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Single-Line to Ground-Fault Detection for Unit Generator-Transformer based on Wavelet Transform and Neural Networks

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Abstract. This paper proposes an approach for the detection of the single line to ground fault on a unit generator-transformer, based on the extraction of statistical parameters from wavelet transform based neural network. In the simulation, the current and voltage signals were found decomposed over wavelet analysis into several approximations and details. The simulation of the unit generator-transformer was carried out using the Sim-PowerSystem Blockset of MATLAB. The statistical parameters analysis involved measurement of the dispersion factors (range and standard deviation) of wavelet coefficients. Regarding the pattern recognition of neural networks performance, the accuracy of SLG-fault detection of neural networks was 97.45 %. The results indicated that dispersion factor feature of wavelet transforms was accurate enough in distinguishing a single line to ground-fault and normal condition for a unit generator-transformer.

Introduction

Small current Ground-Fault (GF) detection has been a major concern in protective relaying for a long time. Relaying engineers and researchers often faces the challenge of developing the most suitable technique that can detect faults with reasonable reliability to secure the run of a power system [1]. In general, a step up transformer at an electric power station can be categorized either as a unit generator-transformer configuration, a unit generator-transformer configuration with generator breaker, a cross-compound generator or a generator involving a unit transformer [2, 3]. A GF on the transmission line or busbar can disturb the system configuration of the generator.

Numerous feature extraction methods based on Wavelet Transform (WT) have been used for the detection and classification of faults. Reference [4] proposes a new technique for arcing fault location by using Discrete Wavelet Transform (DWT) and wavelet networks. Fault classification procedure based on wavelet in transmission is suggested in [5]. Reference [6, 7, 8] describes the feature extraction technique based on fast WT, a fault index and wavelet power for use to detect the stator faults in the synchronous generator and transformer. Abstraction of a statistical parameter as fault detection has been used for fault detection in previous studies, but they only consisted of standard deviation, kurtosis and skewness [9]. Meanwhile, the statistical feature parameters include kurtosis, skewness, crest factor, clearance factor, shape factor, impulse factor, variance, square root amplitude value and absolute mean amplitude value to fault diagnosis in rotating machine, as defined in reference [10].

The new approach as proposed in this paper uses a dispersion factors of statistical parameters for single-line to ground (SLG) detection. In the analysis, the GF signals were calculated by using DWT. The GF detection was carried out including the analysis on significance of Range (R) and Standard Deviation (STD) of the current and voltage wavelet coefficients, as well as the detail and approximate of wavelet coefficients to distinguish SLG-fault.

A WT is an instrument which functions for the extraction of the transient signals. The best select of the mother wavelet plays an important part for detecting different types of transient signals. The finest wavelet for extracting signal information is that which can produce as many coefficients as possible to characterize the individual signals.

In the proposed approach, DWT is used for feature extraction, on condition that high time and low frequency resolution for high frequency and high-frequency resolution, and with low time resolution for low frequencies are required. DWT is applied by using the subsequent equivalence [11].

$$\mathrm{DWT}(m.n) = \frac{1}{\sqrt{a_0^m}} \sum_k x(k) g(a_0^{-m} n - b_0 k) \qquad (1)$$

where "*g(k)*" is the mother wavelet, "*x(k)*" is the signal input and *a, b* are the scaling and translation factors.

The main idea of making a feature extraction is to reduce the amount of information, whether using the original waveform or its transformation format. In this paper, for feature extraction procedure, the coefficient features of wavelet, for example, R and STD value of a wavelet coefficient, had to be intended.

ANN is excellent in solving pattern recognition problems. In pattern recognition, a neural network can be used to categorize the input into sets of target. In this paper, a set input of the dispersion factors in statistical parameters of wavelet coefficients was used for input to distinguish set SLG-fault or normal target categories.

Proposed Methods

The analysis procedure for SLG-fault detection in unit generator-transformer is explained in steps:

- Step 1: The fault signals are obtained from a simplified power system model for GF simulation using Matlab-Simulink.
- Step 2: DWT of the fault signals are obtained and analysed using MATLAB software.
- Step 3: The wavelet coefficients of the fault signals are obtained using signal decomposition.
- Step 4: The extracted dispersion factors of statistical parameters (R and STD value) of wavelet coefficients from WT in various fault simulations are fed into ANN and trained.
- Step 5: The dispersion factor of statistical parameters of WT based ANN distinguish GF from normal condition.

A suitable unit generator-transformer model is compulsory to describe the different states during SLG-fault. GF simulations are recognized using Sim-PowerSystem Blockset of MATLAB, and M-file MATLAB is used for GF detection. The power system models for GF simulation are shown in Figure 1. The data of a generator (G-1=G-2) 25 kV with several generator grounding methods included transformers (Transformer-1=Transformer-2) 25/150 kV with *Yn-Yn* transformer connections. In this paper, the simulation was carried out at different fault locations consisting of primary and secondary side of a transformer-1, and at the generator bus. Fault current and voltage used were from the generator bus (Bus-1).

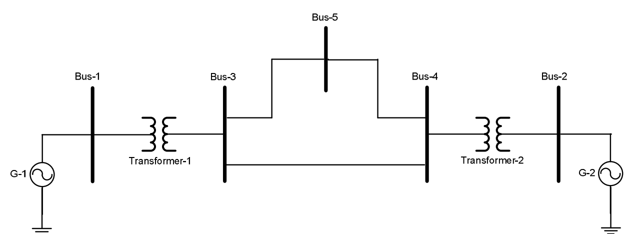

Figure 1. Simulated power system model for ground fault

Analysis of Simulation Result

SLG-fault detection in unit generator-transformer simulations follows a number of general processes. The approach as proposed in this paper consists of three basic stages: (1) signals decomposition, (2) feature extraction and (3) ANN training and verification.

Signals Decomposition

In some studies, *Daubechies* mother wavelet is found efficient for the incarceration of transient occasions and frequency feature extraction during fault in the power system. In this paper, mother wavelet *db3* with the resolution level-3 was used to find the coefficient of DWT for SLG-fault detection in unit generator-transformer. Some typical original signal and parts of the coefficient with a resolution level-3 of DWT *db3* are presented in Figure 2 and Figure 3, respectively.

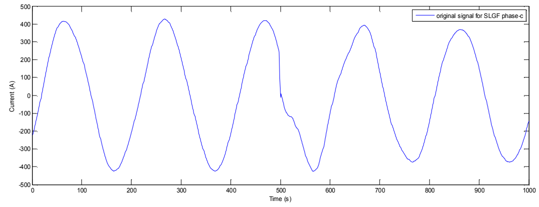

Figure 2. Original signals for SLG-fault current

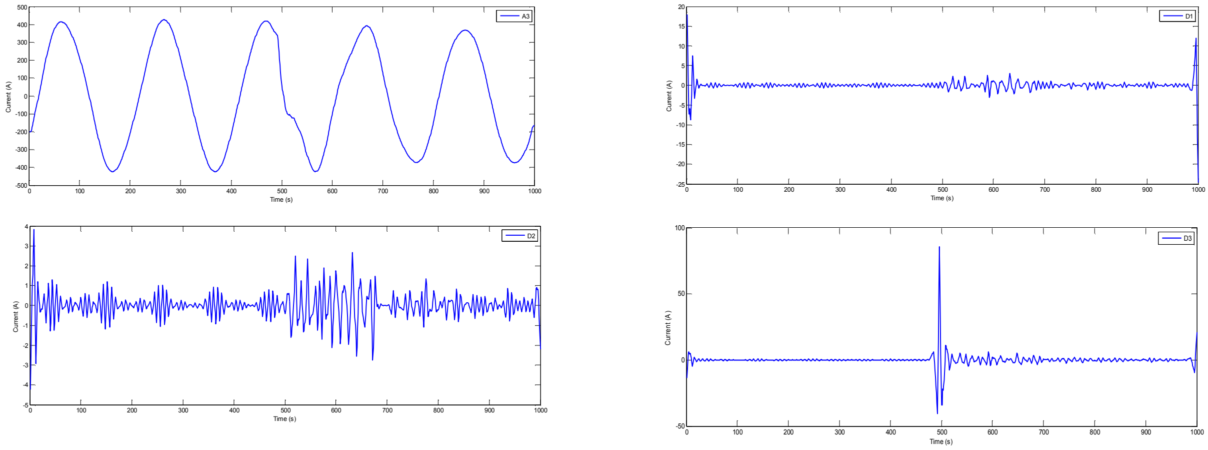

Figure 3. Parts of DWT decomposition for current signals

Features Extraction

To diminish the number of ANN treating component, this paper proposes a new method for determining dispersion factor (R and STD value) of statistical parameters of a wavelet coefficient for ANN input.

When the wavelet coefficient of the fault signals has been produced by signal decomposition, the next stage is the extraction of a dispersion factor of statistical parameters of the wavelet coefficients from WT in various fault simulations. The feature vectors of individual factors are then used as inputs for the ANN. In this paper, 24000 signals were used for dispersion factor feature.

ANN Trained and Verified

In this paper, the pattern recognition set of rules was used for categorizing SLG-fault signals, and normal signals state in the unit generator-transformer. Pattern recognition is the procedure of training a neural network to consign the accurate target classes to a set of input patterns. After one network has been trained, the network can be used to classify patterns it has not realized before.

The network must be able to detect of fault in several situations of a unit generator-transformer. The inputs for network are extracted from the dispersion factor of statistical parameters of current and voltage details of wavelet coefficients. WT is done to reduce the number of ANN processing element, and accordingly.

The performance of the certain ANN is subjected to several parameters, for instance, hidden layers number, hidden neuron numbers, function of transfer, rule of training, parameters of training and initial weights and biases. The architecture of the pattern recognition of WT-ANN used in SLG-fault detection in unit generator-transformer is illustrated in Figure 4.

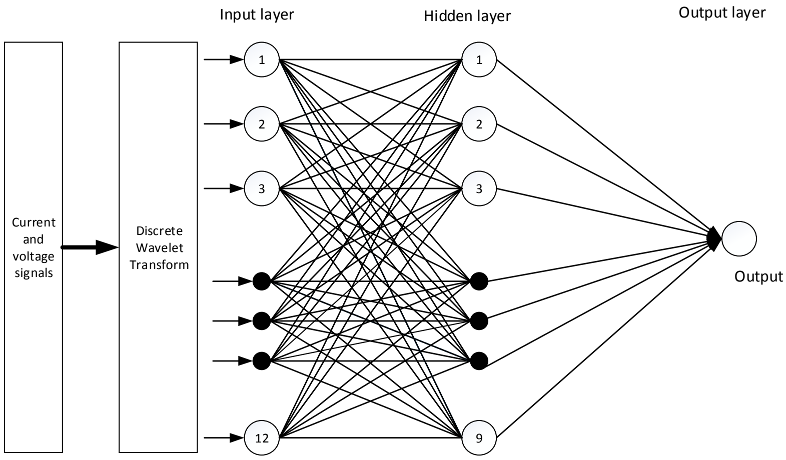

Figure 4. Architecture for WT-ANN of pattern recognition

In this paper, three layers of nodes were used in the analysis with 12 input nodes, 9 nodes of hidden layer and 1 output node. Models were created based on value of R and STD parameters of detail wavelet coefficients. 24000 sets of sample (70% set for training, 15% set for validation and 15 % set for testing) were used for R and STD for ANN network. The Receiver Operating Characteristic for this test is shown in Figure 5.

This curve tells us how well the test. The area under the curve is a measure of the goodness of the test with accuracy 97.45 %. Table 1 shows confusion matrix, which reveals the number of True Positive (TP) and False Positive (FP). While the network correctly identified 20989 (87.5 %) cases as SLG-fault, it identified zero case normal as SLG-fault. 2400 (10 %) cases are correctly identified as normal, while 611 (2.5 %) SLG-fault cases are classified as normal.

Table 1. Confusion Matrix

		Target Class	
		SLG-Fault	Normal
Output Class	SLG-fault	20989	0
	Normal	611	2400

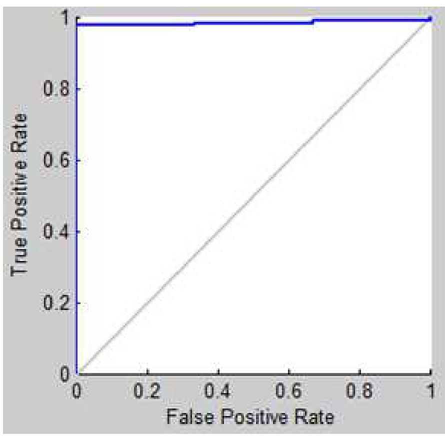

Figure 5. Receiver Operating Characteristic curve as ANN result

Conclusion

Concerning the ANN performance, the accuracy of the SLG-fault detection was 97.45 %. In this paper, analysis of a dispersion factor of a statistical parameters on wavelet coefficients as ANN input successfully detection of SLG-fault at the unit generator-transformer.

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