Electrical Power and Energy Systems 105 (2019) 632–641

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Method for identification of grid operating conditions for adaptive overcurrent protection during intentional islanding operation

Roberta R. Ferreira, Patry J. Colorado, Ahda P. Grilo*, Julio C. Teixeira, Ricardo C. Santos

CECS – UFABC, Santo Andre, Brazil

ARTICLE INFO

Keywords:
Islanded operation
Synchronous distribution generator
Identification of operating conditions
Adaptive protection

ABSTRACT

Currently, it is considered that distributed synchronous generators may operate in intentional-islanding operation mode, in which a portion of the power grid, which consists of load and distributed generation, is isolated from the remainder of the utility system. However, the fault current level of the feeders drastically decreases when the utility grid is disconnected and the protection will not properly operate if the overcurrent settings are not changed. In this paper it is proposed a method for identification of the grid operating conditions, utility connected or islanded. The method is based on the use of a local scheme installed close to the protection device. The scheme uses a thyristor which is fired during a short waveform interval of voltage. The thyristor voltage and current are monitored and used to calculate the grid equivalent impedance. According to the grid equivalent impedance it is possible to determine whether the utility is connected or not. Simulations considering a distribution system and a distributed synchronous generator are used to validate the proposed method. The results show that the method can be used to update the protection settings when the operating condition of the system is changed from utility-connected to islanded operation mode or vice-versa. As a result, the method allows implementing an adaptive protection without the use of communication system or can be used as a backup to increase the resilience in case the communication is lost.

1. Introduction

Intentional islanding is a condition in which a microgrid or a section of the power grid, which contains load and distributed generation (DG), is isolated from the remainder of the utility system and continues to operate. The DG islanded operation can supply portions of the network or critical loads when the connection to the utility system is lost. This practice improves the reliability indices, brings extra revenue to DG owners, and reduces the frequency and duration of interruptions for customers [1–3].

Currently, the majority of utility system operator codes require the disconnection of the DG when it is islanded for safety and security reasons. However, the high-reliability requirements faced by the utilities are increasing the need to keep the DGs operating after a grid disturbance. As a result, the revision of this policy is considered in the standards [4], since there are benefits to all agents involved.

During utility grid-connected operation, the DGs are usually scheduled to provide a fixed power level to the grid. When the generator is islanded from the main grid, the DG has to detect the islanding situation and the operation mode of its speed regulator and excitation system have to be changed to control the frequency and the voltage of the islanded grid [5–7]. Additionally, the fault current level drastically decreases when a portion of the system is islanded. Thus, the protection will not be able to properly operate in case of faults in all parts of the islanded system if the overcurrent protection settings are kept the same. To overcome this issue, an adaptive overcurrent protection can be employed with the use of a microprocessor-based relay [8]. A microprocessor-based relay can store multiple setting groups. The active setting group is chosen by an input signal, which should reflect the system operating condition. Consequently, the key-function is to identify the system operation condition to be sent to the relay.

The identification of the operating conditions can be performed by a communication system, which allows updating the generator controls and protection settings of the feeders [9,10]. This type of system, however, is technically complex and requires a considerable investment, increasing the costs and, as consequence, may not be viable for small distributed generators, especially, for rural areas.

When the system is not provided with communication, local methods should be used to detect the system operating condition and to update the protection settings and the generator controls. Different methods have been proposed for changing the generator frequency and voltage control [11–13], which are basically based on the generator

---

* Corresponding author.
E-mail address: ahda.pavani@ufabc.edu.br (A.P. Grilo).

https://doi.org/10.1016/j.ijepes.2018.09.004
Received 28 March 2018; Received in revised form 30 August 2018; Accepted 8 September 2018

response to small disturbances. These methods can not be used for updating the settings of the protection systems. For this purpose, an adaptive protection that does not depend on communication is proposed in [14]. The method is based on frequency variations produced by the DG islanding detection method and on the information stored in the relays due to short-circuits in different points of the grid.

This paper proposes the use of at thyristor-based scheme for detecting the system condition, which is connected close to the relay and it is responsible for updating the grid operating condition. The use of this scheme allows estimating the system equivalent impedance, which is different for islanded or connected operating conditions. The scheme, as well as its operation, is very simple and allows to determine the system condition efficiently without using communication.

The paper is organized as follows: In Section 2 the proposed methodology is presented. The problem of different fault current levels for grid-connected and islanding operating conditions is discussed in Section 2. The thyristor-based scheme and its working principle are described in Section 3. The model of the distribution system is presented in Section 4. Section 5 brings the simulation results to validate the methodology and in Section 6 the conclusions are presented.

2. Fault currents in a distribution system with DG

Fault currents in a distribution system change after the introduction of DG. In a distribution system without DG, the substation is the only source of current and the current decreases as the distance from the substation increase. However, when the system is embedded with DG units, especially synchronous-generator based DG, the DG will also contribute to the fault current. For example, considering part of a distribution system as presented in Fig. 1, for a fault in line 2-3, the fault current is composed of the utility contribution and the DG contribution. Therefore, the setting of relays should consider the DG fault current contribution.

Assuming the DG of Fig. 1 can operate in islanding mode in the event of a grid power supply failure. The fault currents will change for islanding operation. An example of this operating condition is the occurrence of a fault in line 1-2 and the opening of the circuit breakers of R12 and R21. The loss of the utility grid results in the DG supplying the loads connected to buses 2 and 3. In this situation, if a fault occurs in line 2-3 only the DG will contribute to the fault current. The DG fault current is considerably reduced compared to the fault current from the utility substation, and if the relays settings are not updated, the protection system cannot operate properly in case of a fault.

The detection of the operating conditions can be performed by using a communication system, which enables exchanging information among the grid protective devices. Although the use of communication in distribution systems is promising, it is not reality for most of distribution power systems and especially for rural areas. Therefore alternative solutions should be proposed for enabling the islanded operation of power distribution systems supplied by DGs. Additionally, even in the presence of communication systems, backup methods based on local measurements should be considered to improve the system resilience.

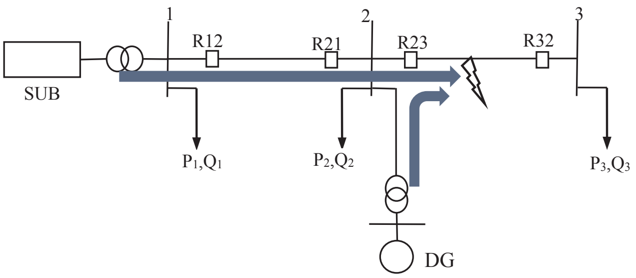

Fig. 1. Distribution system with DG.

3. Methodology for adaptive overcurrent protection

The methodology is based on the local measurements of voltage and current from a thyristor-based scheme. These measurements are used to calculate the grid impedance, which is compared to a threshold impedance to identify the grid operating condition. The scheme should be connected close to the protection device to send the signal containing the grid operating condition directly to the device, which will choose the settings accordingly.

The used scheme is illustrated in Fig. 2. It was based on the one proposed in [15] for DG anti-islanding protection. However, it is worth to highlight that the purpose and methodology proposed in this paper presents a different approach than the one presented in [15]. The scheme is composed of a thyristor connected to the secondary of a sensor transformer, which steps down the voltage to the thyristor operation level. The voltage at the secondary side of the transformer is monitored and used as reference for the firing algorithm of the thyristor. As the scheme will be installed close to the relay, the voltage transformer can be shared with the relay.

The thyristor is fired at a small angle ahead of the voltagés zero crossing point, creating a momentary short circuit. The voltage and current waveforms are illustrated by Fig. 3. The short circuit is limited by the grid equivalent impedance and by the transformer impedance, and it is cleared when the thyristor current reverses direction. If the firing angle is δ, the thyristor current reverses direction approximately on 2π-δ, which means that the thyristor will be turned on for 2(π-δ). For example, considering the firing angle is 170°, the thyristor will turn off on 190° and there will be current during 20° of the voltage waveform. Thus, the current flows by the thyristor during a short interval, which minimizes the impact on the power quality.

The fact that the thyristor current depends on the system equivalent impedance and on the firing angle (δ) can be used to identify the system operating condition, as following discussed. Fig. 4 presents an example of the application of the scheme. The diagram presented in this figure is part of a distribution system with a synchronous generator-based DG. Assuming the DG can operate islanded and, due to the occurrence of a fault, R12 is open and the area delimited by the dotted line is operating islanded, the settings of the relay R23 should be updated considering the new operating condition.

Thus, in order to identify the operating condition, the thyristor-based scheme is connected close to the relay, as presented in the diagram. Once the operating condition is identified, this information is used by the relay to select the proper settings.

The first step to understand the working principle of the thyristor-based scheme is to evaluate the impedance seen by it. The typical impedances of a distribution system are represented in Fig. 5; where R_g and X_g are the resistance and reactance of the generator; R_{ges} and X_{ges} are the generator side equivalent resistance and reactance; R_{sc} and X_{sc} are the equivalent substation short-circuit resistance and reactance; R_{grs} and X_{grs} are the grid side equivalent resistance and reactance; and R_{tr} and X_{tr} are the transformerś scheme equivalent resistance and reactance. The equivalent load impedance is not represented, as it usually presents considerable higher values than the system parameters. Therefore, for the sake of simplicity it is not represented in Fig. 5. However, it is worth to highlight that, in case of a power system with low short circuit power, it may be necessary to consider the load equivalent impedance. The system equivalent impedance seen from the thyristor-based scheme when the generator is connected to the utility system can be calculated by:

$$Z_{system} = (R_{tr} + j\cdot X_{tr}) + Z_{eq} \tag{1}$$

where $Z_{eq} = Z_{eq\_ss}//Z_{eq\_gs}$, and Z_{eq_ss} is the system side equivalent impedance and Z_{eq_gs} is the generator side equivalent impedance. The system side equivalent impedance is given by:

$$Z_{eq\_ss} = (R_{sc} + j\cdot X_{sc} + R_{grs} + j\cdot X_{grs}) \tag{2}$$