DEVELOPMENT OF AN EFFECTIVE ISLANDING DETECTION TECHNIQUE USING DISCRETE WAVELET TRANSFORM

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Abstract

Passive islanding detection technique is a method that monitors parameters such as voltage magnitude andfrequencyat the point of common coupling (PCC) and cause the inverter to shot down when the values significantly exceed the presets limits. The main setback of this method isits large non detection zone. This paper presenta wavelet based passive islanding detection technique. The Root-mean-square voltage at the PCC was measured and decomposed to elve details; the standard deviation of each detailwas calculated for both islanding and non-islanding cases. The percentage difference between Islanding and non-islanding fornear zero load mismatch was found to be 98.96% which shows that the system can clearly discriminate between islanding and non-islanding even for the worst case scenario.

Keywords: Discreet Wavelet Transform; Islanding Detection Methods;Non-Detection Zone; Photovoltaic Cell.

1.0 INTRODUCTION

To mitigate the short falls between consumers' power demand and the transmission line capacity; distributed generators are often interconnected with the grid to supply the consumers' load (Reddy *et al.*, 2019). Distributed generation is electric generation facilities of small power units ranging from 1MW to 5MW connected to an area Electric power system (EPS) at PCC(Pourbabak *et al.*, 2015). Distributed generators are used inthe supply of local loads, voltage support and stability, contingency reserves, to reduce electric line losses, and also improve grid reliability (Kim *et al.*, 2019).

The disconnection of the grid from the PCC is known as islanding. Islanding is a situation in which a minor part of the power system is operating independent of the rest of the power system. This is due to distributed generation units remaining operational when connection to the grid is lost (Markus*et al.*,2016). Islanding causes safety problem, damage of equipment connected to the network and power quality degradation hence the formation of an unintentional island is a concern to both utility companies and consumers.By IEEE 1547 regulation, an islanding condition must be detected and power converters de-energized at most two seconds of its occurrence (Lidula *et al.*, 2009).

1.1 Review of Related Work

There exist several islanding detection methods: the passive method which include under/over voltage (UVP/OVP), under/over frequency (UFP/OFP) involves an uncontrolled monitoring of power parameters at the point of common coupling (PCC). A threshold is set for the parameter of interest above which the system is assumed to be islanded (Thanh*et al.*,2018).Theactive method involves some kind of feedback or controlmechanism that forces the voltage or frequency to deviate outside the acceptable limit such that islanding can be detected using passive method(Marwa *et al.*,2013). The effectiveness of these methods depends onthe number of DGs and the quality of the output power is degraded.The remote islanding detectiontechniques use communication infrastructure and advance signal processing techniques to detect and communicate islandingoccurrence to the PV inverter.

An intelligence-based islanding detection technique for synchronous-based DG was proposed in (Zeineldin& Salama, 2011) while (Heidari*et al.*,2013) proposed an islanding detection technique which extracted features from the inverter terminals. DT classifier was used for the detection of the islanding condition. Heidari*et al.*,(2015) used discrete wavelet transform to developed an islanding detection technique by extracting features both from current and voltage transient signal.Zamani*et al.*,(2019) proposed a scheme that detect the occurrence of Islanding in a synchronous distributed generation.Almadipour*et al.*,(2019) combined modified slantlet transform (MSLT) and machine learning on a passive time frequency domain. In this paper, a passive islanding detection technique using discreet wavelet transforms is proposed.

1.1.1 Non-Detection Zone

The NDZ is a range in terms of power mismatch between DG and the load or load parameter in which in which the Islanding detection scheme under consideration fails to detect islanding. It is used as a performance index to evaluate different anti-islanding algorithm.

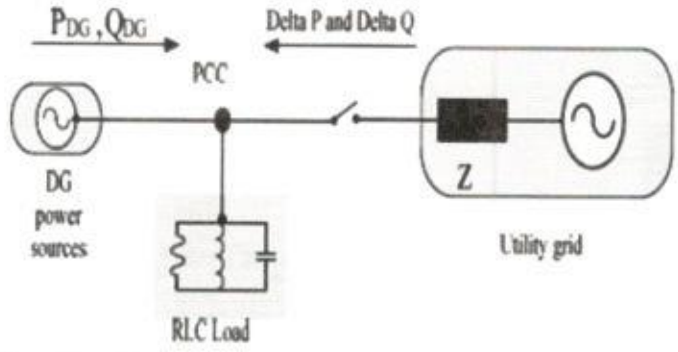

Figure 1: *IEEE1547 Test Circuit*

The power balance equation of a grid connected PV cell is given by Eqn. (1)

$$P_{load} + jQ_{load} = (P_{PV} + jQ_{PV}) + (P_{grid} + jQ_{grid}) \quad \text{.................} \quad (1)$$

Where $P_{load} + jQ_{load}$ is the power consumed by the RLC parallel load.
If $P_{load} + jQ_{load}$ = ($Ppv + jQpv$),there will be no load mismatch and it becomes difficult for passive islanding detection methods to detect islanding occurrence.But usually, there is always a load mismatch between the load and the DG which is denoted by denoted by ΔR, ΔL, ΔC and supplied by the grid; P_{grid} + jQ_{grid}

When the grid is disconnected, the voltage and frequency are forced to a new value V_i and F_i. These values are related to the power mismatch and the thresholds of OVPUVP, OFP/UFP ($F_{min} F_{max} V_{min} V_{max}$) as shown in Eqns. (2) and (3);

$$Q_f\left(1-\left(\frac{f}{f_{max}}\right)^2\right) \le \frac{\Delta Q}{P} \le Q_f\left(1-\left(\frac{f}{f_{min}}\right)^2\right) \quad \text{.........} \quad (2)$$

$$\left(\frac{V}{V_{max}}\right)^2 - 1 \le \frac{\Delta P}{P} \le \left(\frac{V}{V_{min}}\right) - 1 \quad \text{.........} \quad (3)$$

Eqn. (2) represents the threshold for OUF while Eqn. (3) represents the threshold for OUV.These are shown graphically in Figure 2.

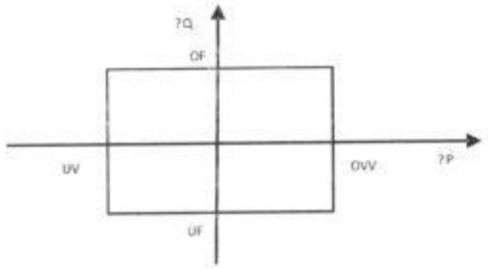

Figure 2: Non Detection Zone of UOV and UOF Passive Technique

2.0 METHODOLOGY

This section outlines the methods that were followed in other to realize the proposed technique,the IEEE1547 test circuit was modeled on the Sim Power System in the MATLAB environment The test circuit comprises the grid, a three phase inverter, and a load modeled as a parallel RLC network. These three components of the test circuit were interconnected at the PCC as shown in Figure 3.

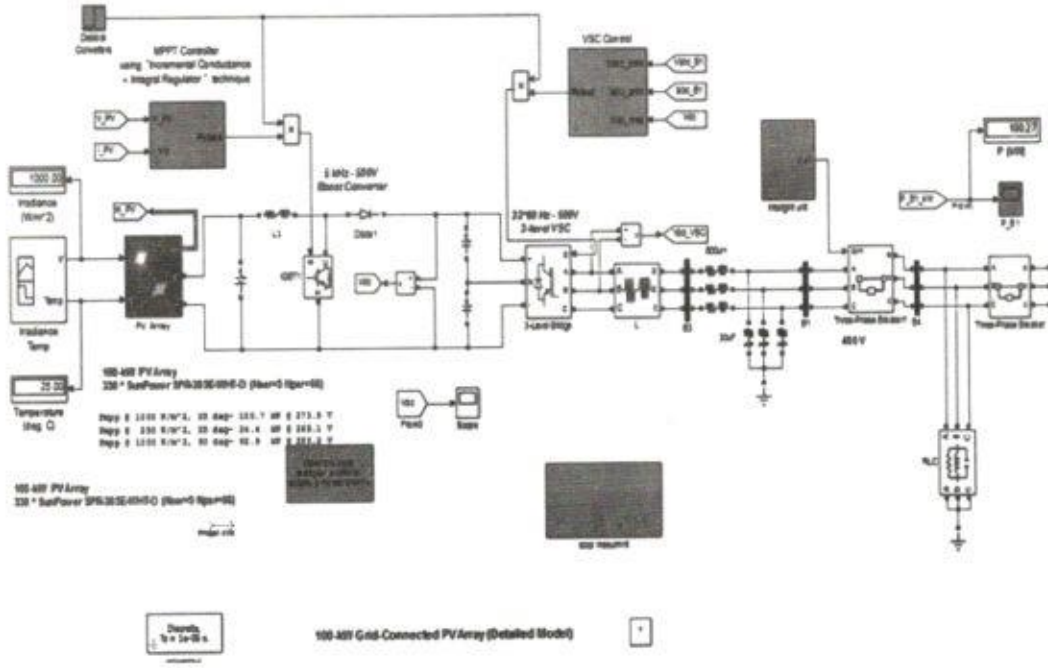

Figure 3: The Circuit Diagram of the System

The voltage signal at the PCC was measured and decomposed to twelve level details using discrete wavelet transform and the standard deviation for each of the detail was calculated for different load variation for both islanding and non-islanding case.

2.1 Wavelet transform

Wavelet transform is a time-frequency representation of a signal. It is a linear transformation in which the basis functions known as daughter wavelets are scaled and dilated versions of the mother wavelet.Wavelet transform provides variable size window which allow for good time and frequency resolutions.

2.2 Discrete wavelet transform

Discrete wavelet transform is a simplified wavelet transform. It has discretized scale and translation variables.The discrete wavelet transform is described in the Eqn.(4).

$$DWT_{\varphi} f(m,n) = \sum_{k} f(k)\varphi^{*}_{m,n}(k) \qquad \text{..............} \quad (4)$$

Where, $\varphi_{m,n}(t)$ is the discredited mother wavelet described in Eqn.(5).

$$\varphi_{m,n}(t) = \frac{1}{\sqrt{a_0^{\,m}}}\varphi\left(\frac{t - b_0 a_0^{\,m}}{a_0^{\,m}}\right) \qquad \text{..............} \quad (5)$$

Where, ao >1 and bo> 0 are fixed real values, *m* is the scale and *n* is the translation which are positive integers. Table 1 presents the detail wavelet frequency bands (Marwa*et al.*,2013), while the flow chart of the proposed technique can be seen in Figure 4.

Table : *Frequency Band of Wavelet Details (Marwaet al.,2013)*

Wavelet Level	Frequency Band (Hz)	Wavelet Level	Frequency Band (Hz)
1-D1	25000-50000	7-D7	390.625-781.25
2-D2	12500-25000	8-D8	195.3-390.625
3-D3	6250-12500	9-D9	97.65-195.3
4-D4	3125-6250	10-D10	48.825-97.65
5-D5	1562.5-3125	11-D11	24.4125-48.825
6-D6	781.25-1562.5	12-D12	Dc-24.4125

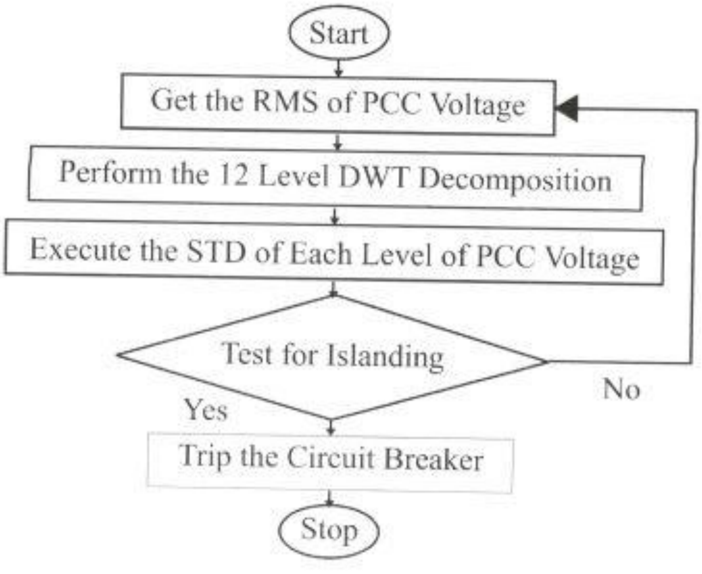

Figure 4: *The Flow Chart of the Proposed Technique*

3.0 RESULTS OF SIMULATION

The proposed technique was applied on the IEEE1547 test circuit. The RMS value of the voltage at the PCC was measured. Then DWT was carried out and finally, the standard deviations of the details were calculated and compared with thenon-islanding case.Figure 5 show an example of the RMS PCC voltage acquired for non-islanding while Figure 6 shows an example of the RMS PCC voltage acquired for islanding case with islanding occurring at t=1s.

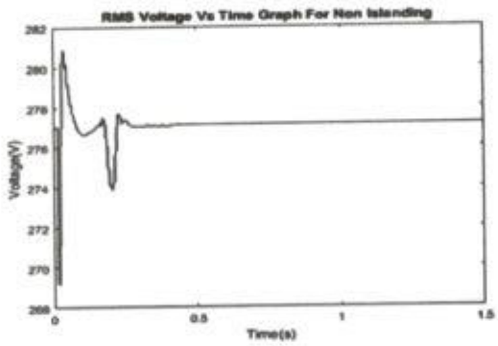

Figure : PCC Voltage for Normal Operation

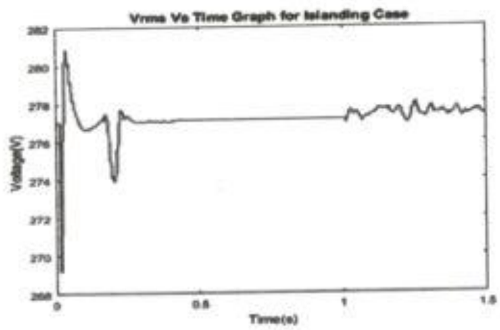

Figure 6: PCC Voltage for Islanding

The DWT was applied for both Islanding and non-islanding cases and the standard deviation for each detail was computed.Tables 2to 5 show the standard deviation of the twelve level details of DWT decomposition for different load variation.

Table : The Standard Deviations of the First quarter of DWT of PCC Voltage

S/No	Load Variation	1st Level		2nd Level		3rd Level	
		None Islanding	Islanding	None Islanding (*10^5)	Islanding (*10^5)	None Islanding (*10^9)	Islanding (*10^9)
1	0%	47.88	4598	5.99	574.6	3.74	360
2	2.50%	47.73	37880	5.97	4735	3.75	3000
	-2.50%	47.22	47389	5.57	5924	3.48	3700
3	5%	47.53	78690	5.94	9838	3.72	6200
	-5%	48.16	93040	6.02	11630	3.76	7300
4	7.50%	47.2	118700	5.90	14840	3.69	9300
	-7.50%	47.22	145800	5.91	18230	3.69	11400
5	10%	48.44	156500	6.05	19560	3.79	12200
	-10%	48.21	190200	6.03	23780	3.77	14900

Table 3: The Standard Deviations of the Second quarter of DWT of PCC Voltage

S/No	Load Variation	4th Level		5th Level		6th Level	
		None Islanding(*10^13)	Islanding(*10^13)	None Islanding(*10^16)	Islanding(*10^16)	None Islanding(*10^19)	Islanding(*10^19)
1	0%	1.17	110	1.85	180	1.48	140
	2.50 %	1.16	930	1.84	1450	1.46	1130
2	- 2.50 %	1.09	1160	1.72	1810	1.36	1420
	5%	1.16	1920	1.80	3010	1.43	2350
3	-5%	1.17	2270	1.86	3560	1.44	2780
	7.50 %	1.15	2900	1.81	4540	1.44	3550
4	- 7.50 %	1.16	3560	1.84	5570	1.42	4360
	10%	1.18	3820	1.86	5980	1.46	4680
5	-10%	1.18	4650	1.84	7270	1.40	5690

Table 4: The Standard Deviations of the Third quarter of DWT of PCC Voltage

S/No	Load Variation	7th Level		8th Level		9th Level	
		None Islanding (*10^21)	Islanding (*10^21)	None Islanding (*10^24)	Islanding (*10^24)	None Islanding (*10^25)	Islanding (*10^25)
1	0%	6.01	500	1.28	100	9.51	900
	2.50%	5.82	4400	1.17	870	6.99	8300
2	-2.50%	5.59	5600	1.21	1090	8.75	700
	5%	5.60	9200	1.15	1800	7.14	17500
3	-5%	5.98	10900	1.19	2150	8.54	20900
	7.50%	5.87	13900	1.19	2710	7.80	26200
4	-7.50%	5.61	17100	1.16	3360	9.87	33100
	10%	6.06	18400	1.25	3570	9.36	34500
5	-10%	5.67	22300	1.18	4400	10.08	43700

Table 5: The Standard Deviations of the Fourth quarter of DWT of PCC Voltage

S/No	Load Variation	10th Level		11th Level		12th Level	
		None Islanding (*10^27)	Islanding (*10^27)	None Islanding (*10^28)	Islanding (*10^28)	None Islanding (*10^30)	Islanding (*10^30)
1	0%	4.05	400	7.79	1000	0.98	90
	2.50%	3.18	4000	7.63	11400	0.14	1730
2	-2.50%	3.63	5500	7.50	14500	0.79	2190
	5%	3.38	8600	4.84	24500	0.38	3570
3	-5%	4.08	10500	11.84	28600	1.3	4310
	7.50%	3.79	12900	7.66	36300	0.47	5390
4	-7.50%	5.08	16700	12.71	44800	1.64	6690
	10%	3.86	17100	8.65	48400	1.53	7140
5	-10%	4.50	22200	12.00	59800	2.18	8810

As seen from Tables, the standard deviation of the PCC voltage signal remains relatively constant even when load was varied for non-islanding case while its value varies significantly for islanding case.The percentage difference between islanding and non-islanding is about 98.96% which shows that the algorithm can clearly discriminate between islanding and non-islanding even for near zero power mismatches.

4.0 CONCLUSION

Passive islanding detection technique was successfully modeled using wavelet transform for easy monitoring of power system parameters such as voltage magnitude and frequency at the point of common coupling (PCC) to safeguard the system from islanding. The root-mean-square voltage at the PCC was measured and decomposed to twelve details; the standard deviation of each detail was calculated for both islanding and non-islanding cases. The Non Detection Zone which is a major setback in the implementation of passive islanding detection can be overcome by the application of DWT. This paper shows that Discreet Wavelet Transform based islanding detection technique is highly effective even for even for near zero power mismatch and a quality factor of 2.5.

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