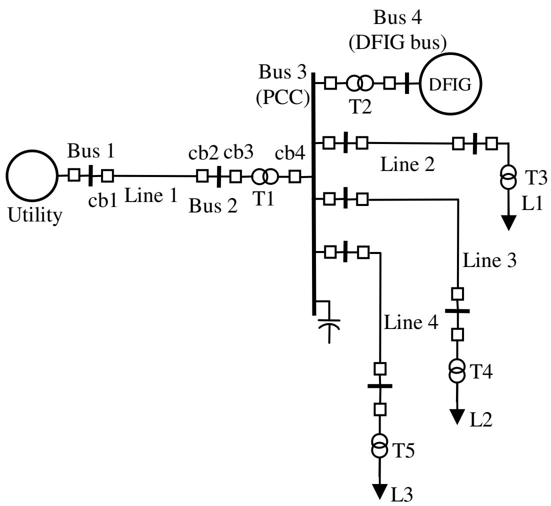

Figure-5
Case study distribution system

Table-1
Predefined system events

Event #	Event Type	Element	Islanding Status
1	Load Outage	L1	-1
2	Load Outage	L2	-1
3	Load Outage	L3	-1
4	Line Outage	Line 3	-1
5	Short Circuit	-	-1
6	Circuit Breaker Trip	cb 1	1
7	Circuit Breaker Trip	cb 2	1
8	Circuit Breaker Trip	cb 3	1
9	Circuit Breaker Trip	cb 4	1
10	Line Outage	Line 1	1

Abovementioned events are simulated under each operating states. Combination of events and operating states result in 90 (=10×9) simulation cases.

Classification Results: In this section classification results for test cases is proposed. Randomly 80% of total features (72 features) are chosen for training and 20% (18 features) are used to test the proposed classification algorithm. Final results of 18 randomly chosen features are listed in table 2.

Table-2
Intelligent anti-islanding protection results

Test Case #	DFIG Generation State (H: High M: Medium L: Low)	System Loading State (H: High M: Medium L: Low)	Event #	Islanding state	Intelligent Anti-Islanding Protection Results
1	H	M	1	-1	-1
2	H	M	1	-1	-1
3	L	L	2	-1	-1
4	M	H	2	-1	-1
5	H	L	2	-1	-1
6	L	H	3	-1	1
7	H	M	4	-1	-1
8	M	L	4	-1	-1
9	M	H	5	-1	1
10	H	M	5	-1	-1
11	L	H	7	1	1
12	M	L	7	1	-1
13	L	H	7	1	1
14	L	H	7	1	1
15	L	M	8	1	1
16	H	L	9	1	1
17	M	M	10	1	1
18	H	H	10	1	1
Number of False Detection Cases					3
Number of Correct Detection Cases					15
Detection Accuracy					83.3 %

The results show that the proposed algorithm can detect the islanding condition with high accuracy. The algorithm has 15 correct and 3 false classifications (test case number 6, 9 and 11).

In test case number 6 and 9 false islanding trip is sent to protection system and in case number 11 islanding condition is not detected by protection system. In case number 3, disconnecting of L3 at its High state causes severe changes in electrical parameters which similar to islanding condition, consequently the algorithm has classified this case as islanding condition and false trip is sent to protection system. In case number 9, a short circuit has occurred. In this condition electrical parameters change sharply and the classification algorithm classifies this case as islanding condition. In case number 11, islanding condition due to negligible difference between generation and demand, is not detected. In this condition because of related balance in the island, disconnection has insignificant effect on the electrical parameters and detection algorithm fails to detect islanding condition. This case represents non-detection zone of proposed protection method.

Conclusion

In this paper an intelligent passive anti-islanding protection method for DFIG units is proposed. The Classification approach is used in order to detect islanding condition. Decision tree algorithm is chosen as the main classifier. Intermittent behavior of wind generation is considered in training data set construction by assuming different generation states for DFIG unit. Rate of change of voltage, frequency, active power and reactive power are employed as feature vector elements. Selected features do not require any mathematical transformations so feature calculation requires less time than transformation-base algorithms. The proposed DFIG anti-islanding protection method was capable to detect islanding condition with high accuracy. The results showed that the proposed method has negligible false islanding trips. Consequently, application of this method will increase the system reliability and reduces the expected energy not supplied by DFIG due to its low rate of false trips.

Appendix: This appendix contains data for case study depicted in Figure 5. The base voltage and power are chosen as 13.8 KV and 10 MVA, respectively. Frequency of system is 50 Hz. Nominal values of distribution system elements are as below: DFIG unit rated Power: 2.2 MW. T1: rated MVA=10 MVA, rated kV= 69/13.8 kV, Dyn, Z=0.00667+j0.0533 p.u., R_G=20Ω; T2: rated MVA=3.0 MVA, rated kV= 13.8/0.48 kV, Dyn, Z=0.0821+j0.575 p.u.; T3: rated MVA=1.5 MVA, rated kV= 13.8/0.48 KV, Dyn, Z=0.0329+j0.023 p.u.; T4: rated MVA=1.0 MVA, rated kV= 13.8/2.4 kV, Dyn, Z=0.021+j0.1094 p.u.; T5: rated MVA=3.75 MVA, rated kV= 13.8/2.4 kV, Dyn, Z=0.0244+j0.148 p.u., RG=3.5 Ω; L1: rated power =1.25 MW, rated kV=0.48 kV; L2: rated power =1.0 MW, rated kV=2.40 kV; L3: rated power =3.2 MW, rated kV=2.40 kV; Line 1: rated kV=69.0 kV, Z_S=0.00151+ j0.00296 p.u.; Line 2: rated kV=13.8 kV, Z_S=0.03760+ j0.05127 p.u.; Line 3: rated kV=13.8 kV, Z_S=0.06141+ j0.03066 p.u.; Line 4: rated kV=13.8 kV, Z_S=0.06065+ j0.10150 p.u.;

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