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Power loss reduction in radial distribution system with multiple distributed energy resources through efficient islanding detection

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ABSTRACT

To provide electric utility service of desired quality at the lowest possible cost, voltage drop and power loss reduction is crucial for distribution network. Distribution systems with Distributed Energy Resources (DER) have shown an enormous potential for power loss and voltage drop reduction. This paper investigates existing islanding detection techniques for feeder performance and proposes a new islanding detection algorithm (NIDA) for node voltage profile improvement and power loss reduction in the distribution network.

The NIDA has been validated with three case studies. It has been investigated for its capabilities to improve the feeder performance in electric distribution system. The proposed algorithm outperforms the conventional approaches, which have many limitations to detect the islanding operation. The non-uniform distribution of electric loads, unity power factor, complexities in the design of control interface and functioning of the system in multi-DER environment are the most common obstacles in implementation of existing islanding detection techniques. NIDA is capable of handling the above mentioned complexities. The simulation results show that NIDA can detect islanding formation during the fault condition. The DER(s) provide uninterruptible power supply to sensitive load in the island, maintaining the nodes voltage and the power loss within the permissible limits.

1. Introduction

Small capacity distributed energy resource (DER) has significant contribution in some energy markets of the developed economies. These systems include solar cells, wind turbines and fuel-cells. In future, many other small capacity power stations like Micro-turbine and small Hydel are expected to join the family of distributed energy resources. Conventionally, some protection schemes for the DER systems have been used to detect electric power quality and islanding operation. Islanding operation is a situation in which electric utility is cut-off due to distribution system fault or maintenance of electrical equipment while DER is supplying electric power to the selected load [1,2]. Islanding phenomena may be responsible for some problems in electric power distribution system. Few of them are:

- ➢ Islanding operation may jeopardize public security and danger to maintenance workers.
- ➢ Islanding phenomena may cause unregulated electric parameters (voltage and frequency) of electric power distribution system so that the electrical equipment may get damaged.
- ➢ Islanding process may cause malfunction of protection equipment.
- ➢ After the recovery of electric utility, islanding operation may cause asynchronous problem between the DER system and the electric utility.

Hence, many islanding control standards, such as, UL 1741, IEEE 1547 and IEEE 929 have been established in Europe, United States of America, Japan and other countries [3]. The detection methods for islanding operation may be classified into active, passive and other methods. The passive detection methods are used to detect the changes of parameters in a power system for determining whether the islanding operation has occurred or not. For example, the passive detection methods include system-frequency detection method, voltage-amplitude detection method, and harmonic-contained detection method. However, both the amplitude and frequency will not change if the power supplied from the distributed power generation system is same as the power demanded by the load. Under such circumstances, these passive detection

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methods cannot detect the islanding operation, and it is known as the "non-detection zone (NDZ)". Accordingly, these passive detection methods cannot meet the requirements of the islanding control standards. In active detection methods, a small fluctuation is added to an output current of the distributed power generation system. When the utility is normal, the small fluctuation cannot affect the distributed power generation system because the utility is very strong. Conversely, when the utility is interrupted, the small fluctuation can cause a great change in frequency or voltage. In this way, protection relays can immediately detect such a change and judge it as an islanding operation. Instantly, the DER system must be disconnected from the utility so as to avoid islanding operation. Nevertheless, these active detection methods must comply with all international islanding control standards. Hence, the fluctuation resulted from these active detection methods must be restricted by the islanding control standards. Otherwise the detection time of islanding process is increased affecting the operation reliability. However, there is a NDZ still existing in some active detection methods.

Conventional approaches have many difficulties to detect the islanding operation. The detailed review of literature reflects that many algorithms have been developed for islanding detection of distribution feeders. Jun Yin and his colleagues have expressed the islanding detection algorithm, based on the proportional power spectral density [1]. Algorithm is robust against the load variations and has fast response during the occurrence of islanding process. However, due to mass load switching and fault, frequency variations may occur. This will increase proportional power spectral density in low frequency band, leading to a nuisance tripping for islanding. A voltage based active islanding detection method for distributed power generation system has been proposed by Wen-jung Chiang and fellow researchers [2]. The moment interruption occurs on utility main; power is supplied by DG to the connected load. The authors have investigated voltage variations by connecting different type of loads including resistive(R), resistive-inductive (RL), resistive-capacitive (RC) and resistive-inductive-capacitive (RLC), respectively. But the effect of inductive and capacitive loads separately connected with DG at the instance of grid failure, have not been analyzed. Furthermore, under load varying conditions, the output current of DG cannot be controlled to a pre-determined value which may cause power quality problems.

Shyh-Jier Huang and Fu-Sheng Pai have developed an algorithm, based on the self-commutated static power converter [3]. The computational procedure involves the sampling of input data including the input voltage and current for each branch and variations in frequency and power. During the occurrence of the islanding, the changes in the frequency and power are compared with their pre-determined threshold values. The incorrect selection of threshold values may increase computational time, causing an adverse effect on the results. Thorough investigation of the algorithm further highlights the difficulties faced during its implementation for distribution system having more than one DG.

In majority of cases, DG(s) are designed to operate at unity power factor. It has been observed practically that the islanding detection techniques which are frequency dependent may not be effective when DG is designed with unity power factor. Unfortunately, these methods suffer from two main drawbacks of the choice of suitable threshold and a large nondetection zone (NDZ). An active islanding detection for an inverter-based DG is presented by H.HZeineldin in which an effort has been made to explore the effects of using DGs to improve the load power factor, through reactive power injection, on the NDZ of over (under) voltage and frequency protection for islanding detection method [4]. Although the proposed islanding detection technique is robust and has negligible NDZ but still it faces serious complexities during both in interface control design as well as parameter selection. As lot of computational work is involved in determining the parameters, the algorithm may fail to provide the accurate results in case of wrong parameter selection. A hybrid islanding detection technique has been developed by Vivek Menon and M. Hashem Nehrir in which power flow and voltage unbalance detection techniques are combined to detect the islanding phenomena [5]. The disadvantage of this method lies in the inaccurate selection of frequency set point for power flow in the system. No proper criterion has been developed to select the frequency set point. The wrong restoration of frequency set point during the islanding detection may adversely affect the system. Other important issue relating to frequency set point is the selection of unity power factor for DG. Frequency based islanding detection techniques may not function properly at unity power factor. A new digital protection algorithm for islanding detection has been suggested by M.A. Redfern [6]. Incase of improper selection of trip setting (K_s), the operation time may be increased. The results may also change drastically under the varying load conditions. Sung II Jang and Kwang-Ho Kim have presented an islanding detection method for DG using voltage unbalance method and total harmonic distortion of current [7]. The proposed algorithm is applicable only for single DG case. F. Katiraei, M.R. Iravani and P.W. Lehn have framed micro-grid autonomous operation during and subsequent to islanding process. This approach has an appropriate control strategy for power electronically interfaced DG unit that can ensure stability of the micro-grid and maintain voltage quality at designated buses [8]. The suggested method is applicable only for balanced load. Furthermore, it cannot be implemented for a case where we have more than one DG. A new control strategy was implemented for intentional islanding of DG by H. Zeineldin and E.F. EI-Saadany [9]. The method represents the hybrid passive islanding for DG. The simulation results show that the interface control is not capable of operating in islanding condition despite the fact that the DG capacity is enough to supply the load. When the islanding mode is operated, the spikes occur in the active and reactive power, frequency and voltage. If duration of spikes is more than pre-determined value, it will affect the operation of islanding detection algorithm and will also deteriorate the power quality of DG.

Guiliang Yin has developed a distributed generation islanding detection method, based on artificial immune system. In this research paper two modules (T and B) have been constructed on the functions of T and B cells of immune system [10]. Based upon these values, digital signal processing system has been established. The algorithm is difficult to implement particularly because of much computational complexity involved. Sung II Jang and K.H. Kim have designed a new islanding detection algorithm for DGs interconnected with utility networks based upon the voltage unbalance and voltage magnitude. The results are valid only for single DG scenario. No test cases were performed for islanding having more than one DG. Khalil EI-Arroudi, et al has developed an intelligent approach to islanding detection in DG [11]. The technique presented can be implemented successfully with high degree of accuracy for multi-DG system and has the ability to optimize the threshold values for various system parameters. However, much computational work is involved in the implementation of technique which may prolong the operating time and adversely affect the results. The data mining technique can be applied to optimize threshold values of the four parameters including frequency, voltage, rate of change of frequency and rate of change of power for different protective devices. Although the data mining approach is very flexible in selecting the type and number of the system parameters, however, the extraction of setting rules from constructed model is too difficult. A relay trip signal is issued only when the measured values exceed the threshold and holds for a preset time-delay. The inaccurate adjustment of preset time-delay may also affect the optimal threshold values for various system parameters. Morris Brenna et al