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Full Length Research Paper

Recurrent artificial neural network based islanding protection by using generator speed deviation

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This paper presents a new islanding detection algorithm for distributed generation. The method contains a multi-layer feed forward artificial neural network structure with tapped time delays and a feedback from output which is generally called Recurrent Neural Networks (RNN) for short-term memory. The inputs of the proposed structure are generator speed deviations with a window of 60 ms time interval. The speed deviation data are produced by using EMTP simulating program for different loading, switching operation, and network conditions. Simulation studies showed that the RNN-based algorithm detects islanding situation faster than the frequency and rate of change of frequency based algorithms. The new algorithm is also stable in loading conditions when parallel operation with the utility.

Key words: Recurrent neural network, islanding protection, power system protection.

INTRODUCTION

The interest of distributed generation has become more common in power systems. During parallel operation of a distributed generator connected to the power system, any fault condition or switching operation can cause separation of the local generation from the power system. This situation is called islanding, and some part of the power system loads can be connected to the distributed generator. Islanding condition causes abnormal operation in the power system and the distributed generation unit, and also causes safety problem. For these reasons, islanding protection is essential for synchronous generators connected to the power systems. In the islanding operation mode all of the distributed generator must be disconnected from the power system immediately.

For islanding protection the most direct method is to monitor auxiliary contacts on all circuit breakers on the power system between the main source of generation and the distributed generation (Redfern et al., 1993). When a switching operation produces an islanding, a transfer trip signal is sent to inter-tie circuit breaker for the purpose of disconnections the two systems. Reactive power export error detection relay measures reactive power flow between the distributed generation and the main power system. Relay operates, when there is a difference between the setting and the actual reactive power.

Another islanding detection method is based on frequency measurement. In the parallel operation mode, there is not load difference and the system frequency remains constant. After islanding occurs, electrical power imbalance causes transients in the islanded system and the system frequency starts to vary dynamically. However, if the power imbalance in the islanded system is small, then the frequency will change slowly. Thus, the rate of change of frequency (ROCOF) can be used to accelerate the islanding detection for this situation (Freitas et al., 2005, Vieira et al., 2006). ROCOF is calculated from the voltage signal considering a measure window over a few cycles, usually between 2 and 50 cycles. Because frequency measurement is affected by voltage distortion, the signal is processed by filters and then the filtered signal is used to detect islanding. If the rate of change of frequency value is higher than a predetermined value, a trip signal is immediately sent to the generator circuit breaker. Frequency-based relay can be set sensitive for fast islanding detection. In this case, the relay may operate false due to electrical transients. Because of nuisance tripping the frequency relays require power imbalance higher than 15 % to detect islanding suitably.

Since islanding condition causes power difference at the generator output, power-based islanding protection technique has been introduced (Redfern et al., 1995). In this algorithm, instantaneous power from the generator

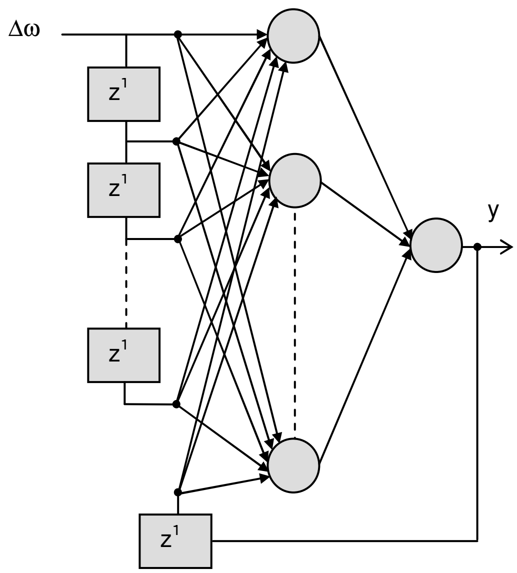


Figure 1 - Proposed recurrent neural network for islanding protection.

terminal is calculated, and then the rate of change of this power is derived. The rate of change of power amplitude is then limited by a function. This clipped signal is integrated over a moving window of a determined length, and tripping is initiated when the absolute value of the integrated signal exceeds the trip setting.

Vector-Surge (VS) relays calculate voltage angle variation ($\Delta\theta$) at the generator terminal. The VS relay setting varies from 2^o to 20^o, the critical power imbalance varies from 18.0 % to 91.7 % (Freitas et al., 2005). Because of false operation, the relay can not detect the power imbalance below 18 %.

All of the above islanding detection methods use voltage and current signals as inputs. These signals are affected by switching operations and harmonics. Because of these problems, generator speed deviations are used to determine islanding condition. In this study, generator speed deviations with tapped time delay as inputs and RNN architecture are used. Different training data sets representing loading and switching conditions are used.

Mathematical basis of the algorithm

Islanding condition can be assumed as a power impact. After power impact, if the load is greater than generators output power connected to power system, extra load is shared by generators according to their rating and inertia constant. The instant immediately following the impact must be studied carefully. In particular, how much of the impact $P_{L\Delta}$ supplied each generator should be exactly determined.

At the instant $t = 0^+$ it is known that, $\delta_{i\Delta} = 0$ for all generators, and there is no speed deviations because of c rotor inertias (Anderson and Fouad, 1993). At this time the source of energy supplied by the generators is the energy stored in their magnetic fields and is distributed according to the synchronizing power coefficients. Since generator rotor angles cannot move instantly, hence the energy supplied by the generators cannot come instantly from the energy stored in the rotating masses.

During the period $0<t<t_g$, where t_g is the time at which governor action begins, there will be overall deceleration (or acceleration) of the generators. The main acceleration of all the generators connected to the system can be defined as:

$$\frac{d}{dt}\frac{\omega_\Delta}{\omega_R} = -\frac{P_{L\Delta}(0^+)}{\sum_{i=1}^{n} 2H_i} \tag{1}$$

where ω_R is the rated angular speed and, H is the generator inertia constant. Furthermore how the generators will share the impact $P_{L\Delta}$ must be determined. While the system as a whole retards at a constant rate, the individual generators retard at different rates. Each generator follows an oscillatory motion according to its swing equation (Anderson and Fouad, 1993, Rudenberg, 1950). Eventually generators will share the increase in load as a function of their inertia constants according to the relation given below:

$$P_{i\Delta} = \frac{H_i}{\sum_{j=1}^{n} H_j} P_{L\Delta}(0^+) \tag{2}$$

In the parallel operation mode of a generator connected to the power system, the generator will share only very small part of the increase load after load impact because of small inertia due to the power system. The speed changes of the generator will be very small. But, in the islanding mode the increase load will only be supplied by the generator. In this situation, the generator speed will decrease dramatically. In the case of load decreasing, the generator speed will increase. These generator speed changes, which have nonlinear characteristics, can be assumed as the indicator of islanding condition.

Artificial neural network model

In this section, the proposed neural network structure and methodology for islanding protection has been presented. Recurrent Neural Networks (RNN) (Arvandi and Sadeghian, 2008) has been used as shown in Figure 1. This RNN is a multilayer perceptron structure:

the input vector (x) dimension is the speed daviation of the generator, One hidden layer has only one neuron with an output denoted by y.

The network structure has 1 input node, a single hidden layer with 15 neurons, and single output node (y). The

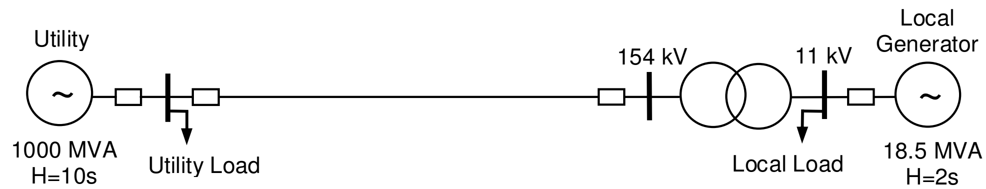
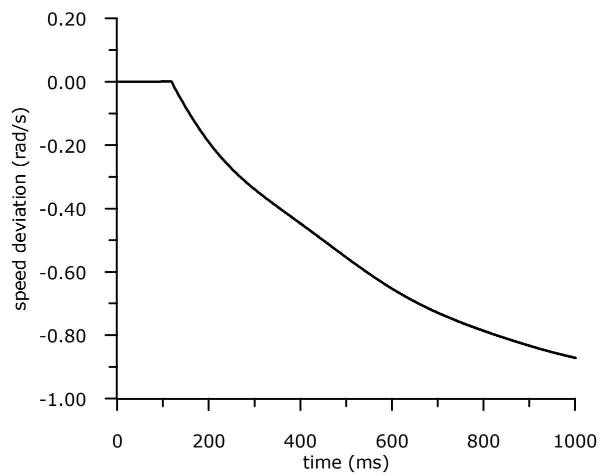
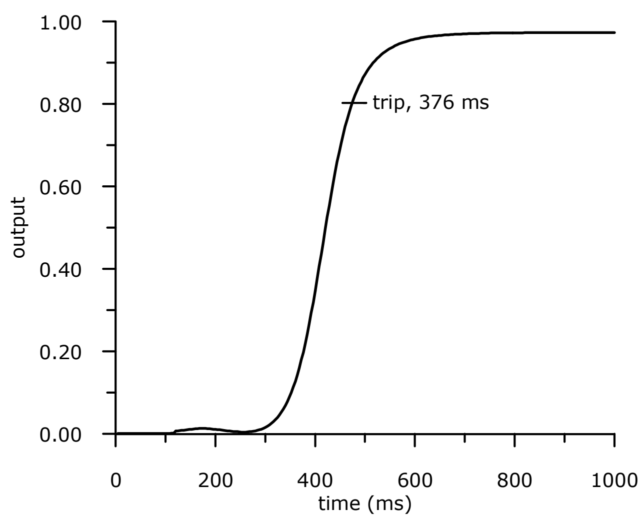


Figure 2 - Single line diagram of the simulated system.



a) Rotor speed deviation



b) RNN output

Figure 3 - Islanding with 5 % increase in local generator loading.

inputs of the network are 60 ms window of speed deviations with 4 ms time shift values, and the output is the trip signal representing the islanding situation, and the output of the network is fed to the input of the network with 4 ms time shift values of the trip signal.

The back propagation algorithm with momentum is used to train the neural network model (Haykin, 1994; Temurtas, 2003, Becerikli, 2003). The algorithm with momentum gives the change $\Delta w_{ji}(k)$ in the weight of connection between neurons i and j at iteration k as;

$$\Delta w_{ji}(k) = -\alpha \frac{\partial E}{\partial w_{ji}(k)} + \mu \Delta w_{ji}(k-1) \qquad (3)$$

where α is called the learning coefficient, E is the sum of squared differences error function, μ is the momentum coefficient, and $\Delta w_{ji}(k-1)$ is the weight change in the immediately preceding iteration. Because of its faster convergence than the standard back propagation algorithm is used.

For training and testing 60 ms length window data of speed deviations representing different operating cases, loading and utility conditions are used. These data are produced by using Electromagnetic Transient Program (EMTP) (Leuven, 1987), which is widely used for power system simulations. During parallel operation the RNN output is assumed 0, and in the islanding condition the output of 1.0 is assumed.

Simulation results

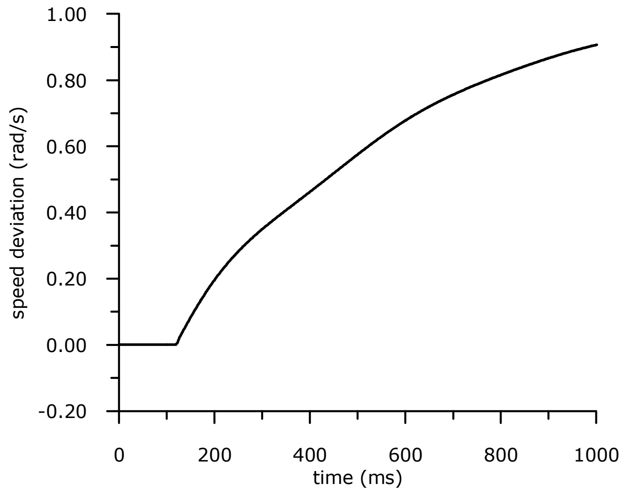
In order to test the new islanding protection algorithm, some simulation studies have been carried out. Power system model shown in Figure 2. and EMTP simulation program is used for loading and switching operations. Speed deviations moving data window which has 60 ms of time length is used as neural network input.

The response to islanding resulting in a 5 % increase on the local generator loading is shown in Figure 3. Immediately following the disturbance the rotor speed starts to decrease. RNN output that is greater than 0.8 is assumed logic “1” and the algorithm sends a trip signal. So the RNN based protection algorithm produced the trip signal 376 ms after the islanding occurred.

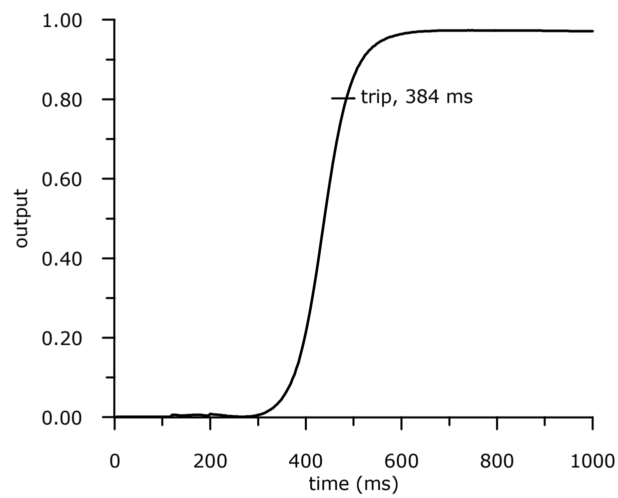
Figure 4 shows the response the islanding resulting in a 5 % decrease on the local generator loading. This time algorithm produced the trip signal after 384 ms.

The system response to islanding resulting in a 10 % increase on local generator loading is illustrated in Figure 5. The RNN based protection algorithm produces a trip signal after 168 ms.

The response to the load changing while the local generator is operating in parallel with the utility is shown in in Figure 6. Load changing is realized at the local genera-

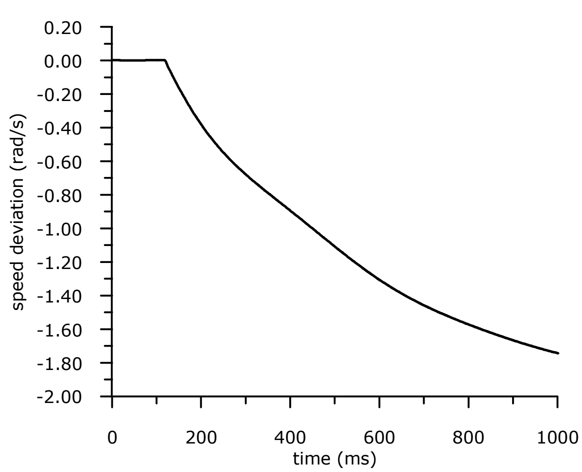


a) Rotor speed deviation

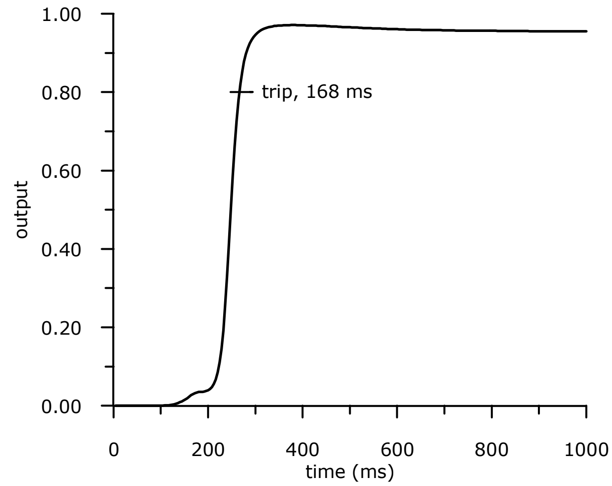


b) RNN output

Figure 4 - Islanding with 5 % decrease in local generator loading.

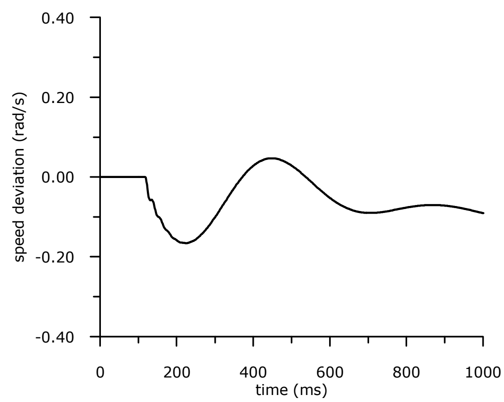


5 a) Rotor speed deviation.

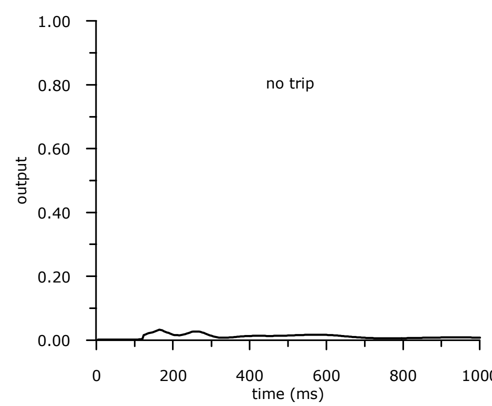


b) RNN output

Figure 5 - Islanding with 10 % increase in local generator loading.



a) Rotor speed deviation



b) RNN output.

Figure 6 - 100 % Load local load increase during parallel operation with the utility.

tor bus with 100 % of local generator capacity. The algorithm produces no trip signal as expected.

Conclusion

An RNN based islanding protection scheme is presented and realized in this study. This protection algorithm, which uses rotor speed deviation, is different from the other islanding protection schemes in terms of quantities measured. Islanding detection algorithms based on voltage and currents measurements are too sensitive and affected by switching operations, and harmonics. The new algorithm measures generator speed deviations and is not affected by harmonics and switching transients.

While the rate of change of frequency based protection algorithm requires an active power imbalance higher than 15% to detect islanding suitably, the new algorithm can detect islanding with 5% active power imbalance. Simulation results showed that islanding situation can be detected within 200 ms with active power imbalance higher than 10%. The RNN based algorithm also pro-duced no trip signal in case of heavy load changing con-ditions operating parallel with the utility as it is expected. Since nuisance tripping in the switching conditions, the frequency relay setting and coordination are very hard task. Therefore, in the proposed islanding detection algo-rithm relay setting can easily be done.

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