ISLANDING DETECTION IN DISTRIBUTED GENERATIONS USING NEGATIVE SEQUENCE COMPONENTS

B. Bala Sai Babu[1], N. Rama Devi[2]

[1]*Final Year M.Tech, EEE Department, Bapatla Engineering College, A.P, India,* **saibabu.dec31@gmail.com**
[2]*Assistant Professor, EEE Department, Bapatla Engineering College, A.P, India,* **ramadevi75@gmail.com**

Abstract

In this paper negative sequence components are used for islanding detection in distributed generation (DG) based system. In this approach, the negative sequence component of the voltage and current signals are analyzed through wavelet transform. The detailed coefficient d1 clearly identifies the event and thus detects the islanding condition. The change in energy and standard deviations of wavelet transform based voltage and current signals are also reported for islanding conditions and other disturbances called non-islanding ones. Also the negative sequence impedance is calculated at the target DG location. This negative sequence impedance effectively detects the islanding conditions. The proposed techniques are tested on islanding and possible non-islanding conditions such as normal operation, sudden load change and tripping of other DGs etc. And found to be more effective in islanding detection at target DG locations in the distribution network.

Index Terms: *Islanding detection, negative sequence voltage, negative sequence current, negative sequence impedance, wavelet transform.*

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1. INTRODUCTION

Distributed generation (DG) is one of the most promising alternatives for generation of electric power in today's time. The need for DG is enhanced world-wide due to the restructuring of the electric power industry and the increase of electric power demand. In addition, the need of DG becomes more important because of the present-day energy shortage and requirements of both power quality and system reliability. Generally, a DG system consists of small-scale power generation resources like wind, photovoltaic, fuel cell, etc., that are located close to loads. The primary advantages of DG systems are that consumers can generate electric power with or without grid backup and the surplus power generation (PG) can be sold back to the grid under low load-demand conditions. But the unpredictable variations in wind speed and solar radiations make wind and photo-voltaic power generation unreliable for uninterruptible power supply to the loads specially when used for stand-alone mode of operation. As a matter of fact, these energy sources need to be interconnected among themselves or to the conventional power generating sources to form hybrid system (HS) for a better power quality and reliable supply with appropriate controls and effective coordination among various subsystems [1,2]. In fact, many utilities around the world already have a significant penetration of DG in their power system.

But there are many issues that need to be seriously considered with the DG connected to utility grid and one of the main issues is islanding detection. If DG feeds power to the local loads and utility grid supply gets isolated due to some emergency conditions, then it is called islanded operation which leads to several negative impacts on utility power system and the DG itself, such as the safety hazards to utility personnel and the public, the quality problems of electric service to the utility customers, and serious damages to the DG if utility power is wrongly restored [3,4]. Therefore, during the interruptions of utility power, the connected DG must detect the loss of utility power and disconnect itself from the power grid as soon as possible. It is desired to know the sources of power system disturbances and find remedies to mitigate them.

Recently, in order to signal the islanding events, several methods have been suggested [5–8]. Among these published techniques, the supervision of auxiliary contacts of circuit breakers between utility networks and distributed generations was first considered, where a transfer trip scheme was utilized in order to disconnect distributed generators from the mains supply. Then, once the utility supply is restored, the distributed generators would be resynchronized to the grid. This method was conceptually feasible, yet because its effectiveness is highly dependent on the monitoring performance, it is often hard to implement in real-world applications. Subsequently, several anti-islanding solution approaches were also proposed; which can be largely categorized into two groups: active methods and passive methods [8–11]. While active methods examine the operation of a power system in a direct manner, passive methods justify the event based on the system parameters.

In active methods, the main theme exists in the design of control circuits such that the required variations can be produced at the outputs of distributed generators. Then, once the loss of grid takes place, this designated bias will accordingly enlarge sufficiently to trip the connected relays, notifying the occurrence of the event. On the contrary, when the utility supply is normally operated, the amount of variations will be insufficient to trip the relays, ensuring that there is no event misidentified. Under several circumstances, this active method has won the confirmation; however, the complicated control circuit for the generation of designated bias may offset its merits. As for the passive techniques, they were suggested based on the measurements of system parameters, which may include phase displacement, system impedance, and the change rate of output power. Based on the deviated voltage, current, or frequency following the loss of utility supply, passive methods would justify the islanding through the monitoring of these parameters [10,11]. Yet, without an accurate understanding of parameter variations in the passive method, the possibility of false alarm may largely increase.

Recently a technique based on Wavelet Transform [12-14] has been found to be an effective tool in monitoring and analyzing power system disturbances. This paper investigates the time-localization property of Wavelet transform(db4) for islanding detection by processing negative sequence components of voltage and current signals get at the target DG location. The time-frequency information derived at the level-1 decompositions (d1), localizes the corresponding islanding events. Further to provide a threshold for detecting islanding conditions from non-islanding ones, the standard deviations (std) and change in energy (ce) of the d1 level coefficients for one cycle are computed.

Further to know the impact of negative sequence impedance in the islanding detection, the same is found out at the target DG location. It is observed that time variation of the negative sequence impedance provides effective islanding detection compared to non-islanding situations. Further, the standard deviation of the negative sequence impedance for one cycle data, detects the islanding conditions accurately over non-islanding ones. Thus the above two techniques based on negative sequence components provide effective islanding detection techniques, which has edge over some earlier techniques.

2. DISTRIBUTION NETWORK

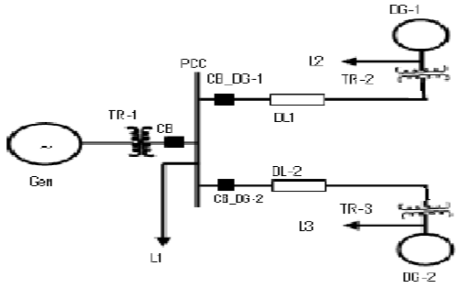

Fig-1: The studied power distribution network

The detailed studied system is shown in Fig. 1. The base power has been chosen as 10 MVA. The studied system consists of radial distribution system with 2 DG units (wind farms), connected to the main supply system through Point of Common Coupling (PCC). The DG units are placed at a distance of 30 km with distribution lines of pi-sections. The details of the generator, DGs, transformers, distribution lines and loads are mentioned as below.

- Generator: rated short-circuit MVA=1000, f=50 Hz, rated kV =120, Vbase = 120 kV.
- Distributed Generations (DGs): Wind farm (9 MW) consisting of six 1.5-MW wind turbines (Doubly Fed Induction Generator) is connected to a 25-kV distribution system exports power to a 120-kV grid through a 30-km 25-kV feeder.
- Transformer T1: rated MVA = 25, f = 50 Hz, rated kV = 120/25, Vbase = 25 kV, R1 = 0.00375 pu, X1= 0.1 pu, Rm= 500 pu, Xm= 500 pu .
- Transformer T2 and T3: rated MVA = 10, f = 50 Hz, rated kV = 575 V/ 25 kV, Vbase = 25 kV, R1 = 0.00375 pu, X1= 0.1 pu, Rm= 500 pu, Xm= 500 pu
- Distribution lines (DL): DL-1 and DL-2:
  PI-Section, 30 km each, Rated kV = 25, rated MVA = 20, Vbase = 25 kV, R_1 = 0.1153 ohms/km, R_0 = 0.413 ohms/km, L_1 = 1.05e-3 H/km, L_0 = 3.32e-3 H/km, C_1 = 11.33e-009 F/km, C_0 = 5.01e-009 F/km,
- Normal Loading data:
  L1 = 10 MW, 5 kVAR.
  L2, L-3 = 12 MW, 0.9 MVAR.

The voltage and current signals are retrieved at the target DG location for islanding conditions and non-islanding conditions (other disturbances). The possible situations of islanding and non-islanding conditions are given as follows

- Tripping of main circuit breaker (CB) for islanding conditions.

- Sudden load change at the target DG location.
- Opening of breaker between the power system and DG.
- Tripping of other DGs apart from the target one.
- Loss of power at PCC

2.1. Negative sequence component of voltage and current signals at DG location for islanding detection.

Negative sequence component is one of the key indicators which quantify the presence of any disturbances in the voltage and current signals retrieved at the target DG location. Thus, in this technique, the negative sequence component of the voltage and current signals retrieved at the target DG location is considered for analysis towards effective detection of islanding and non islanding events. The negative sequence component of voltage and current signals at the target DG location can be expressed by symmetrical component analysis as:

$$V_n = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c) \qquad (1)$$

$$I_n = \frac{1}{3}(I_a + \lambda^2 I_b + \lambda I_c) \qquad (2)$$

Where V_a, V_b, V_c are three phase voltages , and I_a, I_b, I_c are three phase currents retrieved at the target DG location, and $\lambda = 1\angle 120^0$, is the complex operator. The negative sequence component of the extracted voltage and current signals at the target DG location is obtained by passing it through the three-phase sequence analyzer block in MATLAB/Simulink. Out of the three sequential components, it is only negative sequence component of the voltage signal, considered in this study because it reflects the information under disturbance condition. Quantification of the negative-sequence voltage at the target DG location is carried out which provides high degree of immunity to noise, for detection of islanding event and other disturbances due to sudden load change, DG line ct-off etc, thus enable better performance.

2.2 Negative Sequence Impedance for Islanding Detection

As negative sequence components of the voltage and current signals at the target DG location are highly pronounced in case of islanding situations compared to no islanding situations, thus the negative sequence impedance seen at the target DG location has been computed to detect the islanding conditions. The negative sequence impedance has been one of the key indicators in disturbance conditions such as Fault process. Thus, during the islanding process, the negative sequence impedance provides vital information which can be effectively used for islanding detection. The negative sequence impedance can be found as

$$z_n = \frac{V_n}{I_n} \qquad (3)$$

Where V_n is the negative sequence voltage and I_n is the negative sequence current derived at target DG location.

3. WAVELET TRANSFORM

The wavelet transform decomposes transients into a series of wavelet components, each of which corresponds to a time domain signal that covers a specific frequency band containing more detailed information. Wavelets localize the information in the time–frequency plane which is suitable for the analysis of non stationary signals. WT divides up data, functions into different frequency components, and then studies each component with a resolution matched to its scale. In this study, the voltage and current signals are used as the input signals of the wavelet analysis. Daubechies4 (dB4) mother wavelet, is employed since it has been demonstrated to perform well. The islanding of the study cases is detected through discrete wavelet transform (DWT). Both approximation and details information related fault voltages are extracted from the original signal. When the utility grid isolates, it can be seen that variations within the decomposition coefficient of the voltage and current signals contain useful signatures. Filters of different cut-off frequencies are used to analyze the signal at different scales. The signal is passed through a series of high pass filters to analyze the high frequencies, and it is passed through a series of low pass filters to analyze the low frequencies. Hence the signal (S) is decomposed into two types of components approximation (C) and detail (D). The approximation (C) is the high scale, low-frequency component of the signal. The detail (D) is the low-scale, high-frequency components. The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is divided into many lower resolution components which is called the wavelet decomposition tree and is shown in Fig. 2. As decompositions are done on higher levels, lower frequency components are filtered out progressively.

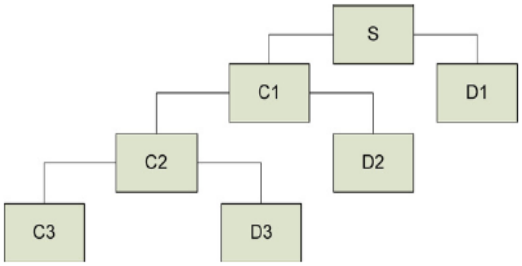

Fig-2: Wavelet decomposition tree

4. SIMULATION RESULTS

The model is simulated at 1.6 kHz (32 samples on 50 Hz base frequency). The voltage and current signals are retrieved at the target DG location (DG-1, DG-2). The islanding starts at 0.3 sec as shown in the Fig.4.2. The complete simulation is carried out using MATLAB-SIMULINK software package.

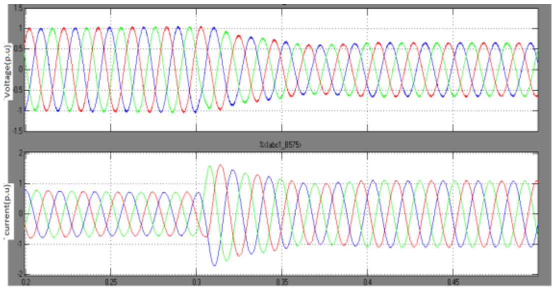

Fig-3: Three phase voltage and current signals under islanding condition at the target DG location (starts at 0.3 sec) for two wind system.

4.1. Negative sequence component and d-1 coefficients for islanding detection

The negative sequence voltage and currents are processed through Wavlet Transfrom (db4) for time localization of the islanding event. The negative sequence voltage and current signals and corresponding d1 coefficients of the voltage and current signals are shown in Fig. 4 & 5 for islanding condition. The d1 coefficients clearly localize the islanding event and thus helps in detecting the same.

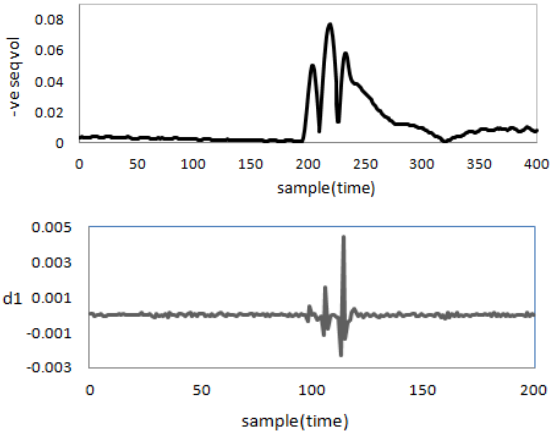

Fig-4: The negative sequence component of voltage and d-1 coefficient for islanding condition.

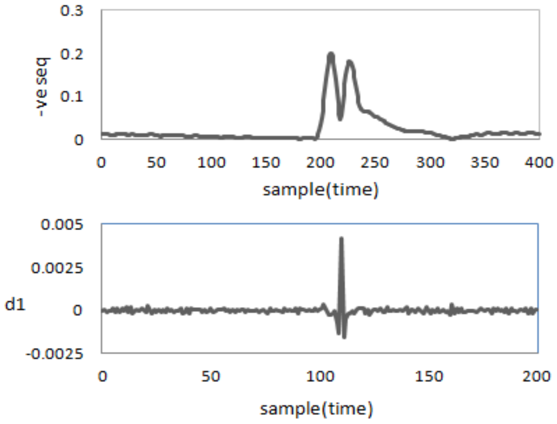

Fig-5: The negative sequence component of voltage and d-1 coefficient for islanding condition.

The comparison between islanding and non-islanding conditions such as normal, sudden load change and tripping of other DGs apart from target are given in Fig. 6, 7 and 8 respectively. It is observed that the d1 coefficients are highly pronounced in case of islanding compared to non islanding situations. In case of 50 % load change (non islanding) , even the d1 coefficients are highly pronounced compared to other non-islanding situations, but still a threshold will work to distinguish between islanding and non islanding condition.

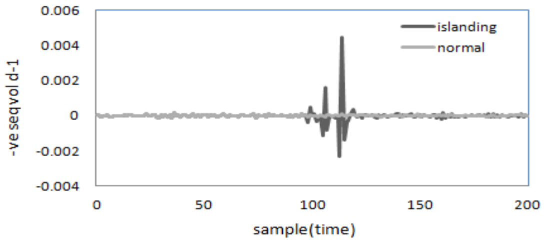

Fig-6: Comparison between d-1 coefficient for islanding and non islanding condition (normal)

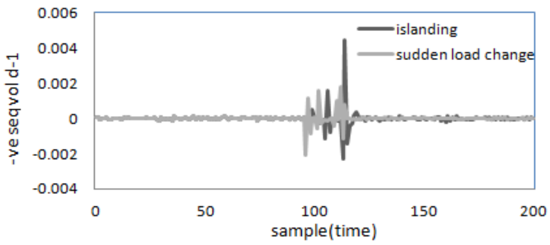

Fig-7: Comparison between d-1 coefficient for islanding and non islanding condition (sudden load change)

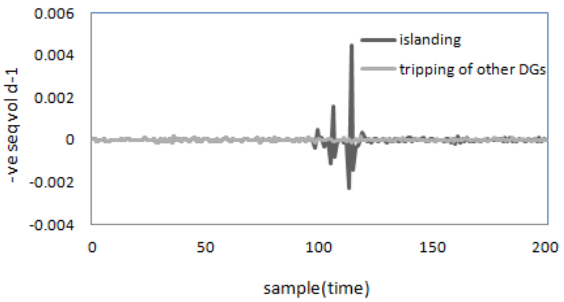

Fig-8: Comparison between d-1 coefficient for islanding and non islanding condition (tripping of other DGs)

The complete statistics of the derived standard deviations and change in energy of the d1 coefficients are depicted in Table-I and II. It is found from the table –I that the change in energy and standard deviations for islanding condition compared to non islanding cases. The above results are for negative sequence voltage retrieved at target DG location DG-1. Similar observations are made for Negative sequence currents retrieved at same target DG location DG-1 as depicted in Table-II. Thus the change in energy and standard deviations are high valued compared to non-islanding cases and thus effective in distinguishing them.

To verify the effect of changing target DG locations, the change in energy and standard deviations are found out for islanding and non-islanding situations at target DG location DG-2. It is observed from the Table-III and IV that the change in energy and standard deviations for islanding case are substantially high compared to non-islanding cases. Thus a threshold can easily be selected for detecting islanding events from non-islanding ones.

Events	**Change in Energy**	**Change in standard deviation**
Islanding	0.0505	0.0378
Normal	0.343e-04	1.2218e-04
Sudden load change	0.0107	0.0149
Tripping of other DGs	0.754e-04	0.001

TABLE 1: Change in energy and standard deviations (Negative sequence voltage) for islanding and non-islanding situations at DG-1

Events	**Change in Energy**	**Change in standard deviation**
Islanding	0.37411	0.1052
Normal	2.10e-04	0.3976e-04
Sudden load change	0.07462	0.0351
Tripping of other DGs	0.0011	0.0033

TABLE 2: Change in energy and standard deviations (Negative sequence current) for islanding and non-islanding situations at DG-1

Events	**Change in Energy**	**Change in standard deviation**
Islanding	0.0505	0.0378
Normal	0.343e-04	1.2218e-04
Sudden load change	0.0122	0.0158
Tripping of other DGs	0.508e-03	0.0033

TABLE 3: Change in energy and standard deviations (Negative sequence voltage) for islanding and non-islanding situations at DG-2

Events	**Change in Energy**	**Change in standard deviation**
Islanding	0.37411	0.1052
Normal	2.10e-04	0.3976e-04
Sudden load change	0.05436	0.0304
Tripping of other DGs	0.359e-03	0.0014

TABLE 4: Change in energy and standard deviations (Negative sequence current) for islanding and non-islanding situations at DG-2

4.2 Negative sequence Impedance for Event Detection

The negative sequence impedance of the islanding versus non-islanding conditions such as normal, sudden load change and tripping of other DGs apart from the target are shown in Fig. 9, 10 and Fig. 11, respectively. It is found that the negative sequence impedance becomes steady after islanding compared to non-islanding situations.

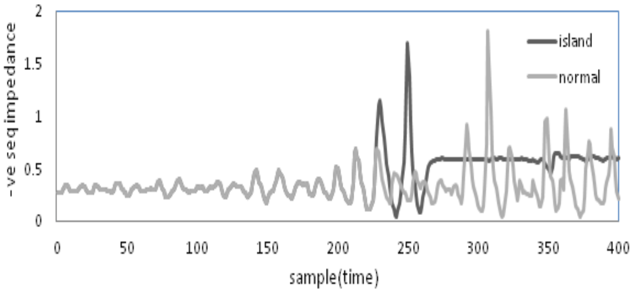

Fig-9: The negative sequence impedance comparison between islanding vs non islanding condition (normal)

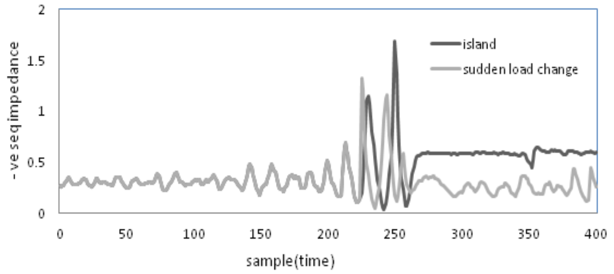

Fig-10: The negative sequence impedance comparison between islanding vs non islanding condition (sudden load change)

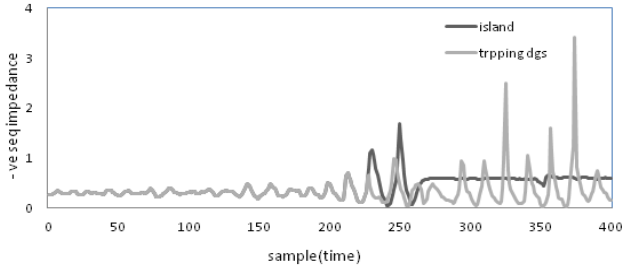

Fig-11: The negative sequence impedance comparison between islanding vs non islanding condition (tripping of other DGs)

To further provide a threshold for islanding detection, the standard deviations of the negative sequence impedance is found out and given in Table- V and VI. To further know the effect of changing DG Locations, the similar observations are made for standard deviations for negative sequence impedance at target DG location DG-2. It is seen that the standard deviation is low for islanding condition compared to non-islanding ones, and thus providing a threshold effectively distinguishes the islanding events from non-islanding conditions. It is observed that the negative sequence impedance is marginally affected when the target DG location is changed. Thus the negative sequence impedance is a potential measure for detecting islanding conditions in distributed generations.

Conditions	standard deviation(std)
Islanding condition	0.2335
Normal condition	0.3450
Sudden load change	0.2642
Tripping of other DGs	0.6260

Table-5: Standard Deviations of the Negative Sequence Impedance seen at DG-1

Conditions	standard deviation(std)
Islanding condition	0.2335
Normal condition	0.3450
Sudden load change	0.2792
Tripping of other DGs	0.3298

Table-6: Standard Deviations of the Negative Sequence Impedance seen at DG-2

CONCLUSION

The proposed technique investigates the negative sequence component of voltage, current and impedance for islanding detection in distributed generations. Wavelet transform is used to process the negative sequence voltage and current signals and the d1 coefficients clearly detect the islanding events from non-islanding ones. Further, the change in energy and standard deviation of d1 coefficients for one cycle signal data is found out which clearly detects the islanding conditions. Also the negative sequence impedance is found out for both islanding and non-islanding events, and it is observed that the standard deviation of the negative sequence impedance of islanding event is very low compared to non-islanding condition, thus able to detect the islanding events effectively. Thus the proposed methods are highly effective for islanding.

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BIOGRAPHIES

B.Bala Sai Babu received the B.E degree in Electrical and Electronics Engineering from Andhra University, Visakhapatnam, India in 2008. Presently pursuing M.Tech degree in Power Systems at Bapatla Engineering College affiliated to Acharya Nagarjuna University.

N. Rama Devi received the B.Tech degree in Electrical and Electronics Engineering from J.N.T.U Engineering College, Kakinada , India in 1997, and the M.Tech degree in Power Systems from the Regional Engineering College , Warangal, India, in 2000. She is currently working as Assistant Professor in the department of Electrical and Electronics Engineering at Bapatla Engineering College, Bapatla.