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Power imbalance application region method for distributed synchronous generator anti-islanding protection design and evaluation

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ABSTRACT

This paper presents a novel graphical approach to adjust and evaluate frequency-based relays employed in anti-islanding protection schemes of distributed synchronous generators, in order to meet the anti-islanding and abnormal frequency variation requirements, simultaneously. The proposed method defines a region in the power mismatch space, inside which the relay non-detection zone should be located, if the above-mentioned requirements must be met. Such region is called power imbalance application region. Results show that this method can help protection engineers to adjust frequency-based relays to improve the anti-islanding capability and to minimize false operation occurrences, keeping the abnormal frequency variation utility requirements satisfied. Moreover, the proposed method can be employed to coordinate different types of frequency-based relays, aiming at improving overall performance of the distributed generator frequency protection scheme.

1. Introduction

Due to the remarkable increase in the number of distributed generators installed in distribution systems worldwide, there is an urgent need to assess the impacts of distributed generation (DG) on the design and operation performance of distribution networks. Among such impacts, islanding detection is an important issue to be analyzed during DG operation. Islanding occurs when part of the distribution network becomes electrically isolated from the main energy supply, yet it continues energized by distributed generators. This is not allowed by many utilities because it can deteriorate the power quality of the isolated system as well as it can be a hazard to utility personnel, consumers and network equipment [1–3]. To avoid islanding, the current practice recommended by utilities and technical guidelines is to disconnect the DG after a loss of mains [1,2,4], typically faster than 2 s. In order to achieve such a goal, some methods can be found in technical literature, which are classified into three categories: communication-based, active and passive methods [2,5,6].

Communication-based anti-islanding techniques may employ SCADA (Supervisory Control and Data Acquisition) systems, PLCC (Power Line Carrier Communication) systems or transfer trip schemes [5]. Some schemes are presented in [2,5–7]. Such methods detect islanding efficiently, since they do not have non-detection zones (NDZs). On the other hand, the need of adequate communication infrastructure leads to high implementation complexity and costs, which can pose as a significant barrier to the use of this type of anti-islanding protection scheme.

Active and passive techniques aim at detecting islanding based on local measures. The basic idea behind active methods is the injection of signals or disturbances into distribution systems, and islanding is detected based on the responses to such disturbances measured at the DG site [2,5,6]. Active methods are dependent on the DG type. As examples, the method of the impedance measurement [8] and the method of DG terminal voltage variation [9] are suitable for synchronous-based DG, whereas the active frequency drift [10], Sandia frequency shift and Sandia voltage shift methods [11] are one of the most employed to inverter-based DGs. Although active methods present a good islanding detection performance, they may cause power quality problems [6].

Passive techniques are based only on local measures. Therefore, islanding is detected if some quantities, such as frequency, voltage, active power, etc. vary significantly after a loss of mains event. Frequency-based relays are widely employed in passive anti-islanding protection schemes [1,2,5,6]. Voltage relays can also be employed [1]. A survey on passive islanding detection techniques revealed a number of other signals or relays proposed for this purpose. To cite a few, in [12,13] the authors proposed a technique based on the DG rate of change of the active power to identify islanding of synchronous DGs. Hybrid techniques have also been proposed. For example, in [14] the authors proposed a method that analyses voltage unbalance and harmonic distortion. Other passive

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methods can be found in [1,2,5,6]. Usually, the implementation of passive techniques is cheaper and simpler than the implementation of communication-based and active schemes. Nevertheless, they tend to have large non-detection zones, if the overall generation meets loads in an islanded system [15,16]. Therefore, one big challenge is how to adjust passive anti-islanding schemes to detect islanding efficiently and to minimize false trip occurrences.

In this context, this paper focuses on the adjustment of frequency-based relays for anti-islanding protection, since such devices are widely employed in DG interconnection protection schemes due to their simplicity and low cost, if compared to active or communication-based anti-islanding protection.

Frequency and voltage-based relays are strongly dependent on the active and reactive power imbalances in the islanded system, respectively [15]. Therefore, they must be carefully adjusted in order to be effective to face the typical active and reactive power imbalance changes, caused by the variation of distribution loads consumption. Moreover, they must attend abnormal frequency and voltage variation requirements [4], and the anti-islanding requirements simultaneously, which can be a hard task since both sets of requirements can be conflicting. For example, an anti-islanding device adjusted sensitive enough to detect islanding efficiently may often disconnect the generator in case of frequency variations caused by disturbances other than islanding. On the other hand, if the same device is adjusted to not violate the abnormal frequency variation requirements, it may not detect islanding conditions within the required time.

In order to overcome the difficulty described previously, this work proposes a novel graphical method that efficiently guides protection engineers to adjust frequency-based relays in order to meet both protection requirements simultaneously. The new method, called Power Imbalance Application Region (PIAR) is based on the non-detection zone concept [15–17], and defines an area in the power mismatch plan (reactive power imbalance *versus* active power imbalance plan), within which a relay non-detection zone must be located, if both protection requirements should be met. Non-detection zones have been used as an effective technique to evaluate the performance of anti-islanding protection schemes in machine-based [15,16] and inverter-based DG [17,18]. In this work, they are also employed as a method to adjust anti-islanding protection schemes. The focus of this paper is the analysis of synchronous distributed generators due to their extensive use in small-scale hydro power plants, combined heat and power (CHP) plants and internal combustion engines. Moreover, providing adequate anti-islanding protection to synchronous distributed generators has become a challenging task, since these machines are relatively large in size in comparison to other DG technologies, and there is a lack of control flexibility [5].

The great advantage of the idea proposed here is that in only one graphic, there is information about the relay anti-islanding performance and its capability to satisfy abnormal frequency variation requirements for all the feasible distributed generation operating conditions. Thus, the protection engineer can adjust anti-islanding devices to satisfy both requirements for most of the power imbalances expected in the distribution system. Standard over/under frequency and rate of change of frequency (ROCOF) relays are employed in this work. The results show the advantages of PIAR to maximize the anti-islanding protection efficiency with and without the coordination between ROCOF and frequency protection functions.

This paper is organized as follows. The concepts of power imbalance application region are explained in Section 2. The application of the method is presented in Section 3, where three main issues are covered: anti-islanding performance maximization, reduction of nuisance tripping occurrences and coordination between different types of frequency-based relays. Finally, the main conclusions are presented in Section 4.

2. Power imbalance application region–concepts

The main idea behind the PIAR method comprises the union between protection requirements against abnormal frequency variation, and the non-detection zones associated with frequency-based relays anti-islanding performance [15,17]. The abnormal frequency variation requirements are given in Table 1, from which the clearing time presented in the third column is the time between the start of the abnormal condition and the disconnection of the generator. As this interval includes the circuit breaker opening time, the relay detection time can be as low as 100 ms. In this work, the range of adjustable under frequencies was changed from 57–59.8 Hz to 57–59.5 Hz, because this is usually employed by many utilities.

The non-detection zones of frequency-based relays are areas in the reactive power imbalance *versus* active power imbalance plan ($\Delta Q \times \Delta P$), which define operating conditions that cause the protection devices to fail to detect islanding [15–17]. They are strongly dependent on the required islanding detection time, relays types and settings, and type of the distributed generator (synchronous, inverter-based or asynchronous). A detailed description of the frequency-based relays non-detection zones employed to the anti-islanding protection of distributed synchronous generators is presented in [15], and a summary of the procedures employed to build them is presented in the next section, followed by a detailed explanation of the PIAR method fundaments.

2.1. Non-detection zones formation

In order to describe the procedures to obtain the non-detection zones (NDZs) let us consider the test system of Fig. 1. Its components were represented by three-phase models. Distribution feeders were modeled as series *RL* impedances and transformers were modeled using the *T* circuit. Synchronous generators were represented by an eight-order three-phase model in the *dq* rotor reference frame [19]. The generator was considered equipped with an automatic voltage regulator (AVR) represented by the IEEE – Type 1 model. In addition, usually, distributed generators do not participate in the frequency regulation of the system and, therefore, they operate at constant active power mode [1]. Thus, the mechanical power was considered constant, and the speed governor was neglected. The loads were modeled as constant impedance type [19]. The AVR was configured to keep the nodal voltage at 1 pu. The complete system data can be found in the Appendix A.

Numerous dynamical simulations are necessary to obtain the non-detection zones of synchronous-based distributed generators, and all of them were carried out using the SimPowerSystems, an extension of Matlab/Simulink [20]. Each simulation comprised an islanding occurrence through the opening of the circuit breaker CB in the distribution system of Fig. 1, under specific load-generation profile, relay setting and required islanding detection time. In order to completely map the DG operating points, the load-generator

Table 1
Interconnection system response to abnormal frequencies [4].

Generator size	Frequency range (Hz)	Clearing time (s)[a]
≤30 kW	>60.5	0.16
	<59.3	0.16
>30 kW	>60.5	0.16
	57–59.8 (adjustable set point)	Adjustable 0.16–300
	<57.0	0.16

[a] Gen. ≤ 30 kW, maximum clearing times; gen. > 30 kW, default clearing times.