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Intelligent islanding detection of a synchronous distributed generation using governor signal clustering

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ABSTRACT

Detection of intentional and unintentional islanding of distributed generation units is one of the major protection issues of the distribution networks. Regarding the safety and reliable operation of a modern distribution network, an expert diagnosis apparatus is required to distinguish network cut off from variety of normal occurrences. Automatic load-frequency controller (ALFC) is an indispensable component of the synchronous generators. Simulation results show that input signal of the governor includes somewhat singular characteristics for each possible phenomenon or disturbance. Therefore, a new method based on Self-Organizing Map (SOM) neural network is proposed using input signal to the governor to cluster various occurrences into islanding and non-islanding categories. Simulation results presented in this paper shows that the input signal of the governor employed by a SOM can cluster a majority of occurrences of the system and distinguishes the islanding phenomenon with high confidence.

1. Introduction

Recently, distributed generation (DG) units have become more common in power networks to overcome some important issues such as growing the load demand, congestion of transmission and distribution lines, and declining the reliability. There will be a clear improvement in the distribution system configuration because of incorporation of DG units at distribution level [2,5,8]. DG sources include many important technical and economic influences through modifying active and reactive power flows. Many Industries and commercial power customers use their own synchronous DGs providing the required energy of the industrial units partially. Moreover, these small generators occasionally operate with low power or as standalone sets. In this situation, they are potentially able to operate in parallel with the main and sell energy to a local electric company. However, grid operators do not generally dispatch the output powers of such small units working in parallel with the main. In case of lack of a suitable operating control system, injected powers of DGs commonly increase the fault level and cause some power quality problems such as harmonics, frequency deviation, and voltage fluctuation. However, the most important dilemma associated with DGs is islanding operation. According to IEEE STD 1547-2003 [1], an island is a condition where a portion of a network is energized solely by the distributed generators while that portion is electrically separated from the rest of the grid. Many power systems include re-closers to cut off a tie line for a short time and protect the equipments against transient faults such as lightning. Automatically reconnection of the isolated part of the system may yield to out of phase reclosing of DGs and failures in the embedded generation units. It occurs if the embedded synchronous generators are not equipped with a reliable recognition facility detecting islanding after a short while of islanding operation. In this situation, quite often, large currents and mechanical torques are produced that can damage the alternators, prime movers, or other coupled devices. Therefore, detection of islanding is a quite essential requirement in particular while employing synchronous generators in a distribution system. The main philosophy of islanding detection is to distinguish islanding and to separate DG from the main on time. Once an islanding occurs, the DG should be disconnected from the main soon, otherwise loss of synchronism might cause some serious problems. Faster disconnection in the case of islanding means less likelihood of loss of synchronism.

Recently, many researchers have been carried out to develop a reliable and economical scheme for islanding detection applicable to various distributed systems. Monitoring and data processing of the output parameters variations of DGs is a fault diagnosis methodology suggested by some papers for making a decision whether an islanding has been occurred or not.

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In general, islanding detection techniques can be categorized into remote and local techniques. Local techniques can be further divided into passive, active, and hybrid techniques.

Remote or communication based loss of main detection techniques are based on communications between the utilities and DGs. Performance of a remote technique might be more reliable than that of a local one, but it has to be mentioned that generally the remote techniques are difficult to be implemented, as they are expensive and need to be updated regularly with modification or development of the network. Transfer trip [2] and power line signaling schemes [3] are two major communication-based islanding detection techniques.

One or a few output parameters of a DG such as voltage, current and frequency are processed by the local techniques to detect the islanding. Among the local techniques, the passive methods require just the values of the measured parameters and detect the islanding through data processing. Rate of change of output power [4], rate of change of frequency [5], harmonic distortion [6] and voltage unbalance [7] are some of the common quantities used in the passive techniques.

Active methods are featured to some schemes where inherently disturbances are locally injected into the system and system responses to these disturbances are processed to detect possible islanding conditions. Some of the well-known active schemes are: power export error detection [8], Slip-Mode Frequency Shift Algorithm (SMS) [9], effective power variation [10], phase shift anti-islanding method based on non-detection zone [11], and Active Frequency Drift (AFD) [12]. Hybrid methods have also been developed which employ both active and passive detection techniques to detect islanding situation more accurately with less influence on grids. Positive Feedback (PF), Voltage Unbalance (VU) [13], Adaptive Reactive Power Shift [14], and Average Rate of Voltage Change correlated with Real Power Shift [15] are some examples of the hybrid techniques.

As a brief discussion, it can be mentioned that none of the previously developed methods are perfect, so, research efforts are still being increasingly carried out to propose a more reliable and economical method for islanding detection. The Automatic Load-Frequency Controller (ALFC) as an important component of a synchronous generator for islanding detection purposes. Normally, every small synchronous generator is well equipped with an ALFC and governor. These controllers are designed such that to respond the load variations quickly and keeping the frequency constant while working as a stand-alone set or an island generator. However, when a generator is equipped with a governor and it is operating in parallel with the main, the governor just controls the output power of the generator regardless of the frequency. Briefly, this controller behaves differently for the islanding situation and when the system is operating in parallel with the main, so it is expected that the features of the internal signals of the controller be different for the two operating conditions. According to this expectation, the current paper investigates the capability of the governor signal for islanding detection purposes. A new method based on governor signal monitoring and by means of Self-Organizing Map (SOM) neural networks as a clustering approach [16,17] for islanding detection is introduced in this paper. This method identifies and clusters the islanding and non-islanding phenomena using only the measured input signal of the governor.

The content of the paper is organized as follows. Section 2 introduces the study system and its modeling. Section 3 illustrates variations of the input signals of the governor for some transient islanding and non-islanding operating conditions for comparison. The SOM concepts are presented in Section 4, and simulation results obtained by the proposed method are illustrated in Section 5. Finally, a conclusion is given in Section 6.

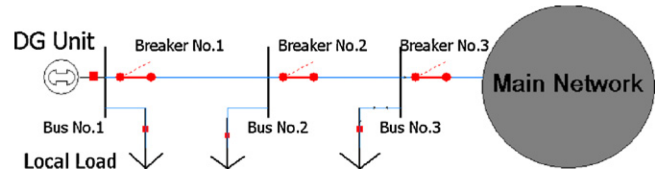

Fig. 1. Study system.

2. System and modeling

The case study system of this article consists of an embedded generator, a local load, a transmission line and an infinite bus as shown in Fig. 1. Three load buses and a few breakers are used along with the transmission line to simulate various load applications and islanding situations. The embedded generation unit is a small brushless salient pole alternator (31.5 kVA) with a diesel engine prime mover, AVR, and governor. Values of all parameters of the machine and controllers as given in Appendix A are normalized properly using the rated values of the machine as the base values.

2.1. Generator

The simulated machine is a three-phase generator whose dynamic equations are given in Ref. [18]. Vector of linkage fluxes (λ), vector of the induced internal voltages (e), and electromagnetic torque (^Te) are calculated respectively by:

$$\lambda = [L(\theta)][I] \tag{1}$$

$$[e] = \frac{d[\lambda]}{dt} \tag{2}$$

$$T_e = \frac{1}{2}[I]^T \frac{d[L(\theta)]}{d\theta}[I] \tag{3}$$

where the vector I represents currents of the field and stator windings and $L(\theta)$ is the matrix of the inductances. Arrays of the inductance matrix comprising the self and mutual inductances of the field and stator windings are defined versus the rotor position angle (θ) and are given in Appendix A.

2.2. Automatic voltage regulator and excitation system

Fig. 2 shows a block diagram of the whole genset including a sampling block, automatic voltage regulator (AVR), excitation system, and generator. The excitation system itself consists of an inverse designed synchronous machine and a three-phase full-wave rectifier diode bridge located on the shaft and connected to the armature windings of the exciter machine. The output terminals of the rectifier are connected to the field winding of the main alternator [19,20].

The AVR involves a PID controller that controls the duty cycle (or mark-space ratio) of the output signal (see Fig. 3). The output signal of the AVR is applied to the field winding of the exciter machine. Parameters values of the AVR are given in Appendix A.

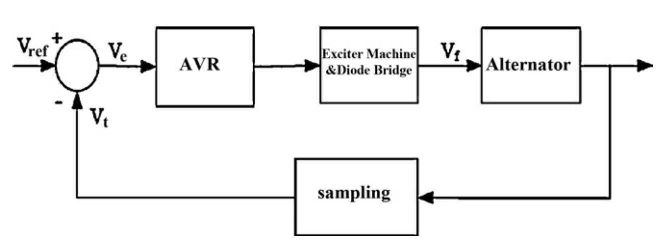

Fig. 2. Block diagram of the genset.