Electrical Power and Energy Systems 63 (2014) 113–123

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Advanced islanding detection utilized in distribution systems with DFIG

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ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 3 May 2014
Accepted 10 May 2014
Available online 26 June 2014

Keywords:
Islanding
ROCOF
DFIG
Interlock function

ABSTRACT

The penetration of distributed generation (DG) in electrical power systems is rapidly increasing these days and more attention is drawn to maintain a healthy distribution system. Islanding operation of DGs is one of the biggest challenges to the distribution system stability. Fast and accurate islanding detection can avoid the possibility of damages to the DGs when they are un-intentionally reconnected to the grid and also provide useful information to the protection and automation design of the stand alone operated system. Rate of change of frequency (ROCOF) method is one of the most commonly employed anti-islanding protection techniques, it offers fast detection and easy implementation. However, it is often easily affected by the system disturbance and might not able to detect the islanding situation if the power imbalance between the DG and the load is small. This paper investigates an inter-lock method which can improve the performance of rate of change of frequency (ROCOF) by applying system impedance estimation. It was found that this new method can help in verifying the ROCOF relay islanding detection and avoiding false operations of ROCOF in a grid connected distribution system which has large load variations. The proposed method was verified using the experimental testing results derived from both an experimental testing model which includes an 8 kW Double Feed Induction Generator (DFIG) and a 9 MW DFIG simulation system.

Introduction

Current technology development for renewable resources such as wind, solar and biomass to be connected into the distribution network to contribute in loss reduction, power quality improvement, and system capacity enlargement is ongoing. Due to the deregulate application of renewable power, the proportion of distributed generation (DG) is rapidly increasing and most of DGs are connected to distribution networks to supply power to both the grid and local loads [1]. There are many power quality issues to be considered with the penetration of DGs and one of the main issues is the DG islanding operation [2–6]. The islanded DGs can still serve local loads and the islanded system can operate as a micro-grid [7] if system is carefully re-constructed and power balance is achieved within the micro-grid. It is important to detect an unintentional islanding situation quickly and accurately to prevent damage to the DGs and also provide useful information for automation design of the stand alone operated system.

Due to a fault or any other disturbances, a distributed generation system can become electrically isolated from the remainder of the power grid and this leads to an islanding operation situation. Islanding detection can be classified as: based on communication and based on local measurement. Communication based islanding detection schemes monitor the state of the all the circuit breakers in the system and send a signal to the local generators through power lines [8] or separate communication equipment [9] when certain breakers are opened and islanding is formed. The power line communicated method [8] uses the existing transmission or distribution lines for signal transportation and requires less investment whereas the method involves a separate communication kit [9] can avoid the influence of power system signal distortion. However, communication methods cannot be widely employed due to the requirement of reliable signal generation, acquisition and amplification. Loss of signal or discontinuous signal might lead to relay mal-function. Local measurement based schemes include active methods which involve continuous injection of certain distortion and passive methods which rely on the system parameters monitoring such as voltage, frequency, power, and harmonic distortions [10–17]. Active islanding detection methods usually offer a zero Non-Detection Zone (NDZ) but the injection [18] and frequency (or voltage) drifting procedure [19–21] cause system disturbance and reduce the power quality level. Authors in [18] introduced a method which involves injecting a sinusoidal current

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http://dx.doi.org/10.1016/j.ijepes.2014.05.003
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from the local DG side and impedance measurement. This method requires additional injection units and works under the assumption that the local DG impedance is much larger than the paralleled system impedance seen from the injection point. The frequency and voltage (amplitude and phase angle) drifting methods are normally utilized in inverter based DGs and the feed-forward control loops have to be modified to accelerate the DG output variations during islanding. Due to fact that system distortions generated by the modified control loops can lead to power quality degradation, those methods cannot be employed in large DG systems and are vulnerable to system load variations. The Passives methods [19–21], such as one of most commonly applied Rate of change of frequency (ROCOF) [12,16,17], suffers from the NDZ and may lead to false operation in case of large system disturbance and load variations. Therefore, to improve the performance of the ROCOF relay, it is necessary to effectively detect the islanding and block the trips signal during a non-islanding and load variation situation.

This paper proposed an impedance-based passive method that can effectively detect islanding and offer blocking signal during a large load variation in non-islanding situation. Experimental tests were carried out to verify the new islanding detection method which combines the ROCOF and the proposed impedance estimation interlock function in a test rig that consists of an 8 kW Double Feed Induction Generator (DFIG). The tests were carried out under two main conditions (islanding and non-islanding with load variations) with different power imbalances between generation and the load were implemented. Voltages and currents were measured at the stator side of the local generator for the proposed algorithm which is able to distinguish the islanding and load changing situations and avoid relay nuisance tripping when disturbance appears in a healthy system. Simulation tests in a more practical system were carried out to evaluate the performance of the proposed method in a system with different dynamic, topology and controls.

The paper is organized as follows: the algorithm overview of proposed method is described in 'Algorithm overview'. The experimental set up is given in 'Experiment setup' and followed by the testing results in 'Experiment results' and 'Simulation'. Finally, the conclusions are provided in 'Conclusion'.

Algorithm overview

In a distribution power system, an islanding operation is only allowed for loads with dedicated generation and energy storage unit. As a result, DG must be equipped with islanding detection unit and disconnected from the grid in a short period of time when the islanding occurs. The proposed passive islanding detection method can be described as below:

An equivalent circuit of an embedded generator equipped with a ROCOF relay operating in parallel with a distribution system is shown in Fig. 1. The embedded generator and the power system feed the load Z_L. The power system frequency is kept constant. If the circuit breaker CB opens during a fault, the generator and the load that composes the system become islanded. In this situation,

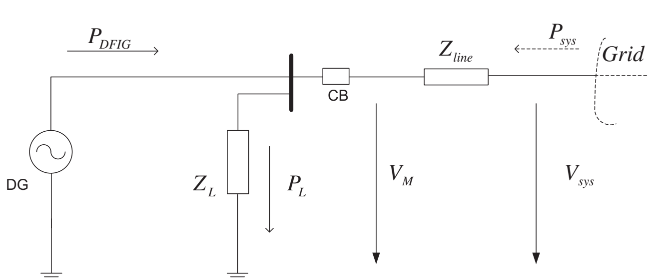

Fig. 1. Equivalent circuit of an embedded generator operating in parallel with grid.

transients are caused by an electrical power imbalance in the islanded system and the system frequency starts to vary dynamically. The islanding condition can be detected by observing such system behavior such as using the rate of change of frequency as the frequency varies according to (1).

$$\left.\begin{aligned} d\delta/dt &= \omega - \omega_0 \\ d\omega/dt &= \tfrac{\omega}{T}\Delta P \end{aligned}\right\} \tag{1}$$

where δ is denoted the power angle; ω is the frequency; ω_0 is the rated frequency; T is the inertia index and ΔP is the power imbalance between the DG and the local load.

However, the ROCOF relay has a non-detection zones when ΔP is close to zero and is vulnerable to the system noise and disturbances caused by load variations. An interlock function is needed to verify its performance and stop false trips during non islanding conditions. The proposed interlock function is based on the relationship between real power and the impedance of the connected system. As shown in Fig. 1, the exported power to the system(P_{sys}) is described in Eq. (2):

$$P_{sys} = \frac{V_M}{Z_{Line}}\left[R_{Line}(V_M - V_{sys}\cos\delta) + X_{Line}V_{sysrem}\sin\delta\right] \tag{2}$$

where V_M is the local measured voltage; V_{sys} is remote grid voltage; Z_{Line} is line impedance magnitude ($\sqrt{R_{Line}^2 + X_{Line}^2}$); R_{Line} is the line resistance and X_{Line} is line reactance.

The line impedance typically consists of the distribution cable impedance and the step-up transformer impedance (reactance dominate). So that $X_{Line} \gg R_{Line}$, and also assuming that the voltage drop on the transmission line is zero and there is a pure resistive load, the local measured power is:

$$P_M = \frac{V_M^2}{Z_L} + \frac{V_M^2\sin\delta}{X_{Line}} \tag{3}$$

and the measured input impedance is:

$$\frac{V_M^2}{P_M} = \frac{Z_L}{1 + \frac{Z_L\sin\delta}{X_{Line}}} \tag{4}$$

When the generator is islanded then $X_{Line} \to \propto$, then this becomes:

$$\frac{V_M^2}{P_M} = Z_L \tag{5}$$

As shown in Eqs. (1), (4), and (5), there will be a noticeable change in the measured input impedance when islanding occurs and the input impedance (V^2/P) will be independent of the power imbalance and voltage phases during islanding. Unlike the ROCOF method which requires certain power imbalance to see a frequency variation, by monitoring the input impedance (V^2/P), it is possible to detect the changes of system configuration regardless of the power flow and this offers a zero non-detection zone. This can be used to verify the performance of ROCOF relay. Also, the measured input impedance (V^2/P) can be employed to distinguish the situations between islanding or non-islanding with load variations and used as an inter-lock function to prevent ROCOF relay from false tripping in a healthy operating system with disturbances which may be caused by load shedding and load adding. The performance of the proposed algorithm will be evaluated in the following sections.

Experiment setup

The proposed islanding detection method and its inter-lock function are verified in an 8 kW DFIG test rig which is based in