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Anti-islanding protection based on voltage and frequency analysis in wind turbines units

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This paper introduces a new islanding detection algorithm method based on voltage and frequency analysis for wind turbines as distributed resource units at the distribution voltage level. The proposed method is based on processing of the rate of change of q-axis component of voltage and accelerates of change of frequency. This method detects the islanding conditions with the analysis of these signals. The studies reported in this paper are based on time-domain simulations using MATLAB, and the feasibility of the proposed method is evaluated with an experimental system. The experimental system parameters are the same as those of the simulated system. The results show that the proposed islanding detection method succeeds in detecting islanding both in the experimental and simulated systems.

Key words: Islanding protection, wind turbine simulator, distributed generation, accelerates of change of frequency (ACOF)-ROCOQA- dq-component.

INTRODUCTION

The increase of distributed resources in the electric utility systems is indicated due to recent and ongoing technological, social, economical and environmental aspects. Distributed generation (DG) units have become more competitive against the conventional centralized system by successfully integrating new generation technologies and power electronics. Hence, it attracts many customers from industrial, commercial, and residential sectors. DGs generally refer to distributed energy resources (DERs), including photovoltaic, fuel cells, micro turbines, and small wind turbines, and additional equipment (Jiayi et al., 2008).

The total global installed wind capacity at the end of 2010 was 430 TWh annually, which is 2.5% of the total global demand. Based on the current growth rates, World Wide Energy Association (WWEA) predicts that, in 2015, a global capacity of 600 GW is possible. By the end of the year 2020, at least 1500 GW can be expected to be installed globally (http://www.renewableenergyworld.com/rea/news/article/2011/05/worldwind-outlook- down-but-not-out). However, connecting wind turbines to distribution networks produces some problems, such as islanding.

Islanding occurs when a DG and its local load become electrically isolated from the utility; meanwhile, the DG produces electrical energy and supplies the local load (Jayaweera et al., 2007) Islanding creates many problems in power systems, and the existing standards thus do not permit DGs to be utilized in islanding mode (Zeineldin et al., 2007). Some of these reasons are the following (Wilsun et al., 2004; Swisher et al., 2001).

(i) Safety hazards for personnel
(ii) Power quality problems for customers load
(iii) Overload conditions of DG
(iv) Out-of-phase recloser connections

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Thus, islanding conditions should be detected within less than 2 s (Wilsun et al., 2004). Originally, the methods of islanding detection were divided into two categories: communication and local. Local methods were classified as active and passive techniques, in which active techniques are based on direct interaction with the ongoing power system operation (Zeineldin et al., 2007). Some important active techniques are impedance measurement (Chowdhury et al., 2009) frequency shift and active frequency drift (Chowdhury et al., 2009), current injection (Guillermo and Reza, 2006), sandia frequency shift and sandia voltage shift (Vinod et al., 2004), and negative phase sequence current injection (Karimi et al., 2008). Passive techniques are based on measurements and information at the local site. Some techniques are under/over frequency or voltage (Chowdhury et al., 2009), total harmonic distortions (http://www.renewableenergyworld.com/rea/news/article/2011/05/worldwind-outlook-down-but-not-out), rate of change of frequency (ROCOF) (El-Arroudi et al., 2007), vector surge and phase displacement monitoring (Kunte and Gao, 2008), rate of change of generator power output (Chowdhury et al., 2009), and the THD technique (Kazemi and Shataee, 2008).

In this paper, a new technique based on rate of change of q-axes component of voltage (ROCOQAC) and accelerate of change of frequency (ACOF) is proposed for islanding detection of wind turbines. The simulation test systems were simulated in MATLAB/SIMULINK using Sim Power System Block Set. The simulation and experimental results show that the proposed islanding detection technique works well to discriminate between switching and islanding conditions.

Proposed technique

ROCOQAC algorithm uses synchronous transformation based phasor estimation of the retrieved instantaneous voltage signals. The signal *x(t)* is represented as follows:

$$X(t) = \sum_{n=1}^{\infty} X_{\max} \cos(n\omega_0 t + \phi_n) \quad (1)$$

Under balanced conditions, each three-phase variable $x_{abc}(t)$ of Equation (1) can be transferred to a stationary $\alpha\beta$ reference frame system by applying the following abc to $\alpha\beta$ transformation:

$$x_{\alpha\beta} = x_a e^{j0} + x_b e^{j2\pi/3} + x_c e^{-j2\pi/3} \quad (2)$$

Where $x_{\alpha\beta} = x_\alpha + jx_\beta$, in order to calculating dq parameters can be used of Equation (3):

$$x_d + jx_q = x_{\alpha\beta} e^{-j\theta} \quad (3)$$

where θ calculated by:

$$\theta = \arctan \frac{x_\beta^{ref}}{x_\alpha^{ref}} \quad (4)$$

One of the excising algorithms for detection of islanding is based on accelerates of change of frequency (ACOF). In this method, Frequency of DG unit is regularly measured and accelerates of change of Frequency is calculated the ACOF, is calculated as:

$$ROCOF = \frac{d^2 f}{dt^2} \quad (5)$$

Islanding condition can be detected by comparison of value of ACOF with a threshold. However, this method is not reliable. Islanding and some other events, such as switching of motors and capacitor banks, may have similar effect on *ACOF*, thus the algorithm may take incorrect decision and interrupt the production of DG in a wrong way.

Here, we propose a new algorithm that employs both ACOF and ROCOQAC in order to detect the islanding event. Figure 1 shows algorithm of the proposed method. In the first step, the frequency of load voltage is measured for ten cycles (0.2 s); ACOF is calculated afterwards. The accelerate of change of frequency is calculated by Equation (5). In next step, ACOF has been compared with its threshold values. If the value of ACOF in some portions of the measurement period (0.2 s) exceeds the threshold value then, ROCOQAC will be calculated and if its value exceeds from its threshold too, in this case islanding will be detected. In other cases when one of them doesn't exceed from their threshold, system will be continue to power production (Figure 1). In this study the threshold value of ACOF set to 75 mHZ/S2 and ROCOQAC threshold value set to 250 V/sec.

Case study

Figure 2 shows a schematic diagram of a wind turbine unit. The DG unit is a wind turbine induction generator, and a capacitor bank is used to improve the power factor. The local load is a three-phase parallel RL before the circuit breaker (CB), in which "r" denotes the series resistance inductance and V_f indicates the voltage drop across the parallel load. The parallel RL is conventionally adopted as the local load for the evaluation of islanding detection methods when the load inductance is tuned to the system frequency. This system, as shown in Figure 2, is connected to a point of common coupling (PCC) with a step-up transformer. To obtain the experimental results, a wind turbine simulator, as shown in Figure 3, was implemented. Figure 4 shows the implemented simulator system. The implemented system parameters are given in Table 1. The parallel load inductance is considered infinite. Thus, the parallel load is only a resistance, and hence the unit of "L" is "inf". Figure 5 shows the motor saturation curve. In the grid-connected condition, the switches SW1 and SW2 are closed. The islanding condition occurs when SW2 is open. The voltage and frequency of DG should have admissible values in both grid-connected and islanded modes. In the grid-connected mode, the voltage magnitude and frequency of the local load at the PCC are regulated by the grid.

Implementation and simulation results

In this study, the simulation is conducted in four scenarios to illustrate the effectiveness of the proposed method.

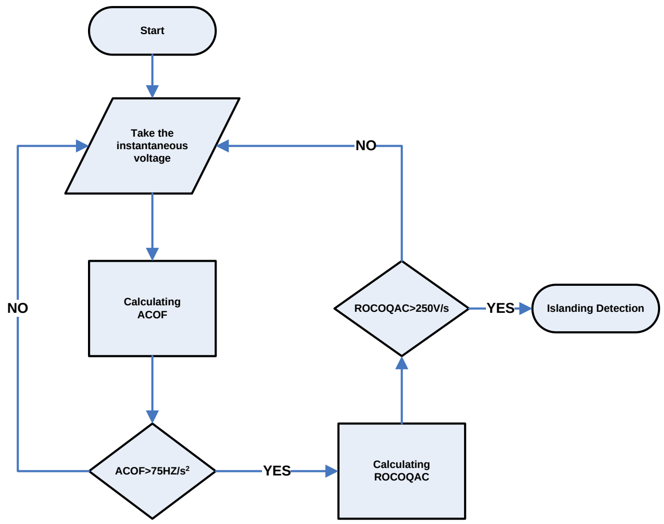
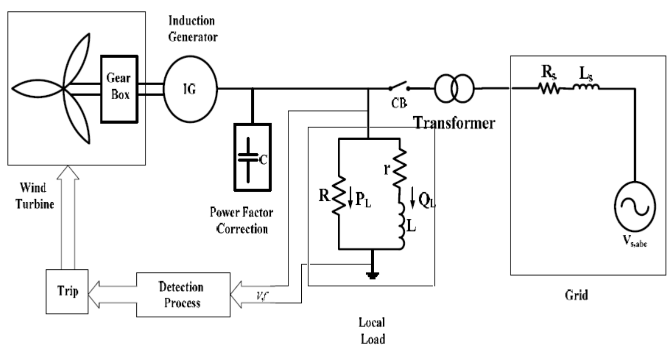


Figure 1. Proposed algorithm in order to islanding detection.



Figur 2. Single line diagram of study system.

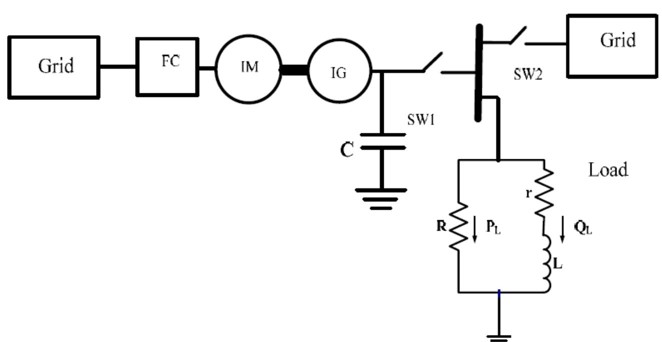


Figure 3. Single line diagram of implementation system in order to islanding condition detection.

Load condition 1

In this case, the load as shown in Figure 2 is set to the values given in Table 1. The DG is connected to the grid and works in grid-connected mode. At t=2 s, the CB is opened, and the system enters islanding mode. Figure 6 shows the dynamic response of the system prior, during and subsequent to the islanding event. Figure 6(a) and

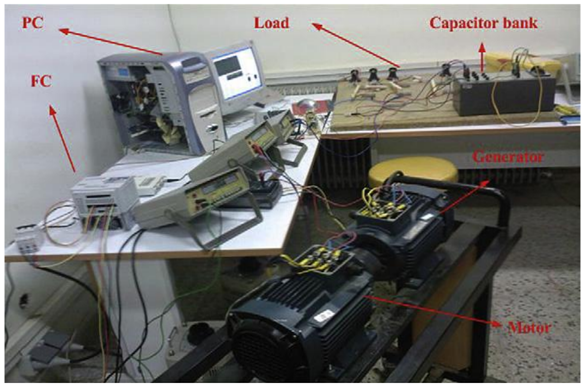


Figure 4. Implementation system in order to islanding condition detection.

Table 1. Parameters of the implemented system.

Parameter		Value
	Sn	2KVA
	Vn	400V
	f	50HZ
Induction motors	PF	0.78Lag
	Rs, Rr	2.3541Ω
	Lr, Ls	0.01678H
	Lm	0.275H
Local load	R	180Ω
	L	Inf
Capacitor	C	36.75 µF

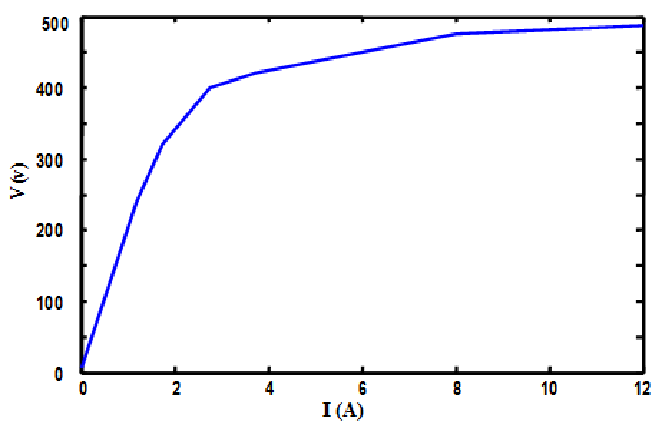


Figure 5. Motor and generator saturation curves.

(b) shows the Δf and voltage of the load and demonstrates that they have no main change prior to the islanding and after the islanding condition. Figure 6(c) shows the ACOF and Figure 6(d) depict the ROCOQAC. According to these figures, at t=2.18 s, the ACOF increases from threshold value. And at t=2.03 s the

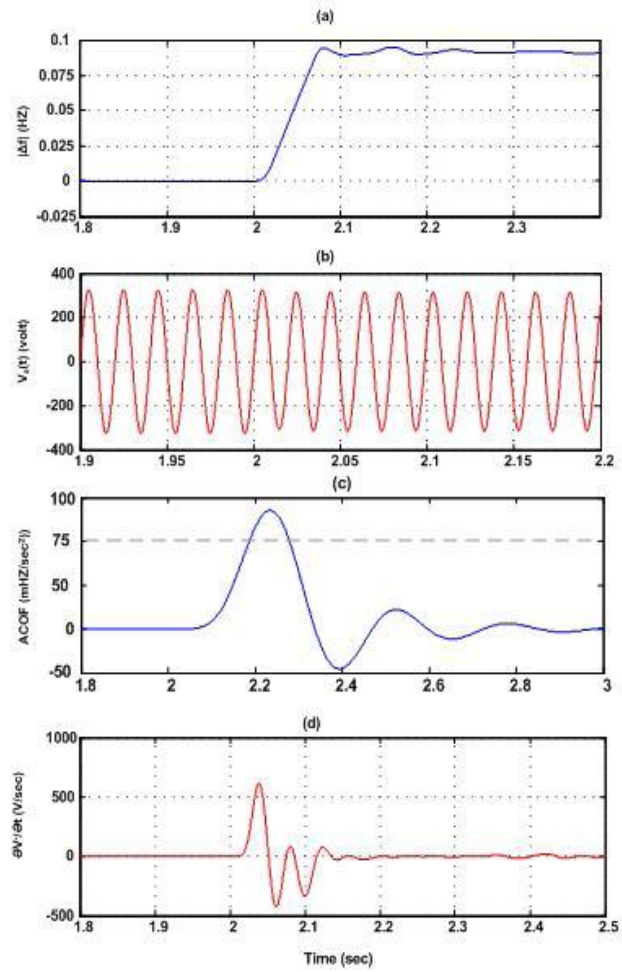


Figure 6. Dynamic response of the simulation system in load condition 1, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

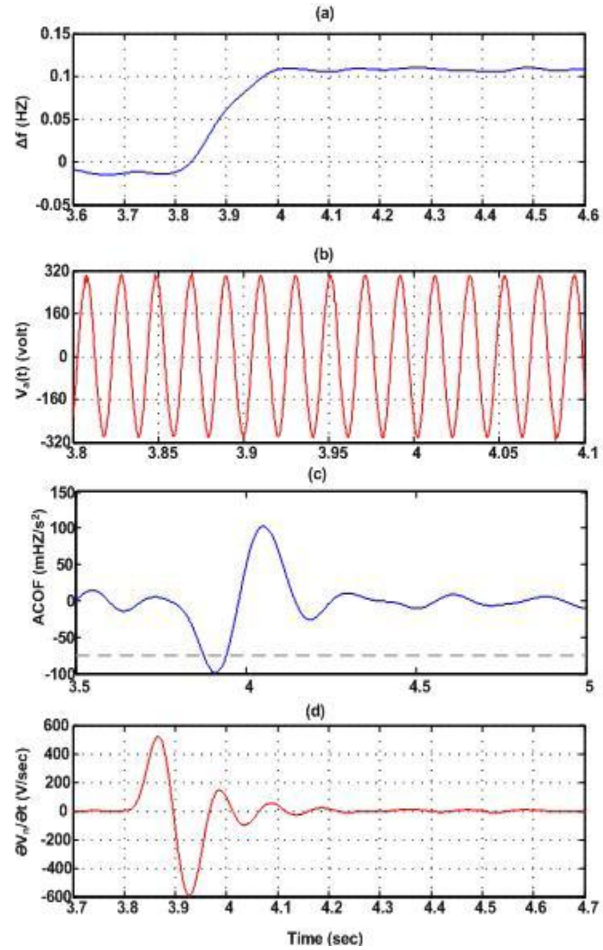


Figure 7. Dynamic response of the experimental system in load condition 1, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

ROCOQAC increases from threshold too. Therefore, the proposed method detects the islanding. In Figure 7, the experimental results for the nominal load are depicted. In the experimental case islanding occurred at t=3.75s. Figure 7(a) shows the Δf of the load and demonstrates that is almost fixed prior to the islanding. Figure 7(b) depicted the instantaneous voltage of phase-a at the PCC. According to these figure the voltage of utility is fixed before islanding, and after islanding. Figure 7(c) and (d) shows the ACOF and ROCOQAC respectively. As shown, the ACOF is increased from the threshold value at t = 3.88s and ROCOQAC increased from the threshold value at t = 3.84s, which leads to islanding detection.

Load condition 2

The system shown in Figure 2 operates in a grid-connected mode. The load absorbs 200 W of real power from the grid and sends 140 var reactive power to the grid and 600 W real powers from the DG. The load parameters are R = 180.5 Ω, L = 3H and C = 40 mF. An islanding event occurs at t=2 s and is detected at t=2.175 s with the ACOF and ROCOQAC (Figure 8c and d). The islanding detection time is shorter than in the previous case study. The voltage magnitude at the PCC and the islanded system frequency change rapidly, but these values do not deviate from their acceptable limits. Figure 8 shows the results of this condition in the simulated system. According to Figure 8(b), the value of the voltage is decreased after islanding, and the frequency of the system, as shown in Figure 8(a), is increased.

The results for the experimental system are depicted in Figure 9. Figure 9(a) and (b) illustrate the Δf and voltage of the load respectively. The voltage of utility is decreased after islanding. Figure 9(c) and (d) shows the ACOF and ROCOQAC values respectively. In this case, at t = 1.2 s, islanding occurs and is detected at t = 1.37 s.

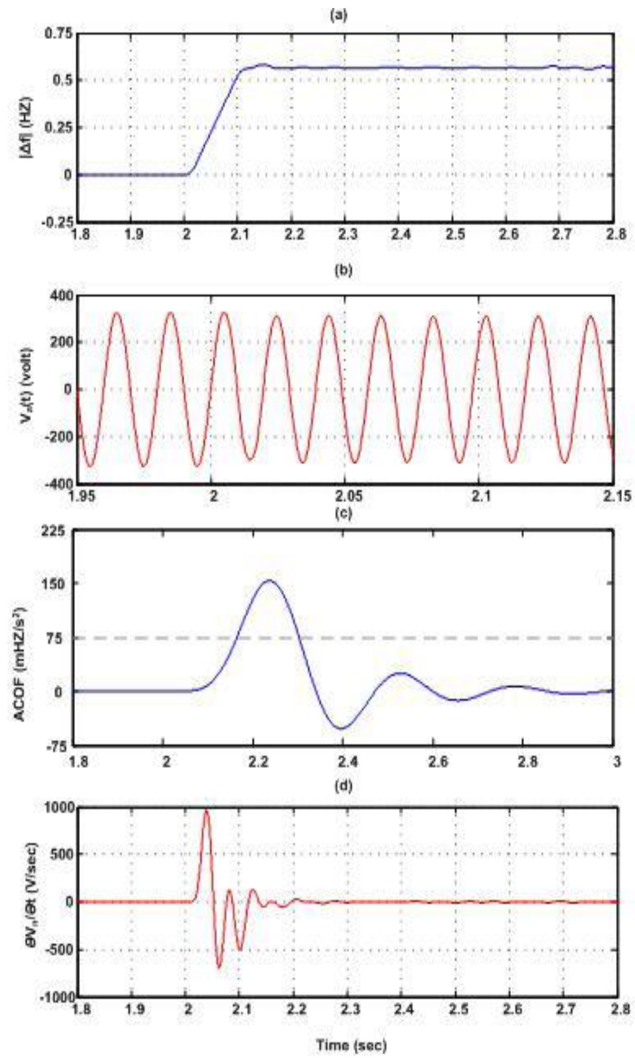


Figure 8. Dynamic response of the simulation system in load condition 2, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

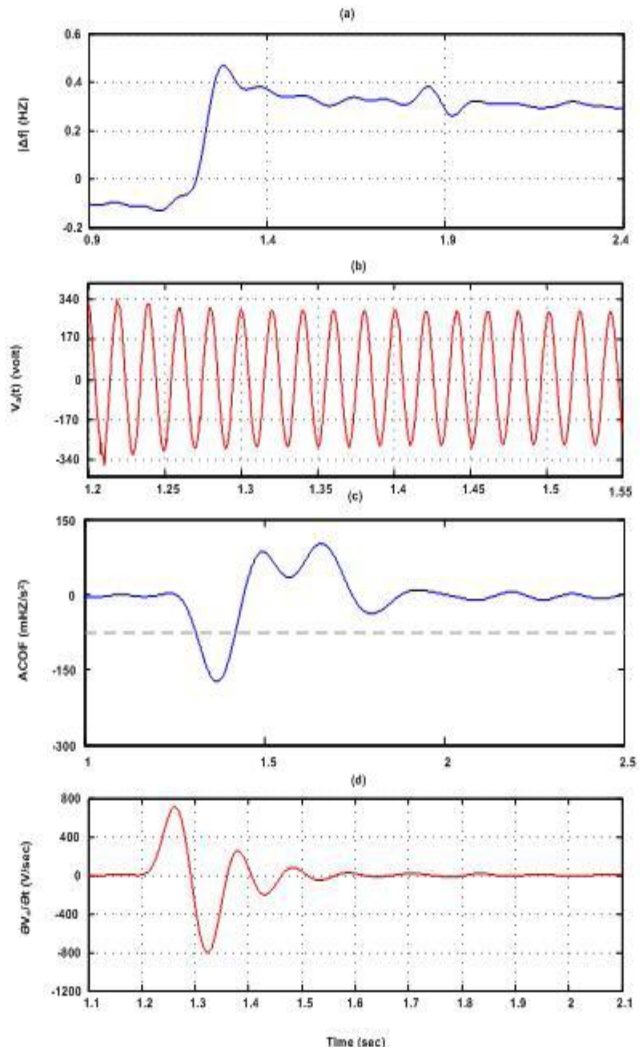


Figure 9. Dynamic response of the experimental system in load condition 2, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

Motor starting condition

The starting of large induction motors may cause a malfunction of the islanding detection algorithm. To study the reliability of the proposed algorithm, a 1.5 kW induction motor is connected to the PCC via a switch in the non-islanding case. The simulation results of the induction motor starting are shown in Figure 10, and the experimental results of this condition are shown in Figure 11. At t = 1.5 s, the induction motor was started. The values of frequency and voltage nearly fixed, as shown in Figure 10(a) and (b) respectively, Figure 10(c) shows the ACOF value that its value does change but the value does not exceeds from threshold value at this time and Figure 10(d) shows the ROCOQAC value is not sensitive to motor switching, and its value does not large change within this time. Therefore, the proposed method does not send a trip and works in a reliable mode. In the experimental mode, the switching of the motor occurred at t = 1.0 s, and the voltage of the PCC decreased at this time as shown in Figure 11 (b). The voltage of grid in this study is 375 V and, at the instant of switching, decreased to 360 V. According to Figure11(c) and (d), it is obvious that the experimental results and simulation results prove the reliability of the proposed method.

Capacitor bank switching condition

Large capacitor bank switching in distribution power systems initiates disturbances. These disturbances are propagated in the distribution system and have some

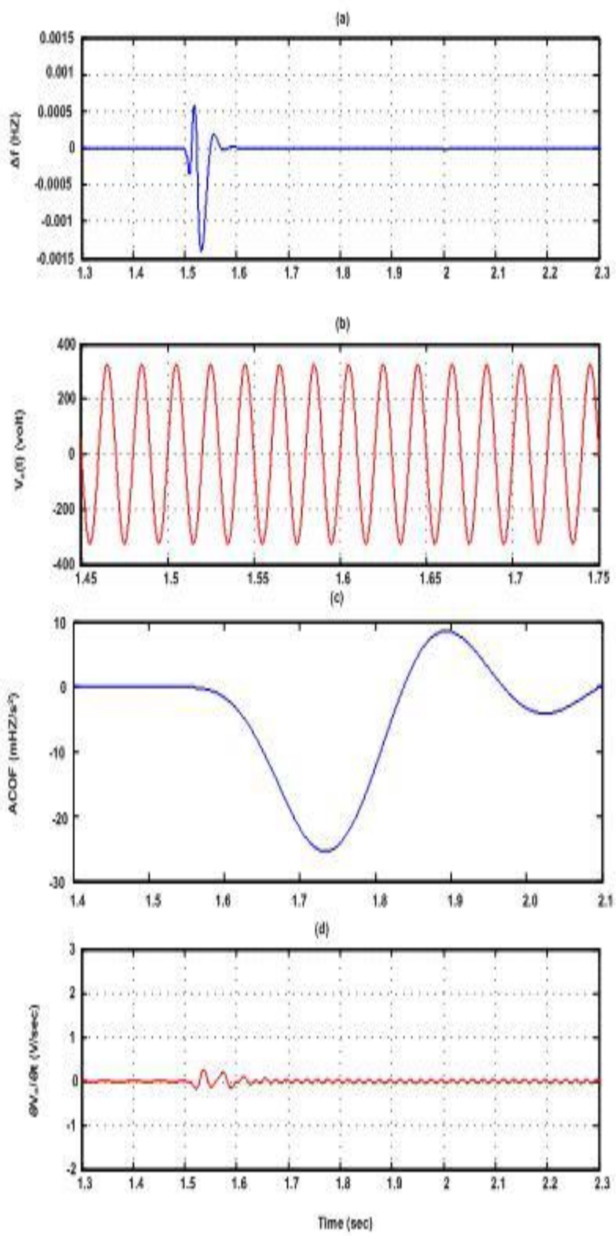


Figure 10. Dynamic response of the simulation system in motor starting condition , a) frequency of PCC, b) Instantaneous voltage of phase-a, c) accelerate of change of frequency, d) rate of change of q-component of voltage.

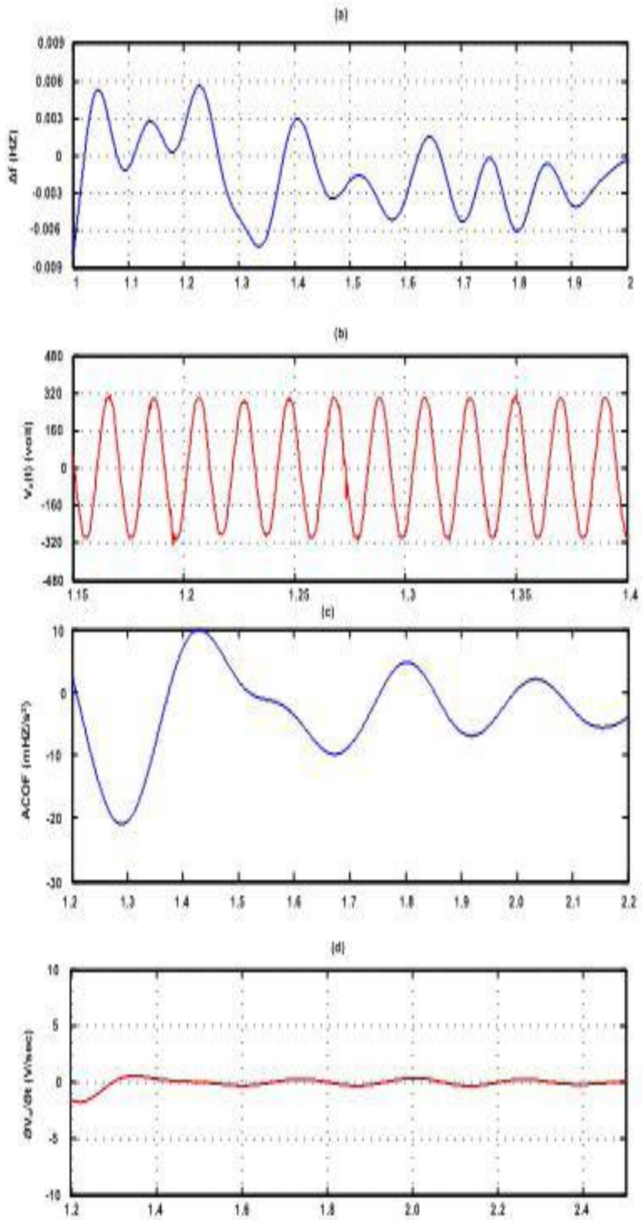


Figure 11. Dynamic response of the implementation system in motor starting condition , a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

effects on the proposed method. To test the proposed algorithm, a large 2 kvar capacitor bank was switched at the PCC in the non-islanding case. This switching occurred at t = 1.5 s. The results for simulation system are shown in Figure 12. At the switching time, the voltage and frequency are almost constant. Figure 12 (c) and (d), shows that the ACOF and ROCOQAC do not change in this condition. The results show that ACOF and ROCOQAC do not have any sensitivity to the switching condition, and the proposed method works perfectly. The experimental results are described in Figure 13. A 2 kvar capacitor bank was switched at t = 2 s. The results confirm the simulation results.

Conclusion

This paper presents a new method based on frequency and voltage analysis (ACOF and ROCOQAC) for the islanding detection of wind turbines. The proposed

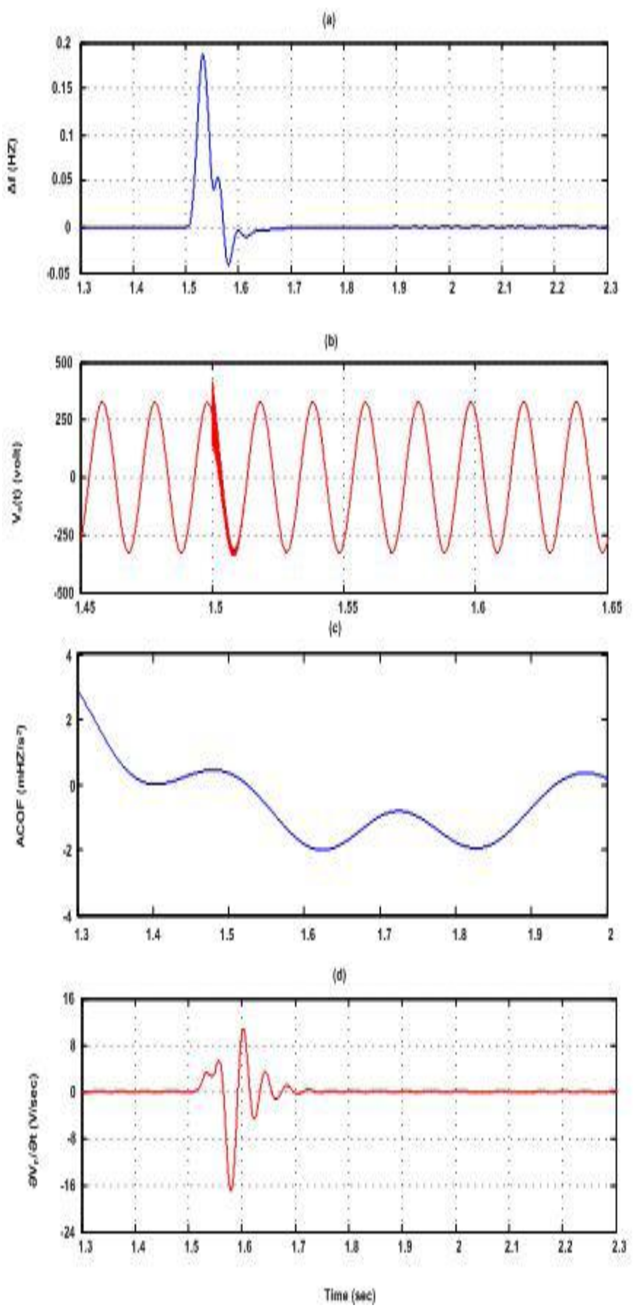


Figure 12. Dynamic response of the simulation system in capacitor switching condition, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

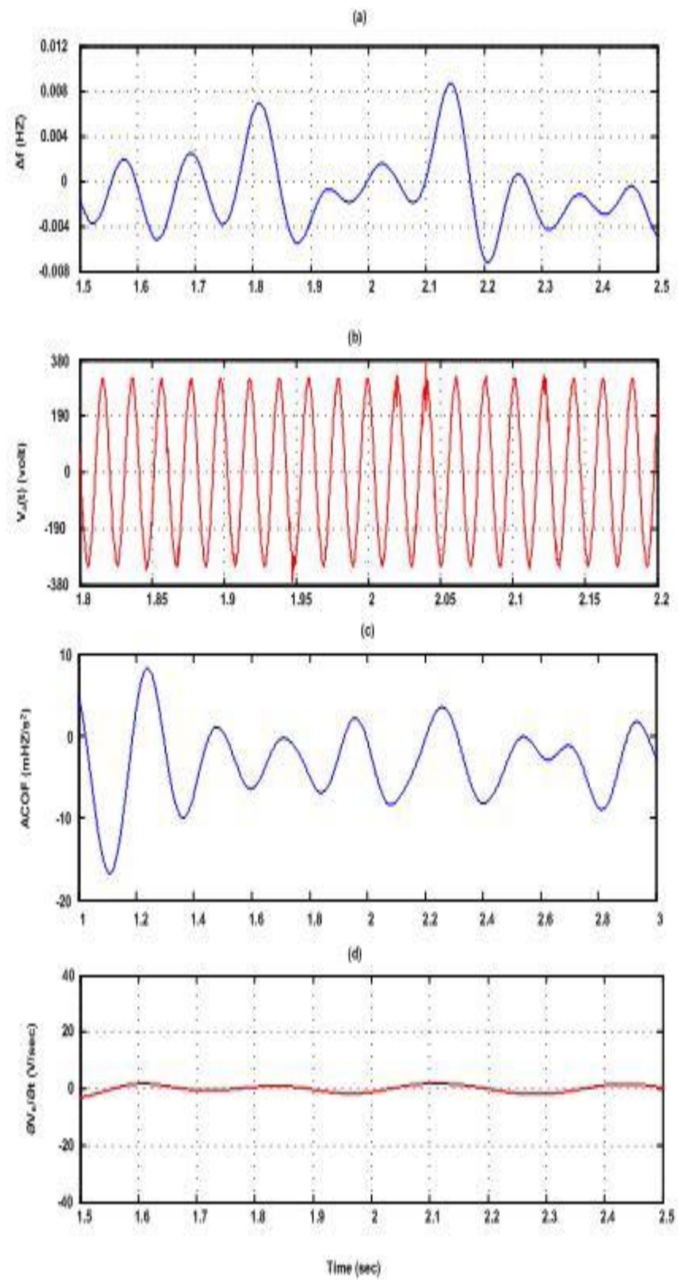


Figure 13. Dynamic response of the implementation system in capacitor switching condition, a) frequency of PCC, b) Instantaneous voltage of phase-a , c) accelerate of change of frequency, d) rate of change of q-component of voltage.

method was simulated and implemented on a wind turbine simulator. The results show the suitable reliability of the proposed method under different load conditions, such as capacitor bank switching and motor starting. Under these conditions, islanding detection is difficult. The method was able to detect the islanding condition of an induction generator type of a wind turbine within less than 0.2 s.

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