Protection of Distribution Network with Solar Farm Distributed Generation using Wavelet-Alienation Technique

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***Abstract* - In the present paper, a wavelet transform based alienation technique has been presented for the detection of islanding condition and faults in a distribution system incorporate with solar energy based distributed generation. A radial five bus system integrated with four PV systems has been considered for the study. The current signals were decomposed with Daubechies wavelet transform at various DG buses to get approximation coefficients. The alienation coefficients of these approximate decompositions were termed as Islanding and fault indices. These indices were compared with predetermined threshold to detect disturbances during Islanding and fault. The suggested algorithm was established by few case studies involving changes in incidence angle. Thus, the proposed algorithm is found to be effective and successful for both Islanding and fault detection.**

Keywords* - *Alienation coefficients, distributed generation, distribution network, islanding, islanding index, wavelet transform, and fault index.

I. INTRODUCTION

Distributed generation (DG) is generally mentioned as decentralized source of generation of electricity. Various resources like wind, diesel, combined heat and power (CHP) and photo voltaic (PV) are used in distributed generations which are generally situated at or near consumers' homes or business establishments. If properly developed, DG can provide a lot of potential benefits to the consumers, along with economic savings, improved environmental performance and with greater reliability. A large development has been taking place in the distributed power generation worldwide. As integration of DGs in the distribution networks increases, there is possibility of increasing in hazard and risk of power system events. It contains some drawbacks such as intimidating safety of the line worker; fail to sustain voltage levels and frequency within the standard permissible limits. Islanding operations of DG normally occurs due to the power supply disconnection from the mains to various reasons but the DG keeps supplying power into the loads and distribution networks.

In the case of islanding condition, DG should be disconnected immediately from the grid and in all utilities. There is a demand for the disconnection of DG from the system as per IEEE 929-1988 standard once islanding takes place (IEEE Standard 929-2000, 2000) and a maximum holdup of 2 sec is needed for the detection of an unintentional islanding in IEEE 1547TM, (2003)[1,2]. As number of technical issues associated with unintentional islanding are higher, all DGs have to be ceased to energize the distribution systems very quickly. Several Islanding detection techniques were proposed in recent years. A detailed review on different methods of islanding detection for DG had been discussed elsewhere [Funabashi et al., 2003, Yin et al., 2004)[3,4]. If DG is energizing the loads without the utility supply, a negative impact is resulted on power system utility and also on DG such as safety risks to utility personal as well as to the public. Furthermore, wrong restoration of utility power leads to poor quality of electric service to the customers and serious damage to the DG [Ackermann et al., 2000, O. Usta and M. A. Refern, 2000)[5,6]. A detailed review on islanding detection methods which have been classified as remote and local methods was given by Aziah Khamis et al., (2013)[7]. Reza Sirjani and Chinedu Frank (2016)[8] presented a combining method based on the rate of change in active, reactive power, frequency and voltage angle. A novel approach was proposed by S. R. Samantha Ray and Trupthi Mayee Pujhari (2009) to detect islanding condition in a DG by extracting negative sequence components of voltages and currents and processed by wavelets at targeted bus[9]. Furthermore, Y. M. Makwana and B. R. Bhaljia (2017) proposed a new technique for islanding detection based on derivation of islanding detection factor which was being derived from the model transformation of the input voltage signals[10]. Ahmad G. Abd-Elkader et al., (2018) demonstrated using voltage index to detect islanding operation, which was suited for multiple DG units[11]. Srdjan Skok et al., (2017) presented a technique for the detection and protection of DG from islanding operation based on synchronized measurement technology (SMT) which requires phasor measurement unit hardware[12]. Similarly, proportional power spectral density, variable impedance at the Grid low voltage strategy, dqo transform based algorithm, discrete wavelet transform and combination of neural network and wavelet transform are the other approaches used for islanding detection (Menon, Vivek, and M. Hashem Nehrir, 2007, Chen et al., 2011, Hashemi et al., 2012, Papadimitriou et al., 2015, Hamed et al., 2015, Elnaz et al., 2017)[13,14,15,16,17,18]. Stability of the system can be maintained with the quick and accurate detection of faults, and supply also can be restored quickly which results in economy improvement and in power quality. Protection scheme for detection, classification and location of faults based on Wavelet transform was proposed by S. Abdul

Gafoor, et al [19]. A protection scheme based on d1 coefficients of Haar wavelet was also proposed in the literature [20]. Fault detection and fault distance calculation in distributed system lines based on components of frequency spectrum with fault generated travelling waves was presented by Javad Sadeh [21]. Yuan Liao proposed a method based on bus impedance matrix to identify fault locations [22]. A. M. EI-Zonkoly proposed a protection scheme by tracing wavelet coefficients based entropy of the measured bus connections [23].

However, still there exists a need of exploring a high speed and efficient islanding and fault detection scheme. Therefore, in the present work, alienation technique based on wavelet is used to develop an algorithm which can detect islanding condition and faults with high speed and less complexity.

2. MATHEMATICAL TOOLS

2.1 Wavelet Transform

In frequency as well as time domain, a Wavelet Transform (WT) is an efficient way of detecting current transients and voltage transients. WT examine the signals of current and voltage in frequency bands and provides a uneven breakup of frequency domain also, WT ,therefore, uses short length and long length window respectively at different frequencies from low to high. To dissect the signal at different frequency bands, the basic functions called Wavelets are used, that are produced mother wavelet through dilation and translation. Therefore, the amplitude and the incidence of frequency will be observed with much precision. WT is described as a function {h (n)} (a low pass filter) and {g (n)} (a high pass filter). The functions of wavelet and scaling are described by the equations given below.

$$\emptyset(t) = \sqrt{2}\sum h(n)\varphi(2t-n) \qquad (1)$$

$$\Psi(t) = \sqrt{2}\sum g(n)\psi(2t-n) \qquad (2)$$

Where, $g(n) = (-1)^n h(1-n)$

The factor √2 maintains the norm of the function for the time compression factor 2. The time compression factor generally corresponds to the scale. A sequential component of {h (n)} defines a Wavelet Transform. There are different types of wavelets like Haar, Daubechies and Symlet etc. The selection of a mother wavelet depends on the type of application.

2.2. Alienations based on Approximation Coefficients

In this present algorithm current signals have been composed across a half cycle. Wavelets have been applied to these samples and disintegrate for acquiring desired approximation coefficients. The coefficient of alienation based on approximation decomposition (Coefficients) has been calculated by the following equation.

$$1 - r_a^2 = A_A \qquad (3)$$

Where, r_a is the calculated correlation coefficient on the basis of approximation coefficients. It has been calculated as follows,

$$r_a = \frac{N_s(\sum p_a q_a) - (\sum p_a \sum q_a)}{\sqrt{[N_s \sum p_a^2 - (\sum p_a)^2][N_s \sum q_a{}^2 - (\sum q_a)^2}} \qquad (4)$$

Where, N_s *is* the number of samples per half cycle

p_a is the absolute value of samples at t_0

q_a is the absolute value of samples consider in previous moving window of half cycle

The divergence between these signals has been called as alienation coefficient. The value of it is existed in between 0 and 1..

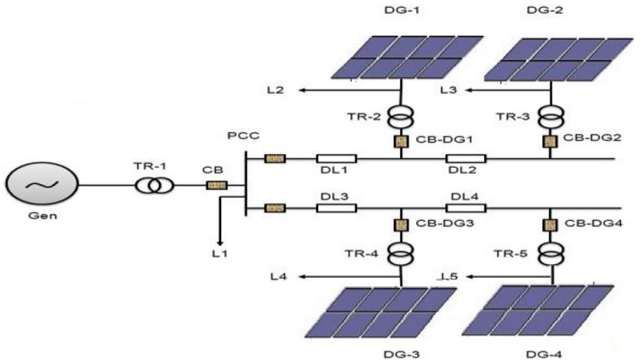


Fig 1 Single line diagram of the system

3. PROPOSED ALGORITHM

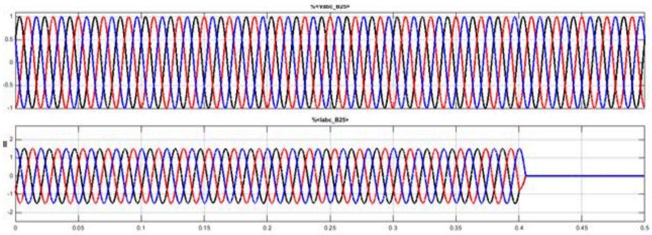
Table 1 Parameters adopted in the present work (S. R. Samantha Ray and Trupthi Mayee Pujhari (2009).

S.NO	COMPONENT	SPECIFICATION
1.	Generator	Rated short circuit MVA=1000 Rated KV=120,Vbase=120kv,f=50Hz
2.	Distributed generations(DGs) (DG-1 to DG-4)	Solar pv cells of (2MW) are connected to a 25kv grid through a 30km,25kv feeder.
3.	Distribution lines DL-1 to DL-4	PI-Section,30km each, rated MVA= 20, Rated KV=25,Vbase=25kv, R0= 0.1153Ω/km,R1=0.413Ω/km,L0= 1.05e-3H/km, L1=3.32e-3H/km, C0=11.33e-009F/km,X1=5.01e-009 F/km.
4.	Transformer T1	Rated MVA=25,Vbase=25kv,Rated KV=120/25, X1=0.1p.u, R1=0.00375 p.u, Rm=500 p.u, Xm=500 p.u.
5.	TransformerT2 to Transformer T5.	Rated MVA=10,rated kv=575v/25kv, Vbase=25KV, X1=0.1, R1=0.00375 p.u, Rm=500 p.u, Xm=500 p.u,f=50hz
6.	Load L-1	15MW,5MVAR.
7.	Load L-2 to Load L-5	8.0MW,3MVAR.

Fig 1 illustrates the line diagram of studied system in the present work. Table 1 lists all the parameters adopted in the present work. This system consists of radial distribution system with four DG units (solar farms) which are connected to the main supply through the Point of Common Coupling (PCC) and it is operated at a frequency of 50 Hz. The base power is chosen as 10 MVA. The DG units are kept at a distance of 30 km from each other and with distribution lines of pi-sections. The system parameters of the DGs, generator, distribution lines, transformers and loads are considered from S. R. Samantha Ray and Trupthi Mayee Pujhari (2009). Three phase currents at DGs and PCC of distribution line are sampled at a frequency of 6400 Hz. These samples are attained over a moving window of half cycle length. These current samples are processed with db1 wavelet to obtain approximation coefficients of third level (A_3). The Alienation coefficient, C_A is obtained by comparing the approximate coefficients of two successive windows of same polarity.

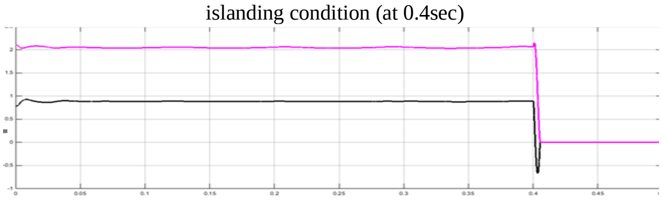
The value of A_a remains zero under normal conditions since the two consecutive windows have similar set of approximations. But in the case of islanding, fault or any other abnormal condition, the approximate coefficient of one window would differ from that of preceding window of same polarity. Hence there is an increase in alienation coefficient from zero to a certain value and it indicates Islanding, fault or any other disturbance. Alienation coefficients are also termed as islanding and fault indices. These islanding indices of three phase currents have been obtained by applying alienation coefficients to approximate decompositions. These islanding indexes are compared with a threshold value to detect islanding and transients with fault.

Fig. 2(a) to 2(h) demonstrates voltage and current waveforms and active reactive waveforms at source, PCC, loads and DGs. There is a considerable change in voltage, current and active, reactive power magnitudes were observed at 0.4 sec where islanding condition is introduced.



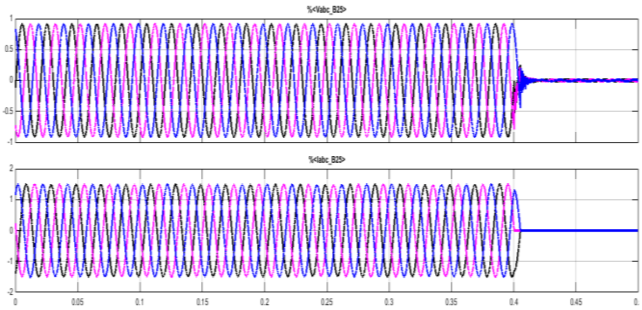
Time (sec)

Figure 2: (a) Voltage and current waveforms at source when system is under islanding condition (at 0.4sec)



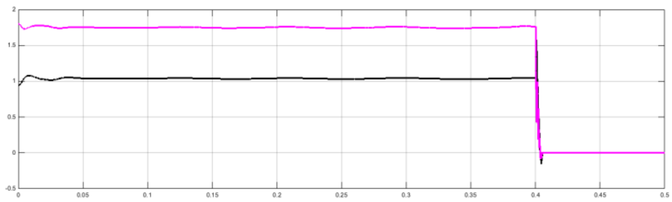
Time (sec)

Figure 2: (b) Active and Reactive power waveforms at source when system is under islanding condition



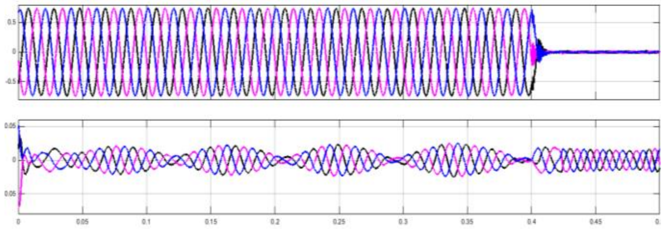
Time (sec)

Figure 2: (f) Three phase voltage and current waveforms at PCC when system is under Islanding condition (starts at 0.4 sec)



Time (sec)

Figure 2: (g) Active and Reactive power waveforms at PCC when system is under islanding condition



Time (sec)

Figure 2: (h) Three phase voltage and current signals at DG-1when system is under Islanding condition at PCC (starts at 0.4 sec)

4. DETECTION OF ISLANDING

The system has been simulated using MATLAB / SIMULINK software. The sampling frequency of 6400 Hz is considered with 128 samples per cycle. The simulation was carried out for 25 cycles and run for 0.5 sec (25 cycles) and islanding is created after 20 cycles (at 0.4sec). Fig. 2 illustrates the detection of islanding at various DGs when islanding is created at point of common coupling (PCC) by opening circuit breaker at 0.4 sec. For islanding condition the comparison of islanding index is done with the threshold value. It can be perceived that the islanding index of islanding is greater than the threshold. Fig. 3(a), 3(b), 3(c), and 3(d) illustrates variation of islanding index of three phases which are above the threshold that indicates islanding condition at DG-1, DG-2, DG-3, and DG-4 respectively. Fig. 3(a) illustrates variation of islanding indexes of DG-1over 5cycles in three phases. It is observed that the variation in alienation coefficients of phase A, phase B and phase C exceeds threshold value (I-TH=0.1). Hence, it is evident that DG-1 is in islanding condition. Fig. 3(b), (c) and (d) illustrate variation of islanding indexes of three phases at DG-2, DG-3 and DG4 respectively..

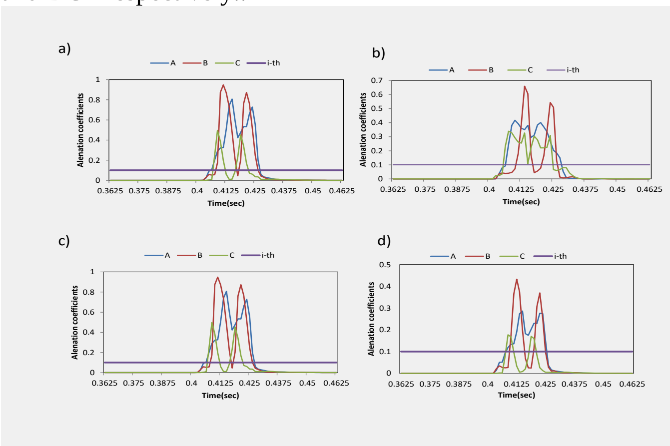


Fig.3 a) variation of islanding indices at DG-1, b) variation of islanding indices at DG-2, c) variation of islanding indices at DG-3, d) variation of islanding indices at DG-4.

4.1 Variation of islanding incidence angle.

The testing of proposed algorithm has been done successfully by varying Islanding incidence angle. Islanding has been applied at regular intervals of 30^0 for testing the proposed algorithm. The variation of islanding indexes of three phases is given in Fig. 3 with different incidence angle. The variation of alienation coefficients of all three phases was observed as above the threshold value. Thus, it is evident from Fig 4 (a), (b), (c), and (d) that the islanding index is always above the threshold at DG-1, DG-2, DG-3, and DG-4 for various incidence angles at PCC. Hence, it can be said that four DGs are in islanding condition.

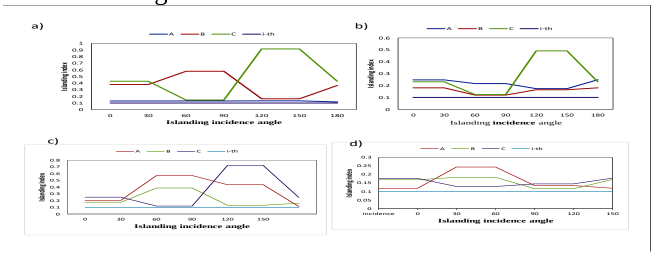


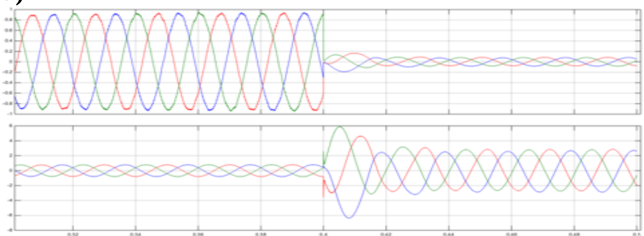
Fig.4 a) variation of islanding index for varying islanding incidence angle at DG-1, b).Variation of islanding index for different incidence angles at DG-2, c).Variation of islanding index for different islanding incidence angles at DG-3, d).Variation of islanding index for different incidence angles at DG-4.

6.3.3 Detection and classification of faults

Faults are simulated at all DGs at 0.4 sec i.e at the 20th cycle. Fault simulation is done after 20-cycles to obtain post fault transients for 5-cycles. The performance of the algorithm proposed at different DGs for various faults with a distance of 30 km from each other is demonstrated in Figure 6 to Figure 9.

Fig. 5(a) illustrates voltage and current waveforms with time at DG-4 during fault ABCG, and Fig.5 (b) shows the approximation coefficients during three phase fault (ABCG) at DG-4. Considerable change was observed in the magnitude from 20^{th} cycle where fault was introduced. From close observation from the results the threshold value is being set as 0.6. The Alienation coefficients are compared with this predetermined threshold and whenever it crosses threshold that phase is considered faulty phase as transients of currents are associated with faults and remaining phases are considered healthy phases and healthy phase is always below the threshold value.

a)



Time (sec)

b)

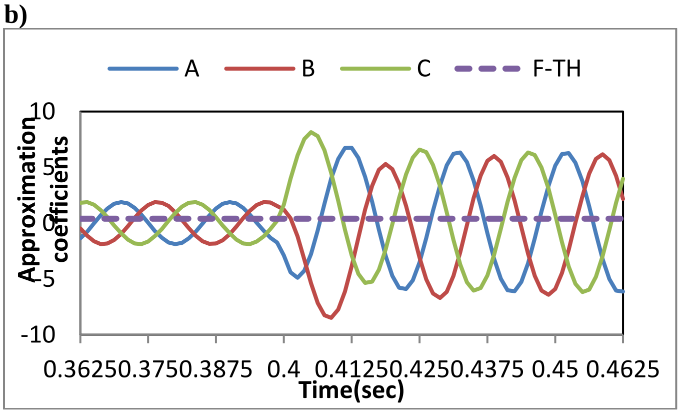


Figure 5: Voltage and current waveforms a) during ABCG fault at DG-4 b) approximation coefficients during ABCG fault at DG-4.

It is observed from Fig.6(a) that the fault index of phase A is above the threshold value but the phase B and phase C fault indices are below the threshold value which is evident that fault is single line to ground (AG) fault. From Fig 6(b) it was observed that the fault indices of all phases i.e. phase A, phase B, and phase C are above the threshold value. Therefore, the fault was recognized and classified as three-phase to ground (ABCG) fault at DG-1 .

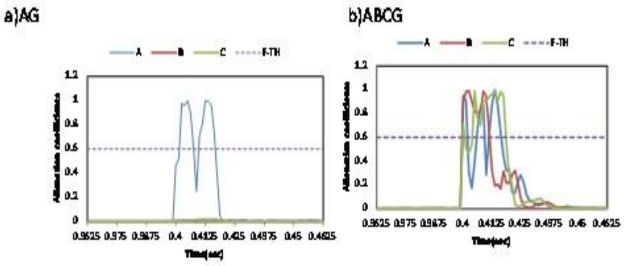


Fig.6. Variation of Alienation coefficients with time a) AG fault at DG-1 b) ABCG fault at DG-1

Similarly, Fig.7 illustrates different faults at DG-2. It can be noticed that the faulty phase is observed above the threshold and healthy phase is observed below the threshold. From Fig. 7(a) it is clear that phase C is above threshold and phase A, phase B are below the threshold value which is evident that CG fault and ABCG fault.

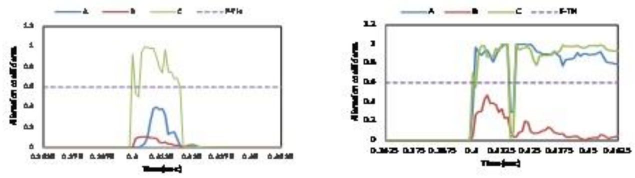


Fig.7. Variation of Alienation coefficients with time a) CG fault at DG-1 b) CA fault at DG-2

Similarly, Fig.8 and Fig.9 illustrates different faults at DG-3 and DG-4. It can be noticed that the faulty phase is observed above the threshold and healthy phase is observed below the threshold. Fig. 8(a) and Fig. 8(b) is evident that BG fault and ABG fault. In the same way Fig. 9(a) and Fig. 9(b) represents BCG fault and ABCG fault.

From the graphs it is observed that the healthy phase never cross the threshold value and faulty phase crosses the threshold value. Once fault index of any phase is greater than the threshold value, it is considered as faulty phase even though the fault index is lower than the threshold for a moment after detection of fault. Fault was detected within 16 samples at every DG.

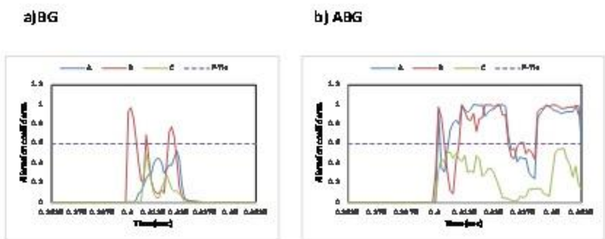


Fig.8. Variation of Alienation coefficients with time a) BG fault at DG-3 b) ABG fault at DG-3

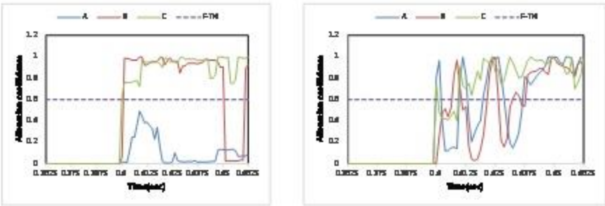


Fig.9. Variation of Alienation coefficients with time a) BCG fault at DG-4 b) ABCG fault at DG-4

5. CONCLUSIONS

The proposed algorithm investigates the successful implementation of the wavelet transform based alienation coefficient approach for effective detection of islanding condition and faults, their classification using current signals in distribution network with penetration of solar energy based DGs. Approximation coefficients over a half cycle have clearly detected the events. Thus the proposed algorithm is successful and fast for the detection of islanding as well as to discriminate transients associated with islanding and load.

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