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Passive Method for Distributed Generation Island Detection Based on Oscillation Frequency

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Abstract*—This paper aims to present a passive island detection technique for synchronous Distributed Generation (DG). The technique is based on frequency oscillation estimation in order to distinguish the islanding from other events that may occur in distribution systems. The island detection uses a small window to estimate the oscillation frequency, obtaining faster responses than the existing methods which use larger windows to estimate the damping and frequency of oscillation. The algorithm performance has been tested considering different generation and load scenarios including short circuits, load and capacitor switching, DG outage and islanding. The technique is reliable since it does not trip for non-islanding event; the island detection time is less than 40 ms and its Non Detection Zone (NDZ) is less than 1.6 % of the DG nominal power. The proposed method has been compared with one of the most common algorithms used in practice, the Rate of Change of Frequency (ROCOF). The results show that the algorithm based on frequency oscillation detection performs better than the ROCOF and its mathematical simplicity is adequate for practical relay implementation.

***Index Terms*—Anti-islanding protection, frequency oscillation, distributed generation, passive protection**

I. Introduction

NOWADAYS due to the increase of renewable energy sources, DGs assumed an important role in distribution and sub transmission systems. However, abnormal operating conditions of the distribution system may cause that the DG remains connected isolated from the main system and feeding local loads. This operating condition is known as DG islanding.

The DG unintentional islanding may cause life-threatening and power quality deterioration, because of the poor voltage and frequency regulation. Besides, it may cause damage to electric power system equipment due to out-of synchronism reclosing. For these reasons, the islanded operation of distribution systems is normally not allowed and the anti-islanding protection is necessary for the connection of DGs at the distribution and sub transmission networks. The IEEE Std 1547 [1] specify that the islanding must be detected up to 2 seconds after the island formation.

To obtain a fast and reliable islanding detection, many techniques have been proposed. These techniques can be classified in local and remote. The last techniques such as Direct Transfer Trip, do not have non detection zone but it is complex when there are many devices upstream that can switch causing islanding. Besides, if the topology changes in the feeder, it may be a problem [2].

Two island detection techniques based on Phasor Measurement Unit (PMU) have been proposed in [3], the first uses the frequency difference and the second uses the change of the angle difference. In [4] is proposed a method based on principal component analysis of a wide-area frequency measurements. The main problem in the algorithms proposed in [3] and [4] is that the time delay introduced and the latency turns the island detection too slow. Typically the methods spend between 500 ms and 3s to identify an islanding. Although it may be less than the 2s required by IEEE standard 1547 [1] this island detection time may be greater than the re-closer time. In general utilities usually auto reclose times around 500 ms, which can result in out of synchronism reclosing.

One characteristic of the remotes island detection techniques is that they might suffer with communication problems, and may involve a very large financial cost, making it prohibitive for small DGs.

The local techniques can be divided into three categories: Active, Passive and Hybrid methods. The active methods inject small signals in the distribution system or force the DG to an abnormal situation, where the connection to the system keeps the DG under normal conditions. The disturbances inserted in the distribution system may cause power quality deterioration [5-7]. If the generators with similar techniques are connected very close to each other, they might cause interference and impair the performance of these techniques. In [8] the performances of active frequency drifty methods are evaluated for multi inverter system. The non-detection zone increases when the inverters try to drift the frequency in opposite directions.

In [9] is proposed a hybrid method that employs Sandia Frequency Shift (SFS) and ROCOF, the method reduces the power qualities deterioration and the non-detection zone when compared with traditional SFS algorithm. In [10] the technique changes the GD active power, based on the detection of the average rate of voltage change, thus making the islanding detection easier. The problem with [9] and [10] is that the time of detection and the NDZ is still dependent of the passive technique threshold.

The passive methods detect the islanding using just the system parameters. Due to the lower cost of these protections, they are widely used in DGs with low power DG. The Rate of

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Change of Frequency (ROCOF) one of the most known and used methods for islanding detection due to its fast island detection [11].

Other passive techniques such as, under/over- frequency, under/over-voltage [12], vector shift, are also applied. Although these techniques are effective for islanding conditions with large power unbalance, passive methods may fail to detect low power unbalance, or spend too much time to detect the islanding occurrence. In addition, events like short circuits and switching of large blocks of load can cause islanding erroneous detection.

In [13] a decision tree classification technique has been utilized, however the methodology requires a very large set of parameter, and suffer with misclassifications. A pattern reorganization method is proposed in [14] and [15].The methods utilize wavelet transform to extract features from the three phase voltage and current. A new wavelet design especially for island detection purpose is proposed in [16].The algorithm utilizes just the voltage and six wavelet coefficients, reducing the computational effort compared to [14] and [15]. The methods [13-16] present intelligent solutions, however they require a training process, which is difficult to implement in practice.

Other passive techniques such as fuzzy-rules [17], and empirical mode decomposition method [18] also had been proposed. These methods have good performance, however require additional maturation period before being used in practice. In addition, there is reluctance on the acceptance of these methods because they are dependent on the user know-how.

Techniques based on the estimation of synchronous machine oscillation frequency are proposed by [19] and [20]. The methods employ windows of 500 ms and 350 ms, respectively, for the oscillation frequency estimation, which demand too much time for islanding detection purposes.

To overcome these problems, this paper proposes an islanding detection algorithm based on the estimation of synchronous machine oscillation frequency to distinguish islanding from other events. The proposed algorithm uses a small window, 2.1 ms, to estimate the oscillation frequency that allows a very fast islanding detection. Although the window is small, the results show that the method is secure and is able to detect islands when the interrupted power at the disconnected point is less than 1.6% of the DG power.

The detection speed improvement is the main contribution of the proposed paper when compared with [19] and [20] . The developed oscillation frequency estimator applies a small window which provides a much faster detection ensuring the system integrity. The algorithm is fault tolerant, and has a reduced non-detection zone.

II. Basic Concepts

In synchronous machines steady state operation the relative position between the rotor and the resulting magnetic field remain almost constant. When a sudden disturbance occurs, the angle between both will oscillate dynamically according to the swing equation given by (1).

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt^2}+D\frac{d\delta}{dt}=P_m-P_e \tag{1}$$

Where, δ is the relative rotor angle, t is time, H is the generator inertia constant, D is the damping coefficient, ω_0 is the DG synchronous speed, P_m is the mechanical input and P_e is the electric power output of the DG.

A. Frequency variation during non-islanding events

When a small disturbance occurs in the electrical system, the DG oscillates and returns to the original state after some time. The electrical power injected by DG in the distribution system can be written as

$$P_e=P_{max}\sin\delta \tag{2}$$

A small perturbation $\Delta\delta$ in δ, from the initial operating position δ_0 can be represented by

$$\delta=\delta_0+\Delta\delta \tag{3}$$

Due to a small perturbation, the swing equation (1) can be linearized and rewritten as

$$\frac{2H}{\omega_0}\frac{d^2\Delta\delta}{dt^2}+D\frac{d\Delta\delta}{dt}+P_s\Delta\delta=0 \tag{4}$$

Where, P_s is known as the synchronizing power coefficient and is defined by the equation

$$P_s=P_{max}\cos\delta_0 \tag{5}$$

Solving the differential equation (4), the frequency deviation from the nominal synchronous speed is given by (6).

$$\Delta\omega=\frac{d\Delta\delta}{dt}=-\frac{\omega_n\Delta\delta(0)}{\sqrt{1-\varsigma^2}}e^{-\varsigma\omega_n t}\sin\omega_d t \tag{6}$$

Where,

$$\omega_d=\omega_n\sqrt{1-\varsigma^2} \tag{7}$$

$$\varsigma=\frac{D}{2}\sqrt{\frac{\omega_0}{2HP_s}} \tag{8}$$

$$\omega_n=\sqrt{\frac{\omega_0}{2H}P_s} \tag{9}$$

The frequency behavior during small disturbances in a synchronous DG connected to the main system is shown in (6). It can be seen that the frequency is given by a damped sinusoidal waveform.

B. Frequency variation during islanding events

During an islanding event, the DG loses the connection with the main system and consequently the synchronizing coefficient is zero. In this way, (4) can be rewritten as (10).

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$$\frac{2H}{\omega_0}\frac{d^2\Delta\delta}{dt^2}+D\frac{d\Delta\delta}{dt}=\Delta P \tag{10}$$

Where, ΔP is the power variation due to the islanding; in other words, the transmitting electrical power in the electrical system split point. In this case it is assumed that the ΔP remains constant during the islanding. ΔP is positive when the electrical power in the split point is flowing from the main system to DG.

Since the rotor angle is synchronized with the stator magnetic field before the islanding, there are the two initial conditions for (10), $\Delta\delta(0)=0$ and $\frac{d\Delta\delta(0)}{dt}=0$. Solving (10), the equation for electrical frequency deviation is obtained.

$$\Delta\omega=\frac{d\Delta\delta}{dt}=\frac{\Delta P}{D}\left(1-e^{-\frac{\omega_0 D}{2H}t}\right) \tag{11}$$

Comparing (6) to (11), it can be seen that the frequency of the DG behaves differently. During the DG parallel operation with the system, the frequency tends to oscillate at the damped natural frequency, ω_d. Disregarding the governors and voltage controls, the frequency does not oscillate during the islanding, but it is given by an exponential response.

III. ISLANDING DETECTION ALGORITHM

Island detection is not a problem when large amount of power is transmitted through the split point before the islanding. In these cases, the large power mismatch will cause an exponential response and large frequency variation.

In islanding with small power mismatch, the presence of voltage and frequency controls must be taken into account. During the first instants of an islanding, the frequency has an exponential behavior; after some time, the frequency control of the DG does the frequency return to its nominal value. In these cases, the frequency will be oscillatory, but the frequency of oscillation will be considerably lower than when the DG is connected to the main electrical system.

The proposed islanding detection algorithm uses a frequency estimator to determine the DG oscillation frequency and to differentiate islanding from other events. The oscillation frequency is determined through (1) using the samples of the GD electrical frequency. In Fig. 1 the proposed islanding detection algorithm is presented.

The frequency deviation from its nominal value, 60 Hz, is compared to the threshold, Th1; if the frequency crosses the threshold, the oscillation frequency must be calculated. This is important to avoid the oscillation frequency calculation when the system is in normal operation. Usually, the frequency of interconnected electrical systems changes in ± 20 mHz; in this way, Th1 is adjusted to be 50 mHz.

When the frequency deviates from its nominal value, the oscillation frequency is calculated as shown in the next subsection.

The calculated oscillation frequency is compared with Th2, if f_{osc} remains less than Th2, a counter will start, and a signal will be sent to disconnect the DG when the counter reaches Th3. These conditions ensure that DG will only be disconnected if the oscillation frequency remains very low, that is a feature of islanding. The selection of Th2 must be less than the DG natural damped frequency of oscillation ω_d. However, (7) was obtained by a linearization that is valid only for small perturbations and it does not consider the effects of voltage and frequency controls. Since an analytical solution for ω_d for large perturbations is not possible, the easiest way to determine Th2 is through simulations analysis of short circuits and loads switching. In this study, for the test system described in the next section, Th2 is selected to be 2.5 Hz.

The small time delay is introduced by Th3 is necessary to introduce more robustness to the method. In the study presented in this paper, the time delay is two cycles of 60 Hz; in other words, Th3 is 256.

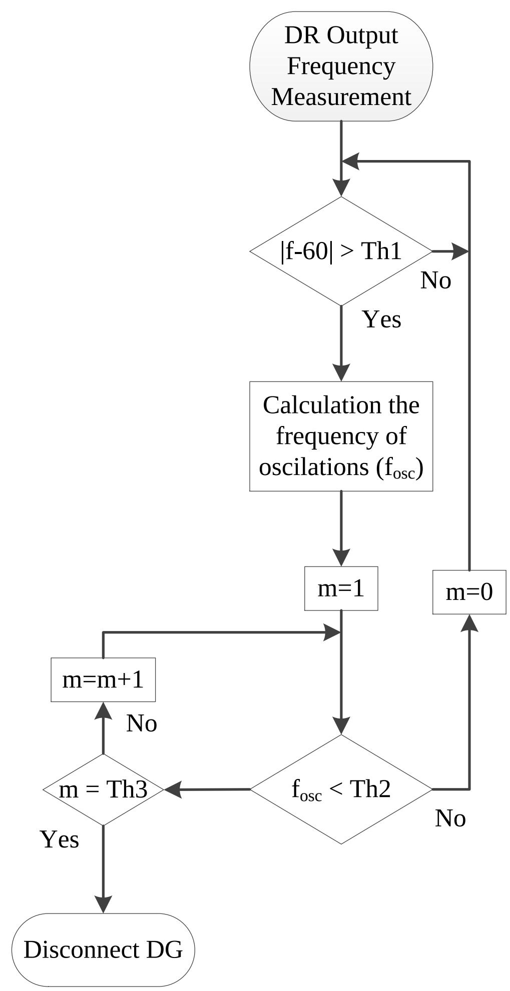

Fig. 1- Proposed island detection algorithm

A. The Frequency Estimation

The synchronous generators oscillation frequency is usually very low, only few hertz. For frequency estimation of these signals some algorithm needs a large window such as 350 ms

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and 500 ms [19],[20]. Although these algorithms are accurate, the delay introduced is very large.

The frequency oscillation estimation method proposed in this paper employs just three frequency samples to estimate f_{osc} (12). The procedure for obtaining the equation (12) is shown in Appendix I.

$$f_{osc}(k) = \frac{f_{sampl}}{2\pi N} \operatorname{acos}\left(\frac{f(k) + f(k-2N) - 2f_0}{2f(k-N) - 2f_0} \right) \qquad (12)$$

Where, f_{sampl} is the sampling frequency, f_0 is the nominal frequency, acos is the arccosine, f(k) the electrical frequency at the instant k and N represents half of the window size.

It is desirable to have the fastest possible estimation convergence. In this way, N should be the lowest integer possible. On the other hand, larger N gives more accuracy for the method. In the studies carried out in this paper, N is set to be 8, resulting in a window length of 16 samples (2.1 ms). The window used in the proposed methodology is much smaller than the one presented by [13] and [14], allowing a much faster protection function.

Islanding and non-islanding events are presented in Figs. 2 and 3 respectively. The test system in which the simulated events were accomplished is described in the next section. In Fig. 2, the behavior of the proposed algorithm during a heavy load switching is presented. The system frequency crosses the Th1 but the algorithm does not trip because the oscillation frequency is greater than Th2.

In Fig. 3, the behavior of the proposed algorithm during an islanding is presented. In the first millisecond the frequency can be modeled by an exponential function. After some time, the voltage and frequency regulators start to operate and the frequency assumes an oscillatory behavior, but with lower frequency oscillation than the natural frequency. It is important to note that the largest effect on the oscillation frequency is due to the frequency regulator. However, the voltage regulator has a much smaller response time, thus affecting the frequency in the first milliseconds after islanding. Therefore, it must be considered.

In Fig. 3 - A can be seen that during islanding the frequency crosses the Th1 and Fig. 3 - B shows that its oscillation frequency remains lower than the Th2 in most of the simulation time. After to meet the criterion set by the threshold 1, 2 and the time delay set by the Th3, the algorithm releases the sign of trip according to the Fig. 3 - C.

Due to the fact that oscillation is not perfectly sinusoidal, the measured oscillation may sometimes fail and cross the Th2. But as shown in Fig. 3 and verified in the tests in the next section, the oscillation frequency remains lower than the Th2 in most of the simulation time, which is enough to detect islanding.

The arccosine function always returns a real values in the interval [0,π]. Since the frequency signal are not a perfect cosine function during islanding, in some situations f(k)+ f(k-2N) - 2f0 can be bigger than 2f(k-N) - 2f0. In those cases the equation is not between the limits [-1,1] and the value of the arccosine is taken equal to zero. However, this not affects the performance of the method, since was verified just during islanding, and to set the oscillation frequency to zero enable the island detection. This behavior can be observed in the Fig. 3 - B, in the interval between 0.1 and 0.14 seconds.

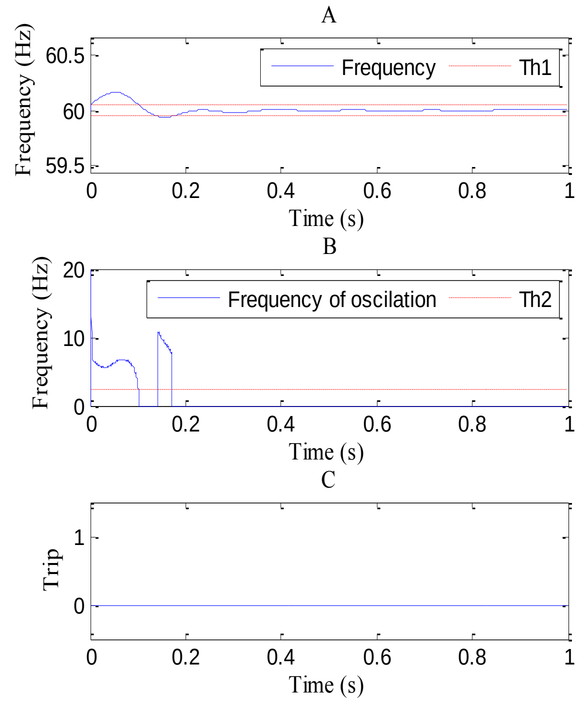

Fig. 2- Performance of the proposed algorithm during heavy load switching.
A – DG electrical frequency, B – DG frequency of oscillation, C – Trip Signal

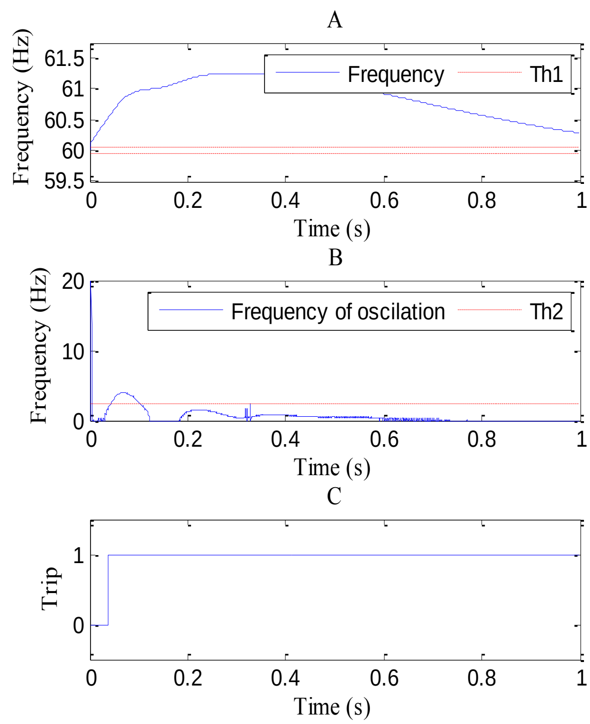

Fig. 3- Performance of the proposed algorithm during islanding.
A – DG electrical frequency, B – DG frequency of oscillation, C – Trip Signal

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IV. Simulation and Results

To evaluate the performance of the proposed method, it has been applied on the IEEE 34-bus distribution test system, shown in Appendix II. A generator was connected to bus 854 through the transformer presented in Table 1. The generator presented in Table 2, the DG voltage and frequency regulators are given in [21]. A 0.2 MVA load, with 0.92 inductive power factor is connected directly to the DG node.

TABLE 1
DISTRIBUTED GENERATOR TRANSFORMER DATA

Parameter	*Value*
854- Point of Common Coupling	
Three Phase Transformer	
Rated Power	3.0 MV A
Nominal Frequency	60 Hz
Rated Voltage	24.9/2.4 kV
Connection	D/yn
Vector Group	Phase Shift 1 ×30deg
Positive sequence reactance (X1)	0.059371 p.u.
Positive sequence resistance (R1)	0.008667 p.u.
Zero sequence short circuit impedance	0.06 p.u.
Zero sequence short circuit reactance	0.0087 p.u.

TABLE 2
GENERATOR PARAMETERS

Parameter	*Value*	*Parameter*	*Value*
Reference Machine	Not Flag	Direct axis reactance (Xd)	1.56 p.u.
Mode of Local Voltage Controller	Voltage	Quadrature axis reactance (Xq)	1.06 p.u.
Dispatch - Voltage	1.0 p.u.	Direct axis transient reactance (Xd')	0.26 p.u.
Nominal Apparent Power	3.125 MVA	Direct axis subtransient reactance (Xd")	0.15 p.u.
Nominal Voltage	2.4 kV	Quadrature axis subtransient reactance (Xq")	0.15 p.u.
Power Factor	0.8	Direct axis short-circuit transient time-constant (Td')	3.7 s
Connection	Yn	Direct axis short-circuit subtransient time-constant (Td")	0.05 s
Inertia Time Constant (rated to Sgn) H	1.071 s	Quadrature axis short-circuit subtransient time-constant (Tq")	0.05 s
Leakage Reactance (XL)	0.088 p.u.	Main flux saturation -Sg10	0.17 p.u.
Rotor Type	Salient pole	Main flux saturation -Sg12	0.60 p.u.

The proposed method is compared with the one of the most-known islanding detection methods, the Rate of Change of Frequency (ROCOF). The method was adjusted to four typical settings, which are shown in Table 3. Due to the high sensitivity of ROCOF protection, it can be temporized to avoid unwanted trip due to short circuits. ROCOF4 operates if the voltage remains greater than 0.8 p.u. The ROCOF 1, 2 and 3 do not use any voltage constraint to avoid improper trip in short-circuits.

TABLE 3
RATE OF CHANGE OF FREQUENCY METHODS CONFIGURATION

	ROCOF 1	*ROCOF 2*	*ROCOF 3*	*ROCOF 4*
df/dt (Hz/s)	0.500	1.500	2.500	0.500
Delay (s)	0.150	0.050	0.050	0.150
Voltage constraint (p.u)	-	-	-	0.8

The IEEE 34-bus distribution system, and two load conditions, 100% and 50%, were considered. When the load is 100 %, the loads are the same as described in the test system. When it is 50%, all system loads are reduced to 50% of the original value. Table 4 presents, respectively, the line switched, the load condition, the power generated by the DG, the active and reactive power interrupted by the switching.

Table 4 presents non-islanding load switching tests comprehending distribution system section cut-off localized in different point. In these tests the proposed method and the based on the ROCOF had good performance. Just the ROCOF 2 failed once tripping for a switching of the section 854 – 852, load at 100%, and generation at 1.0 MW.

TABLE 4
CONDITIONS DURING LOAD SWITCHING TEST

O. Line	*Load*	*P_G (MW)*	*P_{OP} (MW)*	*Q_{OP} (MVar)*
854 - 852	100%	2.5	1.511	0.107
834 - 842	100%	2.5	0.565	-0.376
854 - 852	50%	2.5	0.754	-0.381
834 - 842	50%	2.5	0.285	-0.593
854 - 852	100%	1.0	1.507	0.112
834 - 842	100%	1.0	0.563	-0.374
854 - 852	50%	1.0	0.75	-0.375
834 - 842	50%	1.0	0.284	-0.558

As shown in Table 5, the proposed method shows a better performance during islanding. The detection time is 37ms in most cases, much faster than the ROCOF method. The proposed algorithm was successful in cases where all algorithms based on rate of change of frequency failed due to the very low transmitted active power in the switching point, which is 1.6% of the DG nominal power.

Table 6 shows the performance of the methods during a short circuit sustained in the system for 350ms. After this time the fault line is disconnected, thus causing the DG islanding. In Table 6 it can be seen the short circuit bus and the fault resistance. The islanding detection time shown in Table 6 is the difference between the protections trip times and 350ms. In this way, negative times represent protections trip before DG islanding; in other words, they represent failed trips.

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TABLE 5
PERFORMANCE OF ISLANDING DETECTION METHODS DURING ISLANDING EVENTS

Operating characteristic of the System					*Islanding Detection Time (ms)*				
O. Lines	Load	P_G (MW)	P_{OP} (MW)	Q_{OP} (MVar)	Proposed	ROCOF 1	ROCOF 2	ROCOF 3	ROCOF 4
800 - 802	100%	2.5	-0.38	-0.11	37	150	50	50	150
830 - 854	100%	2.5	-75	-0.18	37	150	50	50	150
800 - 802	50%	2.5	-1.32	-0.67	37	150	50	50	150
830 - 854	50%	2.5	-1.61	-0.71	37	150	50	50	150
800 - 802	100%	1.0	1.12	0.13	37	150	50	50	150
830 - 854	100%	1.0	0.72	0.04	37	150	50	50	150
800 - 802	50%	1.0	0.05	-0.31	137	Not det.	Not det.	Not det.	Not det.
830 - 854	50%	1.0	-0.13	-0.49	213	Not det.	Not det.	Not det.	Not det.

TABLE 6
PERFORMANCE OF ISLANDING DETECTION METHODS DURING PHASE TO GROUND SHORT-CIRCUITS, SUSTAINED FOR 350MS, AND FOLLOWED BY ISLANDING

Operating characteristic of the System					*Islanding Detection Time (ms)*				
S.C..Bus	O. Line	Zfault (Ω)	Load	P_G (MW)	Proposed	ROCOF 1	ROCOF 2	ROCOF 3	ROCOF 4
802	802 - 806	0	100%	2.5	37	150	-223	307	Not det.
802	802 - 806	60	100%	2.5	39	150	-230	50	Not det.
816	816 - 824	0	100%	2.5	82	189	323	578	Not det.
816	816 - 824	60	100%	2.5	48	150	-230	Not det.	Not det.
830	830 - 854	0	100%	2.5	120	208	440	Not det.	Not det.
830	830 - 854	60	100%	2.5	66	150	-230	Not det.	Not det.
802	802 - 806	0	50%	2.5	140	401	-223	50	Not det.
802	802 - 806	60	50%	2.5	37	Not det.	-230	50	Not det.
816	816 - 824	0	50%	2.5	145	490	50	50	Not det.
816	816 - 824	60	50%	2.5	37	540	-230	50	Not det.
830	830 - 854	0	50%	2.5	147	490	50	50	Not det.
830	830 - 854	60	50%	2.5	37	527	-230	50	Not det.
802	802 - 806	0	100%	1.0	37	128	-227	-219	Not det.
802	802 - 806	60	100%	1.0	37	150	-229	50	Not det.
816	816 - 824	0	100%	1.0	37	150	50	50	Not det.
816	816 - 824	60	100%	1.0	37	150	-230	50	Not det.
830	830 - 854	0	100%	1.0	37	150	50	50	Not det.
830	830 - 854	60	100%	1.0	37	150	-230	50	Not det.
802	802 - 806	0	50%	1.0	37	123	-300	-221	Not det.
802	802 - 806	60	50%	1.0	37	150	-230	50	Not det.
816	816 - 824	0	50%	1.0	37	150	-223	50	Not det.
816	816 - 824	60	50%	1.0	37	150	-231	-223	Not det.
830	830 - 854	0	50%	1.0	37	150	50	50	Not det.
830	830 - 854	60	50%	1.0	37	150	-231	-222	Not det.

The proposed method did not fail in any simulated case, detecting the islanding in most of the cases in 37ms after the DG islanding. ROCOF 1 failed only once and had some detection time very high, more than 500ms. ROCOF 2 failed in almost all cases, having negative islanding detection times. It means that the algorithm detects the islanding before it happens, that is, during the short circuit. ROCOF 3 failed seven times. It was detected the Islanding during the short circuit in four times and did not trip during real islanding in three cases. ROCOF 4 did not detect islanding because the voltage at Point of Common Coupling was smaller than the constraint voltage.

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In Table 7 it is presented the performance of the algorithms for temporary phase to ground short circuit. The faults are located at different points of the distribution system comprehending downstream (bus 852 and 842) and upstream (bus 830). The short circuits remain during 350 ms and vanish spontaneously without any switching. The proposed algorithm as well as ROCOF 1 and ROCOF 4 worked well in all simulated cases. ROCOF 2 and ROCOF 3 failed respectively in 20 and 3 cases.

Fig. 4 presents the time detection for islanding caused by switching in the bus 802, the interrupted power is changed by a load introduced in the same bus. In the Fig. 4 - A the interrupted reactive power remains zero and active power is changed from 1.6% to 28 % of DG nominal power. It can be seen that the proposed method detects islanding with power mismatch much less than the ROCOF. The shaded area in Fig. 4 represents the NDZ. It is shown that for active power mismatch greater than 1.6% the method operates correctly. In the Fig. 4 - B the active power remains zero and the reactive power is changed from 1.6% to 28%. The ROCOF does not operate for any of the simulated case, however the proposed algorithm has the ability to detect islanding for reactive power mismatch greater than 12%.

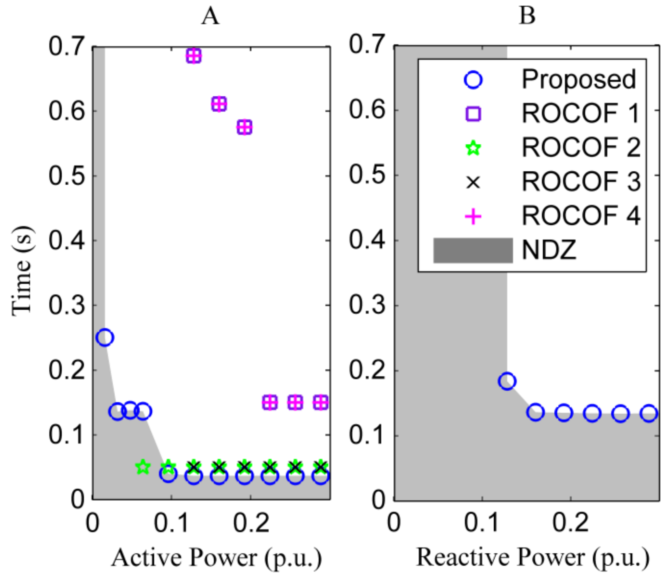

Fig. 4. A - Anti island methods time detection and NDZ for active power variation. B - Anti island methods time detection and NDZ for reatcive power variation

TABLE 7
PERFORMANCE OF ISLANDING DETECTION METHODS DURING TEMPORARY PHASE TO GROUND SHORT CIRCUIT, 350MS

Operating characteristic of the System				*Islanding Detection Time (ms)*				
S.C..Bus	Zfault	Load	P_G (MW)	Proposed	ROCOF 1	ROCOF 2	ROCOF 3	ROCOF 4
830	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
830	60	100%	2.5	Not det.	Not det.	120	Not det.	Not det.
852	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
852	60	100%	2.5	Not det.	Not det.	124	Not det.	Not det.
842	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
842	60	100%	2.5	Not det.	Not det.	125	Not det.	Not det.
830	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
830	60	50%	1.0	Not det.	Not det.	120	Not det.	Not det.
852	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
852	60	50%	1.0	Not det.	Not det.	123	Not det.	Not det.
842	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
842	60	50%	1.0	Not det.	Not det.	124	Not det.	Not det.
830	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
830	60	100%	2.5	Not det.	Not det.	120	Not det.	Not det.
852	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
852	60	100%	2.5	Not det.	Not det.	124	Not det.	Not det.
842	0	100%	2.5	Not det.	Not det.	Not det.	Not det.	Not det.
842	60	100%	2.5	Not det.	Not det.	125	Not det.	Not det.
830	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
830	60	50%	1.0	Not det.	Not det.	119	128	Not det.
852	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
852	60	50%	1.0	Not det.	Not det.	122	Not det.	Not det.
842	0	50%	1.0	Not det.	Not det.	Not det.	Not det.	Not det.
842	60	50%	1.0	Not det.	Not det.	123	Not det.	Not det.

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The methods were also tested for switch of a 0.3 MVAr capacitor located at bus 844, for a loading level of 50% and 100% and for two generation levels of 1 MW and 2.5 MW. None of the methods detected the islanding incorrectly.

To simulate a DG outage, a second generator DG 2 with identical characteristics to the DG 1 has been connected at the bus 854 each generating 1MW. DG 2 is disconnected for two load conditions 50% and 100%. The proposed method, ROCOF 1, ROCOF 4 and ROCOF 3 did not fail in any conditions, the ROCOF 2 failed in both.

V. Discussion

The method proposed in this paper was reliable and safe since it did not trip for non-islanding event; detect islanding condition in less than 40 ms even under lower power mismatch. The Non Detection Zone (NDZ) is less than 1.6 % of the DG nominal power.

The methodology presented in this paper showed significant advances compared with the traditional protection as ROCOF and others recently proposed as [19] and [20]. Compared with the ROCOF, the method is much faster and secure. The improved security avoids unnecessary DG outage and improves the power quality, minimizing the not supplied energy cost. With respect to the papers [19] and [20] the method has faster convergence without loss of security. The improvement in the island detection increases the confidence that no reclosing operation can occur before the DG turn off. In this way, the fast detection avoids out of synchronism reclosing, and consequently, potential damages to generator and other distribution system equipment. Furthermore, it is not possible to apply the fuse saving scheme, when the island is not detected and the DG still feeding a fault.

VI. Conclusion

An efficient and suitable passive island detection method for distribution generation system with synchronous generators has been presented. It is based on the estimation of the synchronous generators oscillation frequency. Differently from the previous algorithms proposed in literature, the proposed method employs a frequency estimation algorithm that requires a small window, and does not calculate the damping coefficient, which usually requires a large time window. Several simulations have been performed for different scenarios with islanding and non-islanding events and the proposed methodology proved to be faster and more sensitive than ROCOF islanding protection. The developed algorithm is able to detect islanding in unbalance power less than 1.6% and up to 40ms, in most cases. The proposed method is able to identify the vast majority of non-islanding events.

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APPENDIX I

Let's consider the frequency deviation from rated value given by (13)

$$\Delta\omega_k = \omega_k - \omega_0 \tag{13}$$

Where, ω_k is the electrical frequency, ω_0 is the rated frequency. Neglecting the damping effect, the frequency deviation (6) can be rewritten in a discretized simplified way as a generic periodic oscillation

$$\Delta\omega_k = A\cos\left(\omega_{osc} k\Delta t - \pi/2\right) \tag{14}$$

Where, k is de time instant, A is the amplitude of oscillation and ω_{osc} is the frequency oscillation. Considering two other delay times N and 2N from k

$$\Delta\omega_{k-N} = A\cos\left(\omega_{osc}\left(k-N\right)\Delta t - \pi/2\right) \tag{15}$$

$$\Delta\omega_{k-2N} = A\cos\left(\omega_{osc}\left(k-2N\right)\Delta t - \pi/2\right) \tag{16}$$

Adding (14) to (16) and dividing by (15)

$$\frac{\Delta\omega_k + \Delta\omega_{k-2N}}{\Delta\omega_{k-N}} = \frac{\cos\left(\omega_{osc} k\Delta t - \pi/2\right) + \cos\left(\omega_{osc}\left(k-2N\right)\Delta t - \pi/2\right)}{\cos\left(\omega_{osc}\left(k-N\right)\Delta t - \pi/2\right)} \tag{17}$$

The solution of (17) for the oscillation frequency is given by

$$\omega_{osc} = \frac{1}{2N\Delta t} a\cos\left(\frac{\omega_k + \omega_{k-2N} - 2\omega_0}{\omega_{k-N} - \omega_0}\right) \tag{18}$$

Or in Hertz

$$f_{osc}(k) = \frac{f_{sampl}}{2\pi N} a\cos\left(\frac{f(k) + f(k-2N) - 2f_0}{2f(k-N) - 2f_0}\right) \tag{19}$$

APPENDIX II

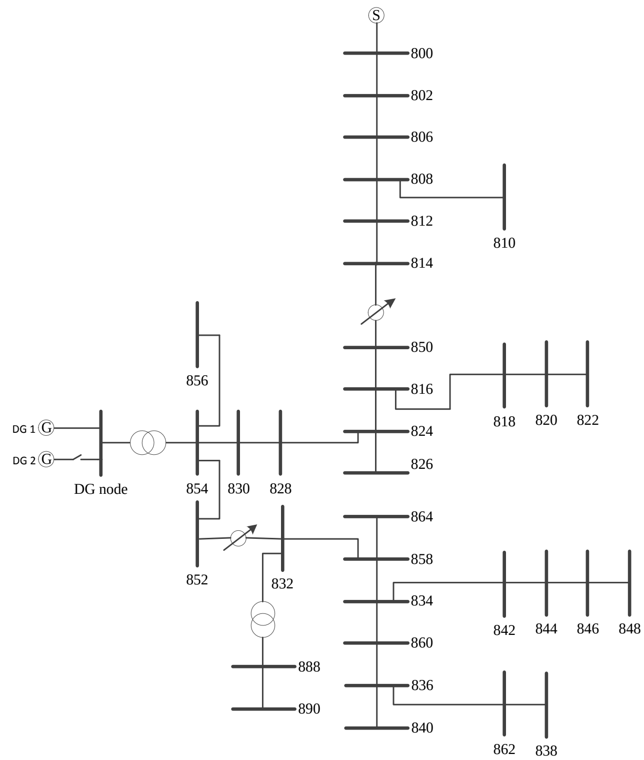

Fig. 5 - IEEE 34 Node Test Feeder [22]

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