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Islanding Detection in Distributed Generation Integrated Thimi – Sallaghari Distribution Feeder Using Wavelet Transform and Artificial Neural Network

Basanta Pancha[1], Rajendra Shrestha[2], Ajay Kumar Jha[3]
Department of Mechanical Engineering, Pulchowk Campus, IOE, TU, Lalitpur, Nepal
Corresponding author: [1]*basanta.pancha@gmail.com*, [2]*rsfluid@hotmail.com*, [3]*akjha@ioe.edu.np*

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Abstract: In response to the problem of increased load demand, efforts have been made to decentralize the power utility through the use of distributed generation (DG). Despite the advantages of DG integration, un-intentional islanding remains a big challenge and has to be addressed in the integration of DG to the power system. Islanding condition occurs when the DG continues to power a part of the grid system even after the connection to the rest of the system has been lost, either intentionally or un-intentionally. The unintentional islanding mode of operation is not desirable as it poses a threat to the line workers' safety and power quality issues. There are many methods which may be used to detect the islanding situation. Passive methods such as under/over voltage and under/over frequency work well when there is an imbalance of power between the loads and the DG present in the power island. However, these methods has larger Non Detection Zone (NDZ) and fail to detect the islanding condition if there is a balance of power supplied and consumed in the island. Remote technique of islanding detection is reliable but is not economical in small network area. Active technique of islanding detection distorts the power quality of the system as it introduces external signal in the system. This paper uses the Wavelet Transform (WT) to extract the features of voltage signal at PCC (Point of Common Coupling) and these features have been used to train Artificial Neural Network (ANN). The ANN model trained by these WT features, which understands the pattern of input feature vector, have been used to classify the islanding and non-islanding events. In this proposed method, NDZ has been efficiently eliminated which is created due to difference between active and reactive power during islanding condition. No power quality problem exists in this method as there is no disturbance injection. Hence, this proposed method is better than conventional passive and active methods.

Keywords: Distributed generation, discrete wavelet transform, ANN, islanding detection

1. Introduction

In recent years, one of the major concerns is to meet the exponential increase of the load demand in the deregulated power sector. The most preferable solution among all alternatives for electric power generation in today's world is the placement of DGs in the distribution sector. Despite of the advantages of DG connection to the utility grid, there are many challenges that need to be seriously think about and one of the main issues is islanding detection. Islanding is a condition in which part of the distribution network is disconnected from the remainder of the grid while supplying the power to the local loads as shown in Fig. 1 [2].

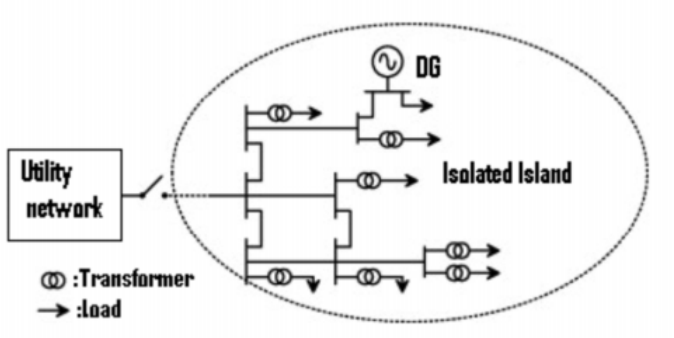


Fig. 1: Islanding condition

According to IEEE 1547-2003, the isolation time should be less than 2 seconds and the related DGs shall be isolated within that period from the distribution system. Unintentional islanding gives rise to various problems related to power quality, safety hazard, voltage and frequency instability, and damage to the system equipment's, etc. So, it is necessary to formulate an efficient methodology to detect an islanding detection in the distribution system with high reliability at different operating conditions [3].

Islanding detection techniques may be classified as passive or active. Passive techniques use information available at the DG side to determine whether the DG system is isolated from the grid but have larger NDZ. Active techniques have a faster response and a smaller NDZ but have power quality issues. Recently, pattern recognition technique based on Wavelet Transform has been found to be an effective tool in islanding detection. This paper investigates the time-localization property of Wavelet Transform and Artificial Neural Network (ANN) as a classifying medium for islanding detection by processing negative sequence components of voltage signals retrieved at PCC.

2. Theory of Wavelet Transform

Wavelets are functions, used to efficiently describe a signal by decomposing it into its constituents at different frequency bands called wavelet coefficients. By passing through a low pass filter, levels of DWT of objective signal is calculated resulting approximation coefficients ($A_i(n)$) and by passing through a high pass filter, detail coefficients ($D_i(n)$) is calculated. The filter outputs are subsampled by 2. This process can be repeated to decompose more levels of the approximation coefficients which are shown in Fig. 2 [4].

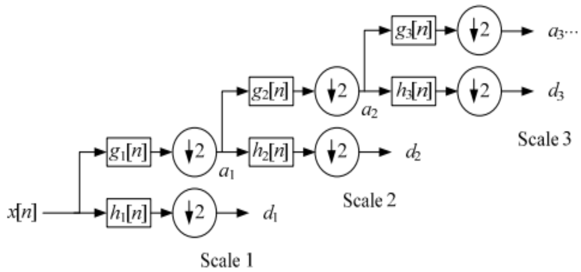


Fig. 2: Wavelet Transform

3. Methodology

The proposed technique is based on the feature extraction method using Wavelet Transform (WT) and ANN as event classifier for islanding detection. The negative sequence component of voltage signal at Point of Common Coupling (PCC) was measured and processed by the discrete wavelet transform. Detailed coefficients (D1, D2, D3 and D4) were used for feature extraction from the measured parameter and these features are then fed to a trained ANN model to detect islanding condition.

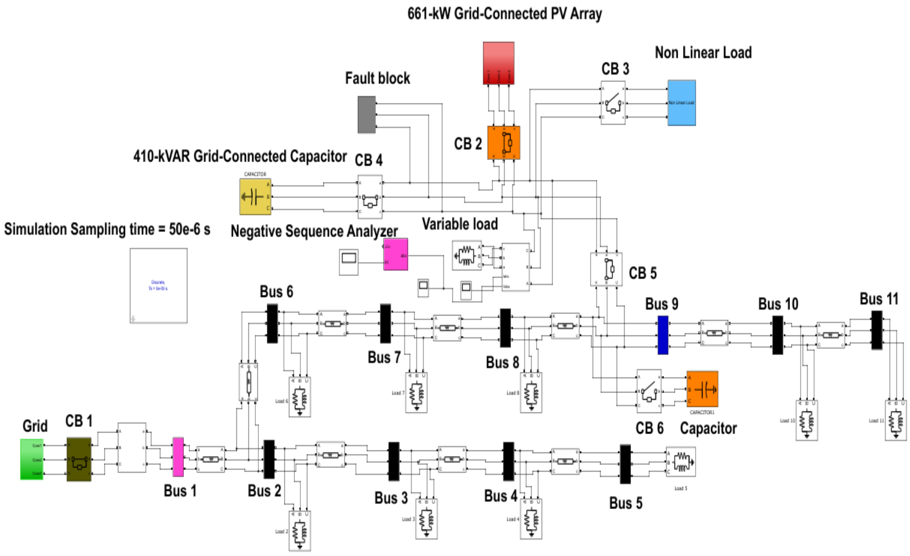


Fig. 3: MATLAB simulation of DG integrated Sallaghari Feeder

The system under study shown in Fig. 3 was simulated in MATLAB/Simulink. The system model contains a 661 kW solar PV and 410 kVAR capacitor at bus 9. Nine different sets of data corresponding to nine different cases (one islanding and eight non-islanding) were simulated in Simulink. The simulated non-islanding cases include normal condition, single line to ground fault (L-G), line to line fault (L-L), line to line to ground fault (L-L-G), three phase fault (L-L-L), three phase to ground fault (L-L-L-G), non-linear load switching and capacitor switching at PCC.

3.1 Data Collection

The secondary data includes line data (resistance and reactance) and load data (active load and reactive load) of Sallaghari Feeder [5].

3.2 Choice of mother wavelet and wavelet levels

Daubechies wavelet family is one of the most suitable wavelet families in analyzing power system [1]. In this paper, the db4 wavelet (with four quadrature filter bank) has been used as the mother wavelet for analyzing the transients associated with islanding. Db4 is a short wavelet and therefore it can efficiently detect transients. The input signals were decomposed for 4 wavelet levels. Detailed coefficients (D1, D2, D3 and D4) were used for feature extraction since it has the maximum change in amplitude before and after disturbances. The bandwidth of Wavelet function (D_i) is [$F_s/2^{i+1}$, $F_s/2^i$] [4]. The sampling frequency (F_s) was chosen 1 kHz.

3.3 ANN Structure

The proposed ANN has nine input layers, four hidden layers and one output layer. Backward propagation algorithm was used in the proposed ANN. The input layers are percentage loading, energy content (E1 to E4) and Standard Deviation (SD1 to SD4). The output state was labeled by numerical values from 1 to 9 for Normal, Islanding, L-G fault, L-L fault, L-L-G fault, L-L-L fault, L-L-L-G fault, Non-linear load switching and Capacitor switching conditions respectively.

The energy content and Standard Deviation in the details of each decomposition level for all negative sequence voltage signals was calculated using the detail coefficients in the corresponding level. Equation (1) shows the calculation of the energy content (E_j) and Equation (2) is the formula for calculating Standard Deviation (SD_j) for the j^{th} detail coefficients.

$$E_j = \sqrt{\sum_{i=1}^{N} |x_i|^2} \quad (1)$$

$$SD_j = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \mu)^2 \quad (2)$$

where x_i is amplitude of i^{th} sample of Wavelet Transform of signal at j^{th} level, N is the number of samples and μ is the mean of the Wavelet Transform of signal at j^{th} decomposition level.

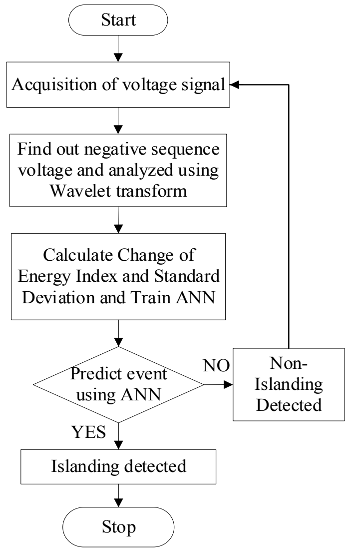


Fig. 4: Flowchart of islanding detection using Wavelet and ANN

4. Results of Wavelet-ANN based Islanding Detection Method

4.1 Wavelet Transform

The differences existed in the negative sequence voltage during different types of events represented by signal *s*, are shown in Fig. 5 to Fig.13.

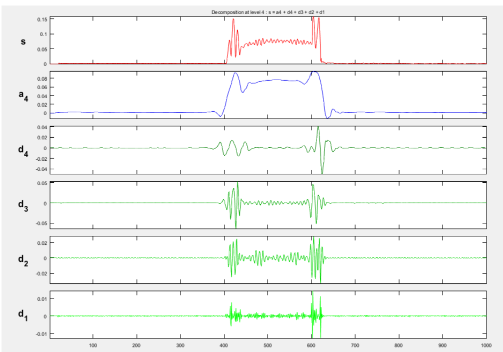


Fig. 5: Normal condition

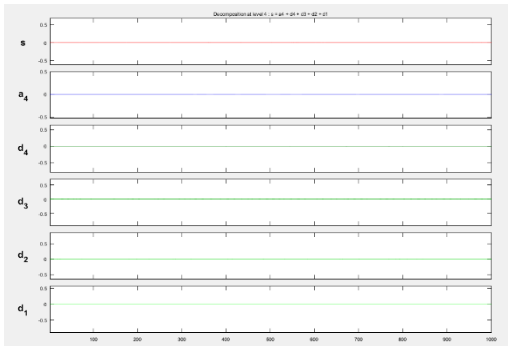


Fig. 6: Islanding condition

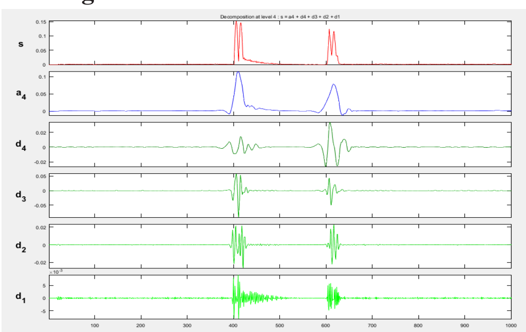
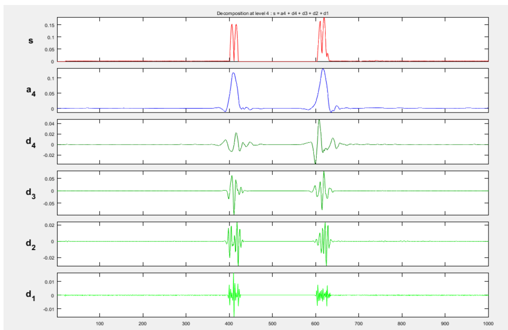


Fig. 7: L-G fault Fig.



8: L-L fault condition

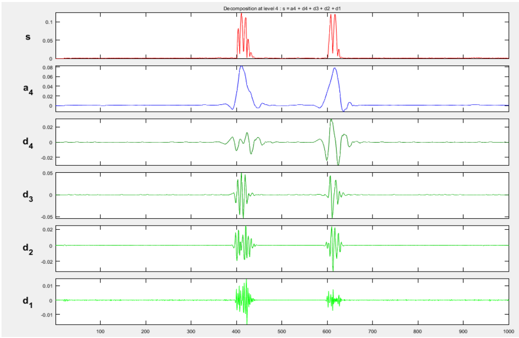


Fig. 9: L-L-G fault condition

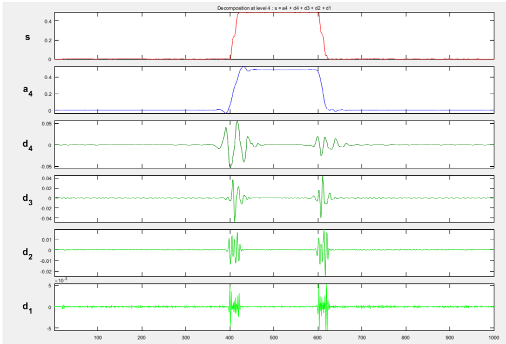


Fig. 10: L-L-L fault condition

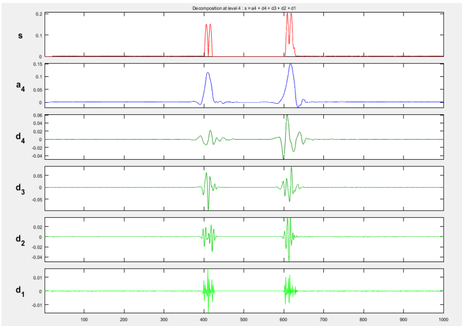


Fig. 11: L-L-L-G fault condition

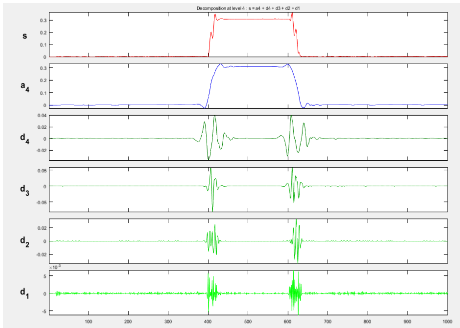


Fig. 12: Non-linear load switching

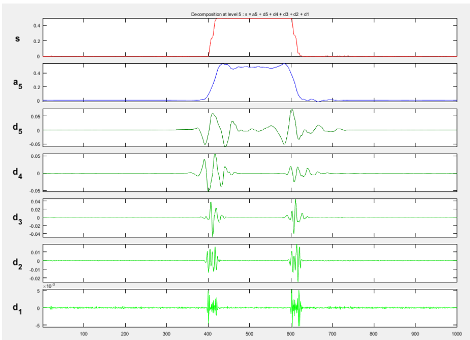


Fig. 13: Capacitor switching

4.2 ANN Prediction

The differences reflected on WT indices were fed to ANN and ANN was able to detect the events with 96.67% accuracy. Dataset consist of total 99 samples in which, each of nine cases of events has 11 samples. In order to generalize the ability of the ANN classifier, cross-validation technique was used. In cross-validation, the available simulated data were divided into two sets, first was the training set (70%) for which ANN was trained and the parameters were set. The remaining samples were test samples (30%) for which the algorithm was tested. Table 1 shows the results of ANN prediction on test dataset.

Table 1: ANN Prediction Results on Test Dataset

Data type	Cases									Total
	Normal	Islanding	L-G	L-L	L-L-G	L-L-L	L-L-L-G	Nonlinear load	Capacitor Switching	
Sampled data	11	11	11	11	11	11	11	11	11	99
Trained data	8	5	8	8	8	8	8	8	8	69
Tested data	3	6	3	3	3	3	3	3	3	30
Accuracy (%)	100	83	100	100	100	100	100	100	100	96.67%

4.3 Non Detection Zone Analysis

The proposed method was able to detect the islanding condition in non-detection zone with 100% accuracy. Total 126 sampled data were simulated equally for normal and islanding conditions by varying active and reactive power mismatch from 0 to 1%. Figs. 14 and 15 show the three phase voltages at PCC during normal and islanding conditions when active and reactive power mismatch between load and DG was zero. It can be seen that both waveforms are almost identical. WT was able to extract the parameters to distinguish normal and islanding conditions as shown in Fig. 16 and Fig. 17 respectively.

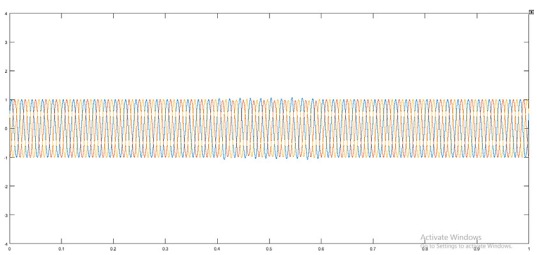


Fig.14: Three phase voltage at PCC during normal condition

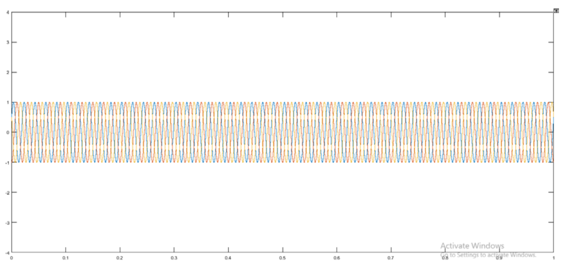


Fig. 15: Three phase voltage at PCC during islanding condition

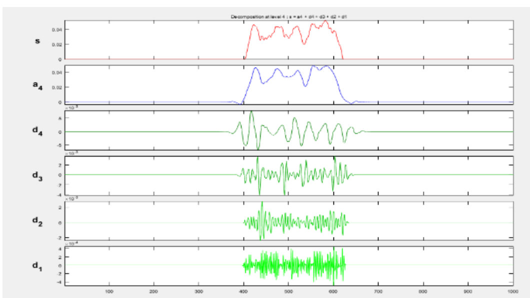


Fig. 16: Wavelet Transform of negative sequence voltage at PCC during normal condition

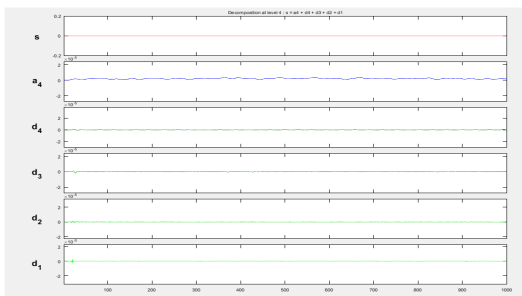


Fig. 17: Wavelet Transform of negative sequence voltage at PCC during islanding condition

5. Conclusion

Many schemes have been proposed to detect islanding such as passive, active and remote techniques. Passive techniques work well when there is power imbalance between the power generated from the DG and the power consumed form the load. Remote technique of islanding detection is reliable but is not economical in small network area. Active technique of islanding detection distorts the power quality of the system as it introduces external signal in the system.

WT-ANN based islanding technique was successfully implemented for Sallaghari Feeder distribution system. Wavelet Transform was capable of decomposing the voltage signals into different frequency bands. It can be utilized in extracting discriminative features from the acquired negative sequence voltage signals. The energy content and standard deviation of wavelet details are then calculated and fed to a trained ANN model which was capable to distinguish between islanding and non-islanding events with 96.67 % accuracy. The proposed ANN model was also able to detect the islanding condition in NDZ with 100% accuracy thereby validating its effectiveness.

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