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The algorithm with synchronized voltage inputs for islanding detection of synchronous generators

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ABSTRACT

This paper presents a new algorithm for the islanding detection of synchronous generators. The algorithm uses synchronized phase voltages measured in all three phases on the main grid side and at the bus bars of the generator as input signals. Synchronized voltage measurement was performed using synchronized measurement technology (SMT). The algorithm based on digital phase comparison is the measured voltages and, based on the Islanding Detection Index (IDI), detects the occurrence of islanding operation. The algorithm testing was performed on the model of a radial distribution grid with two synchronous generators. The radial distribution grid is modeled in the MATLAB/Simulink software package. The test results show the good properties of the proposed algorithm.

1. Introduction

The integration of distributed generators (DGs) into the distribution grid has become more and more popular in recent years. This leads to improved power supply quality and reliability in critical conditions, as well as reduction of losses in the distribution grid. In order to assess the maximum contribution of DGs linked to the distribution grid, it is necessary to assess all their positive and negative effects on the distribution grid. One of the problems that arises in DGs connected to the distribution grid is the occurrence of islanding operation of DGs.

The occurrence of islanding operation is created if the connection between the DGs and the distribution grid is interrupted. This mode of generator operation usually arises as a result of a fault on the line connecting the generator to the main grid, and which is disconnected by opening the circuit breaker at the beginning and the end of the line. In this case, the DGs will operate in the islanding mode and supply loads existing on the DG side. According to the IEEE 1547-2003 standard, the DGs must be disconnected for 2 s after the islanding operation occurrence [1].

Islanding operation of the generator can cause a number of side effects that can be negatively impacted both on the generator itself and on consumers in the islanding grid part also. When islanding operation occurs, the voltage and frequency in the islanding grid part cannot be controlled by the main grid, and if the generator is unable to maintain the voltage and the frequency within the permitted limits, the equipment of the consumers who are power supplied in the islanding grid can be damaged. In the part of the grid that operates in islanding operation with DG, the short circuit current changes, which can negatively affect the relay protection devices coordination. In the islanding operation, there is a risk of turbine and generator damage if the non-synchronized generator is connected in the grid again. Also, one of the undesirable effects is the potential risk for maintenance workers as the islanding's grid part continues to be supplied by the DGs side. Due to all of the above mentioned potential problems that may arise in the islanding operation, it is necessary to detect the specified operating mode timely and disconnect DG.

A wide range of different methods for the detection of islanding operation of DG can be found in the literature. Methods for the detection of islanding operation can be classified into local, intelligent and remote. Local methods can be further classified as passive, active and hybrid methods.

Passive methods are based on measuring one or more system parameters such as voltage, frequency, and voltage angle. The disadvantage of these methods is the inability to detect islanding operation in modes when the power imbalance is low. Some passive techniques are based on the under/over frequency or under/over voltage relays [2], the vector surge relays [3], the rate of change of frequency (ROCOF) [4], the rate of change of frequency over power (ROCOFOP) [5], voltage imbalance and total harmonic distortion of current (THD) [6], the rate of change of output power (ROCOP) [7], and the system impedance monitoring [8].

Active methods are based on the identification of certain

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disturbances that are sent to the grid and which arise as a result of the islanding operation of DGs. This group includes Sandia frequency change based methods [9], Sandia voltage change [10], current injection [11], injection of the negative current component [12], injection of the negative voltage component [13], and the injection of the VF signal [14].

Hybrid methods represent a combination of passive and active methods. This group can include methods based on the voltage imbalance and the change in the set point of the frequency [15], the proportional power spectrum density [16], the average rate of voltage change and real power shift [17], and the rate of change of reactive power and load connecting strategy [18].

Intelligent methods have emerged in recent years with the development of computer and digital technologies. This group can include methods based on the application of fuzzy logic [19], decision tree (DT) [20], support vector machine (SVM) [21,22], artificial neural networks (ANN) [23], and adaptive neuro fuzzy inference system (ANFIS) [24]. Also, some papers suggest a combination of the aforementioned intelligent methods.

Remote methods are based on external communication over telecommunication connection between the DG and the locations at the supply points where the circuit breakers are located. These are distinguished by a high level of reliability compared to local methods because the monitoring of the circuit breaker condition is done through the central system. However, the installation of the sensors and communication system is expensive, which is the main disadvantage of these methods. Methods based on PMU application [25–27] can also be classified into this group.

2. Development of the algorithm

2.1. Criteria for islanding detection

In normal operating mode, the generator is connected to the distribution grid. The voltage of the main grid V_I and the voltage of the generator V_{II} have approximately the same phase angle.

When the generator enters the islanding operation, sudden release or an additional load of the generator will occur, depending on whether the generator has covered the local load and sent the excess power into the grid, or a part of the power from the grid was taken to cover the local load.

As a result of a sudden change in load, there will be a rate increase or decrease, which will result in a loss of generator synchronization with the grid. If in the steady state operating mode due to the auto reclosing a non-synchronized generator is connected to the grid, the generator can be damaged.

If in the islanding part of the grid the needs of loads for active and reactive power are less than those that the generator delivers as a result of the excess of active power, there will be an increase in frequency and an increase in voltage as a result of the surplus reactive power. If the needs of the loads for active and reactive power are greater than the generation of the generator, there will be the frequency reduction or voltage reduction in the islanding part of the grid.

In determining the criteria on which the algorithm operation is based, a starting point is the swing equation of the synchronous generator, which can be expressed as follows [28]:

$$\frac{2\cdot H}{\omega_0}\cdot\frac{d\omega}{dt} = P_{SG}-P_{Load} = \Delta P \quad (1)$$

$$\frac{d\theta}{dt} = \omega-\omega_0 \quad (2)$$

where is ω_0 nominal angular velocity of power system, and ω angular velocity of the generator. By combining the Eqs. (1) and (2), the following equation for change of the generator angular velocity can be obtained:

$$\Delta\omega = \frac{\omega_0\cdot\Delta P}{2\cdot H\cdot S_n}\cdot t_i \quad (3)$$

Based on the previous equation, it can be assumed that in the normal operating mode the phase difference between the generator voltage and the voltage of the grid is approximately equal to 0 because there is no angular velocity imbalance. When the occurrence of islanding operation arises, it will reach an imbalance in angular velocity, which will cause a change in the difference in voltage phase angles. Therefore, it can be concluded that when the islanding operation occurs, the voltage measured on the side of the main grid will retain approximately the same phase angle, while at the voltage measured on the side of the generator, the angular velocity imbalance will occur, which will cause the phase angle to change:

$$v_I(t) = V_I\sin(\omega_0 t) \quad (4)$$

$$v_{II}(t) = V_{II}\sin(\omega_0 t \pm \Delta\omega t) \quad (5)$$

where v_I *(n)* is the phase voltage samples measured on the main grid side, and v_{II} *(n)* is the phase voltage samples measured at the bus bars of the generator.

Since after entering the generator in the islanding operation the frequencies of the grid and the generator are not the same, the phase angle of the generator voltage V_{II} will change. In the event of islanding operation, the grid voltage V_I will retain the same phase angle as before the occurrence of the disturbances, so that it can be used as a reference signal. Due to the change in the phase angle, the voltage vector of the generator V_{II} will rotate at a different velocity in relation to the main grid voltage, and this will manifest by the changes of their mutual angle δ in the range of ± 180°.

The proposed algorithm uses the phase voltages measured on the side of the main grid and at the terminal of the generator as input signals.

2.2. Synchronized voltage measurement

In the last decade, the use of synchronized measuring technology (SMT) was limited to the use in transmission systems only due to the price. However, with the development of digital and communication technologies, there has been a significant drop in the price of synchronized measuring unit (SMUs), which made them attractive for use in distribution grids. The application of synchronized measurement in the distribution grid for the protection of DG from islanding operation was presented in [25–27]. The SMT architecture is shown in Fig. 1. The SMUs are installed at the generator location and on the main grid side and via voltage transformers (VT1 and VT2) in real time collect data on the phase voltages in all three phases. A timestamp obtained via a GPS

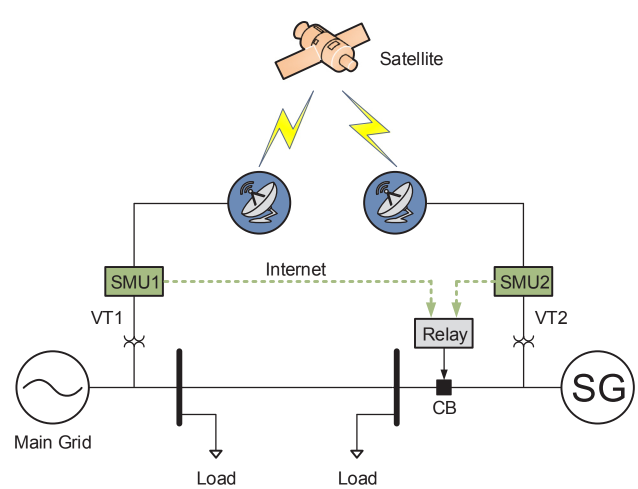

Fig. 1. Synchronized measuring technology architecture.