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Passive Islanding Detection Methods for Integrated Distributed Generation System

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Abstract

This article presents a review of different passive islanding recognition approaches for an integrated system. The IEEE 1547 standards recommend that islanding be recognized in under 2 seconds, as it poses a risk to persons working on the system and related equipment. This paper reviews various passive techniques that detect islanding within 2 seconds. It is very helpful for researchers seeking suitable islanding strategies for their system.

Keywords: Smart Grids, Distributed Generation, Local islanding detection, Remote islanding detection, Passive methods.

1 Introduction

Renewable Distributed Generation (DG) systems are attracting intense interest [1]. Research on the growth of DG systems and their utilization is increasing around the world due to their advantages and the low pollution they produce compared to regular fossil fuel sources. In conventional power networks, power is received by consumers, but in the DG connected smart grid, consumers can also produce power [2]. Small scale power generation systems such as photovoltaic, mini hydro, tidal, biomass connected to the utility at the distribution area are termed DG. The major problem with such DG systems is unintentional islanding [3]. The concept of islanding recognition is depicted in Fig. 1. DG is associated with the grid through transformers and suitable switchgear. If the main CB is isolated, islanding occurs with local load and DG. The islanding recognition approaches are separated as shown in Fig. 2 into local and remote islanding recognition strategies. The local islanding techniques are further broken down into active, passive and hybrid approaches. The two main parameters that influence the understanding of islanding are NDZ and DG interconnection standards. The area of parameters where an islanding technique fails to find islanding is called NDZ [4]. DG interconnection standards will cover the issues of DG with the existing power network. The optimization algorithm, energy management systems and controlling of islanding grids are important elements in protecting the system. This article reviews different islanding identification techniques in detail, together with their merits and disadvantages. This paper is very helpful for researchers looking to select an efficient islanding detection technique for future islanding detection.

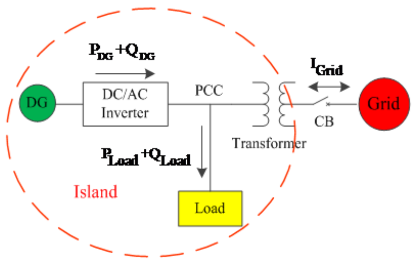

Figure 1: The concept of islanding in the power network

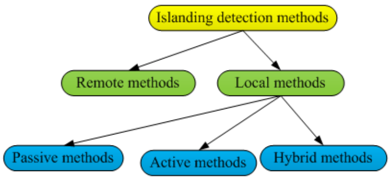

Figure 2: Classification of islanding recognition approaches

2 Local islanding detection methods

2.1 Passive islanding detection (PID) techniques

Passive approaches use regional signals such as voltage, current, frequency, active and reactive power, phase angle, THD at PCC to find the situation. When the DG is in the utility connected mode, there can be no more deviations in these passive parameters, but when the network is islanded, changes in these parameters are outside the standards and are used to detect islanding [5]. The recognition process of PID techniques is depicted in Fig. 3. Care must be taken when fixing the threshold values to differentiate islanding from non islanding cases such as switching transients and short circuit faults. These accurate methods are very simple to implement - no power quality issues - but suffer from large NDZ [6].

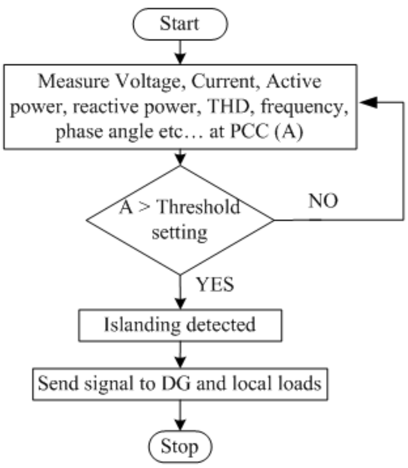

Figure 3: General flowchart of the PID Technique

2.2 Over/under voltage, over/under frequency method

The basis passive approach is an OUV / OUF technique. In this approach, the voltage and frequency of the network at PCC are estimated to find out whether or not the situation is established. The threshold values of voltage and frequency can be received from Eq. 1 and Eq. 2.

$$(\frac{v}{v_{max}})^2-1\leqslant\frac{\Delta P}{P_{DG}}\leqslant(\frac{v}{v_{min}})^2-1 \quad (1)$$

$$Q_f(1-(\frac{f}{f_{min}})^2)\leqslant\frac{\Delta P}{P_{DG}}\leqslant Q_f(1-\frac{f}{f_{max}})^2 \quad (2)$$

where the values of $v_{\max}$, $v_{\min}$, $f_{\max}$ and $f_{\min}$ are 110%, 88%, 60.5 and 59.5 Hz respectively [7]. It can recognize the situation when the voltage and frequency are greater, or can lower the setting [8].

2.3 Rate of change of frequency (ROCOF)

This approach recognizes islanding when the ROCOF measured at the PCC is not at the setting value. Phase locked loop (PLL) is used to measure the frequency level in the system. In the integrated system, the measured changes are very much lower than the islanded system. The frequency changes are called ROCOF [9]; [10]. The expression for the ROCOF is given by equation (3) [11].

$$\frac{df}{dt}(k)=\frac{f(t_k)-f(t_k-\Delta t)}{\Delta t} \quad (3)$$

where $f\left(t_k\right)$ is the frequency at the time of k^{th} sample, $f\left(t_k-\triangle t\right)$) is the estimated magnitude of frequency $\triangle t$ earlier the kth segment time i.e. $t_k-\triangle t$. The NDZ of this approach is less than that of the voltage, frequency approach [12]. This approach fails to find minimum power islanding in the network. Fixed setting parameters differentiate islanding events from non islanding situations with this approach [13]; [14].

2.4 Rate of change of active and reactive power (ROCOP)

In this approach, the ROCOP is used to recognize islanding. During normal grid connected operation, the changes in ROCOP are less, and at islanding they are more [15]. Particular care is required when finalizing the threshold values, to differentiate between switching events and islanding events [16]. This method is very efficient for unbalanced load but failed to detect islanding when it is under balanced islanding.

2.5 Voltage Unbalance (VU)

This approach is based on the VU of three phase voltage [17] signals information at PCC. When the grid is lost, less variation in load also leads to VU. The ratio of NSV to PSV is used to detect islanding as voltage unbalance factor (VUF) [9]. Equation (4) indicates the VUF as

$$VU_t = \frac{NSV}{PSV} \cdot 100 \tag{4}$$

where is the VU at t^th direct of time. The statement (5) represents the deviation of VU from the study state value of voltage during load switching and islanding

$$VU_t = \frac{VU_s - VU_t}{VU_s} \tag{5}$$

where the voltage is unbalance of predefined value and is the voltage unbalance at t^th instant of time.

2.6 Phase jump detection

This approach detects islanding with the use of phase jump among the voltage and current yield of the inverter [17]. The modified PLL is used to find the change in phase angle. When islanding occurs, the inverter yield current is constant, but the inverter voltage changes its path, as is shown in Fig. 4 [18].

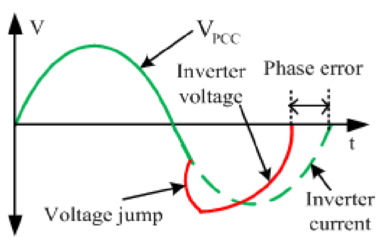

Figure 4: PJD basis principle of operation

Due to the latest path of voltage, phase error occurs. If this error is higher than the setting parameters, then islanding is estimated and the inverter is tripped. The advantage of this approach is that it has no effect on transient response or the quality of power supplied [18].

2.7 Voltage unbalance and THD based islanding detection

It recognizes islanding cases when the combined changes of both VU and current THD are greater than the preset threshold value. Generally, low harmonics (<5%) are present in the grid connected system. When the system is islanded, the load is associated with the inverter. Due to a change in the impedance of load, the harmonic content of voltage and currents increase [17]. Harmonics also increase when nonlinear loads are switched. Hence, to overcome false tripping for islanding events, the VU method is used in combination with the THD technique [19]. Rate of change of reactive power (ROCORP) in combination with THD is also used to detect islanding, when both ROCORP and THD are greater than preset values.

2.8 Change of source impedance

In general, DG has a small impedance; if it connects to the grid its impedance is greater than the impedance of the source. When the network is islanded under unbalanced load after disconnecting from the microgrid (MG) its impedance at PCC changes [20]. Islanding is found by continuously monitoring impedance at PCC. But this approach does not recognize islanding for balanced loads.

2.9 Rate of change of voltage (ROCOV) and power factor

This approach is useful particularly when DG and the load have the same capacity and also for the detection of loss of parallel feeders. Islanding is determined by continuously monitoring the combination of ROCOV and power factor at PCC [21]. When the system is islanding, the voltage magnitude and power factor change. This method clearly differentiates islanding from switching events.

2.10 Rate of change of frequency over active power

This technique uses the ROCOF over active power (df/dp) for islanding recognition. This approach has less NDZ compared to ROCOF relay [22]. It will also recognize islanding in small and medium power islanding conditions. The validation of threshold parameters is difficult in this approach, because ROCOF and ROCOAP settings are appropriate.

2.11 Rate of change of frequency over reactive power

This is one of the best techniques for islanding recognition in a DG system [23]. Compared to ROCOF, ROCOP, ROCOV, OUV/OUF passive methods, this method differentiates neatly between islanding and non islanding situations [24]. It will detect islanding when the ROCOFORP is higher than a predefined setting parameter. It will also work for zero power islanding detection with smaller or zero NDZ. It is one of the best PID techniques available.

2.12 Rate of change of phase angle difference

In this strategy, the phase angle among voltage and current at PCC is computed for islanding detection [25]. The current and voltage values at PCC are used for computing the phase angle difference. Islanding is found if the ROCOPAD is beyond a specified threshold value. This technique has NDZ less compared to the ROCOF technique. It can also work for balanced islanding detection.

2.13 Rate of change of negative sequence voltage and current

The zero, negative and positive sequence signals are extracted by using the sequence analyzer at PCC with inputs of voltage and current. Generally, the zero sequence parameters existed when the faults are associated with the earth. Islanding is a case of a power system problem without contact with the ground. Positive and negative component parameters are available in islanded networks. Islanding is recognized by observing the changes in negative sequence voltage and current [26]. In the grid integrated case, these changes are not available, but in the islanding case these variations are higher than the threshold values and islanding is recognized. Balanced islanding is possible with this method.

2.14 Rate of change of positive sequence voltage (PSV) and current (ROCOPSVAC)

Positive sequence signals are available in all cases of micro grid operations. The PSV and current are computed by using the sequence analyzer [27]. Islanding is recognized if the values of ROCOPSVAC are higher than the threshold value. Balanced islanding is detected with zero NDZ using this approach [28]. It will exterminate switching events and islanding events perfectly.

2.15 Phase angle between NSV and current

In this method, the current and voltage values are determined at PCC. The phasor of current and voltage values are estimated using the least squares approximation approach [29]. The sequence analyzer will calculate the NSV and NSC. The phase angle difference between NSV and NSC are obtained by the statement (6)

$$\phi = Phase\ angle\ between\ NSV\ and\ NSC \quad (6)$$

If the angle is higher than the estimated setting values, the situation is approximated. This signal parameter is a positive slope for islanding situations, whereas it is zero for non islanding situations [30].

2.16 Rate of change of regulator voltage, over reactive power (ROCORVORP)

This approach uses the regulator voltage and reactive power as islanding parameters, because they are directly proportional to each other and independent of changes in inertia [11]. The active power and frequency change due to variations in the inertia constant, but they are independent of excitation. Even small changes in inertia cause more deviations in the frequency and active power. However, the changes in reactive power and excitation are very fast for a variation of excitation. First, the reactive power and the exciter voltage are calculated, from which the ROCORVORP is calculated. If the ROCORVORP is higher than the present setting, then islanding is confirmed. Under other conditions, non islanding is confirmed. The excitation and CB switching strategy (CBSS) is also used for islanding detection [31]. This method can detect balanced islanding with small NDZ, but will take more time for detection than ROCOF, OUV/OUF relays.

2.17 Transient component based approach

In this method, the transient component of signals and positive sequence superimposed component current angle at PCC is used for islanding detection. The transient index value is computed from the voltage signals obtained at PCC. The variations in both parameters are used to detect islanding. This method accurately differentiates switching events from islanding events. It will accurately detect balanced islanding [32].

2.18 Forced Helmholtz oscillator

This is the latest passive islanding identification approach introduced for detecting islanding phenomena, for both inverter based DG and synchronous DG systems. It will use the modified frequency at PCC for islanding detection. This method is based on the chaos concept and is implemented with a forced helmholtz oscillator [33]. It is better suited for inverter based DG than synchronous DG. Islanding is detected with this method at up to $\pm 0.4\%$ of power mismatch. It will validate non islanding events.

2.19 Switching frequency of the inverter

This approach will detect islanding by observing the switching frequency of the inverter [34]. During grid connected mode the frequency is constant, but it changes during islanding. The authors proposed that this approach can find islanding within 20 ms of islanding occurriing, which is less than the shortest CB reclosing time of 150 ms [35]. It is best suited for inverter-based multiple DG units. The NDZ of this procedure is zero.

2.20 Signal processing methods S-Transform (ST)

The improvement of WT with phasor data is termed as ST [36]. ST advancement is utilized for islanding recognition and investigation of power quality related issues based on running at changeable and expandable narrow gaussian windows. In the presence of noise, multi resolution technique-based ST is used to obtain accurate results after processing each phase frequency. In [37], the spectral intensity satisfaction of the S contour was received against the NSV, and current signals were processed using ST. In the same way, in [38] NSV was refined using ST. Islanding is recognized by computing energy signal and the basic changes of the contour. The weakness of using this ST technique is that it will degrade the power quality due to transients [39].

2.21 Wavelet transforms (WT)

Wavelet transforms are the best engineering tools for speech and signal processing applications. By observing the voltage waveforms at PCC islanding is detected with wavelet transforms. Hence it is a passive method. This method gives a good result for inverter based DG systems with a quality factor of 2.5 for parallel RLC loads. The quality factor of loads is nearly 2.5 or less [40] and this application does not affect power quality. By obtaining information from the ROCOP at PCC the wavelet packet transform differentiates islanding neatly from switching events by using node variation of the power index [41]. Spectral change in higher components of voltage change at PCC is used to detect islanding with nearly zero NDZ in the worst case of islanding within 2.5 cycles [41].

2.22 Fuzzy and S- Transform

In this method a discrete fast S- transform and fuzzy rule based strategy was used for islanding recognition. The NSV and NSC of target DG are inputs to the S-transform [42]. This fuzzy rule based strategy differentiates between islanding and non islanding cases. It has been tested for multiple DG units and achieved islanding detection within one cycle [30]. This method clearly classifies switching events from islanding events, even during heavy disturbances.

2.23 Discrete wavelet transforms (DWT) and S transform

In the DWT and S-transform approach, islanding is recognized by deriving NSV from DG sources. Islanding is detected after processing the NSV with S-transforms and wavelets in different cases. It not only finds islanding events, it can also find the type of DG system [36]. After processing the voltage signal at PCC, power quality issues and islanding events are classified [40]. It is only with DWT that islanding is detected by using current signals at PCC within one third cycles (5.5 ms) for a 60 Hz system during closely balanced islanding [43]. A comparison of various passive methods in terms of detection time, NDZ and power quality issues [44] is set out in Table 1.

Table 1: Comparison of PID techniques

Name of the PID technique	NDZ	Detection time	Power quality
OUV/OUF	Large	4 ms to 2 sec	*
ROCOF	+	24 ms	*
ROCOP	+	>one cycle	*
V-THD and I-THD	More with high value of Q	45 ms	*
ROCOFOP	Lower than ROCOF	100 ms	*
PJD	+	10-20 ms	*
VU	Large	53 ms	*
VU and THD	Medium	>ROCOF (within 2 s)	*
Switching frequency	1.60%	<40 ms	*
ROCOFORP	#	Not mentioned, better than 16 passive parameters	*
ROCOPAD	+	<ROCOF	*
ROCONSVAC	#	80 ms	*
ROCOPSVAC	#	10 ms	*
PNSVNSC	#	Within quarter cycle (4.16 ms)	*
ROCOEVORP	#	Not mentioned	*
ROCOEVO with CBSS	#	300 ms for balanced islanding & 100 ms for unbalanced islanding	*
Signal processing based passive approaches			
Wavelet	Nearly zero		*
DWT	#	50 ms	*
WPT	#	Within one cycle (5.5 ms)	*
Wavelet coefficients	#	Very small	*
DWT & ST	#	24 ms	*
Fuzzy and ST	#	Within one third of cycle	*
FGNA	#	Within one cycle (20 ms)	*

3 Conclusion

This paper presents a brief survey of islanding recognition approaches for grid integrated energy systems. As per IEEE 1547 standards, islanding should be found within 2 seconds of occurrence. The NDZ of passive techniques is found to be greater than in AID and HID techniques. In AID techniques, the NDZ is less, but they degrade power quality. HID techniques combine the features of both active and passive techniques, and their NDZ is lower than with PID techniques. RID techniques are free from NDZ, but they are much more complex to implement than local techniques. Most PID techniques fail to detect balanced islanding and some of the methods do not work for multiple DG connected systems. Future research will seek to detect balanced islanding with passive methods and to develop methods that will work on multiple DG systems without degrading power quality.

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