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Implementation of ROCOPS Method for Anti-Islanding Protection of Wind Turbine

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Abstract

In recent years, based on the growing importance of clean energy in comparison with conventional energy production from fossil fuels, DG systems are gradually becoming more popular all over the world. These resources solve many problem of system. However, these resources create some other problems too. One of the most problem of DGs is unwanted islanding. This paper addresses reliable passive islanding detection algorithm based on the change of positive sequence (ROCOPS) of voltage signal analysis method. At first, all possible linear and nonlinear load switching, motor starting and capacitor bank switching is simulated. The ROCOPS signal of these conditions is measured for all conditions. From of these data, the reliable value of ROCOPS based on thresholding is calculated. 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 is a test system that impalement for islanding condition detection. The results show that the proposed islanding detection method succeeds in detecting islanding both in the experimental and simulated systems with negligible Non Detection Zone (NDZ).

Keywords: Islanding Detection, ROCOPS, Wind Turbines, Wind Turbine Simulator, Thresholding, Non-Detection Zone.

1. Introduction

Rapid technological developments in generation and storage of energy, the growing concern on environmental issues, increasing prices of oil and natural gas and global warming led to great affirmation on alternative energy sources such as solar and wind [1]. Increasing of clean energy is caused DG systems are gradually becoming more popular all over the world. Further, the DG systems increase energy efficiency and improve power quality of the distribution network [2]. However, installing DG in power systems may create some problems [3-4]. One of these problems is unwanted islanding. The islanding condition occurs when a portion of the utility system that contains both load and DG remains energized while it is isolated from the remainder of the utility system [3]. IEEE standard recommends disconnecting all DGs within 2 s after the formation of unwanted island [5].

Islanding detection techniques can be classified in three major groups include passive, active and remote methods [6]. Remote detection techniques are based on communication between the utility and the DGs. These schemes include power line signaling [7] and transfer trip [8]. Although these techniques may have better reliability than active and passive techniques, they are expensive to implement and hence uneconomical.

Active techniques are based on applying a disturbance into distribution systems and forcing the islanded system to become unstable. Some active islanding detection approaches include active and reactive power variation [9, 10], sandia frequency shift and sandia voltage shift [11, 12], impedance measurement, frequency shift and active frequency drift [13], current injection [14], reducing the injected current periodically and monitoring the voltage [5], high-frequency signal injection [15], virtual capacitor [16] and virtual inductor [17],

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phase-PLL perturbation [18], slide-mode frequency shift [19], active frequency drift or frequency bias [20, 21]. The most of these techniques are employed to inverter-based distributed generations and advantage of these methods is their relatively small Non Detection Zone (NDZ). However, the main challenges of these methods are power quality problems and designing the complicated control circuit.

In Passive techniques certain system parameters such as voltage, frequency and etc are measured and the islanding is detected through data processing. One of the simplest passive methods in islanding detection is over/under voltage and frequency. In match condition of load and generation, the change in system parameters might be very small and within the thresholds, thus leading to an undetected islanding situation [3]. Some other passive techniques are total harmonic distortions [22], rate of change of frequency [13], phase displacement monitoring, vector surge [23], rate of change of generator power output [13], rate of change of phase angle derivation [24] and Wavelet energy [25] and S-Transform methods [26]. The main challenges of passive techniques are large NDZ and threshold selection. If the threshold for permissible disturbance in these quantities is set to a low value, then nuisance tripping becomes an issue, and if the threshold is set too high, islanding may not be detected.

This paper presents a novel algorithm based on ROCOPS of voltage signal for islanding detection of wind turbine distributed generations. In order to verify the proposed strategy an implemented wind turbine simulator system is test using proposed strategy. This method could be reduced the NDZ as it possible. Also, in order to overcome to threshold challenge, the thresholding method is used for detection process. At first, all of ROCOPS signal of positive sequence voltage is measured for any switching and islanding condition of study system. From of these values, threshold value is calculated based on thresholding method. After that, for other islanding and non-islanding conditions the proposed strategy system is tested. Reduction of NDZ, Avoidance of threshold selection, dominance of power quality problem using signal processing and test method on implemented system are mainly ability of proposed strategy.

The proposed detection algorithm is applied on wind turbine system which is simulated in MATLAB/Sim Power System. Also, the feasibility of the proposed method is evaluated with an experimental system. The experimental system is a simulator wind turbine system. The obtained detection results for any islanding and switching conditions, shows the efficiency of the proposed approach.

2. Systems Description

Figure 1 shows a schematic diagram of a simulated wind turbine unit. The DG unit is represented by a wind turbine and induction generator, a capacitor bank used in order to power factor correction of DG unit. The local load is represented by a three-phase parallel RL before of circuit breaker (CB). A parallel RL is conventionally adopted as the local load for evaluation of islanding detection methods when the load inductance is tuned to the system frequency. This system, as represented in Fig.1, equally connected to point of common coupling (PCC) with step-up transformer. In order to obtain the experimental results, a wind turbine simulator as Fig 2 was implemented. Fig 3 shows the implemented simulator system. Parameters of the implementation system are given in Table 1. and motors saturation curves shown in Fig 4. In grid-connected condition the switches SW1 and SW2 are closed. Island condition is occurred when SW2 is open.

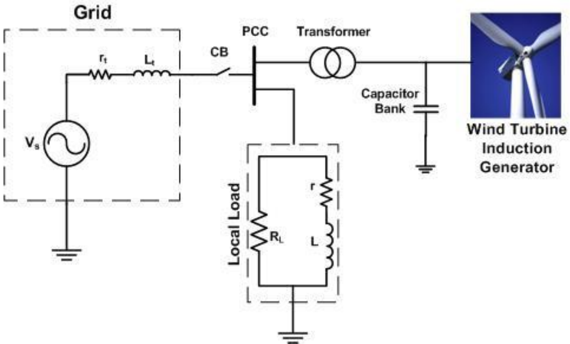

Fig.1. Single line diagram of study system

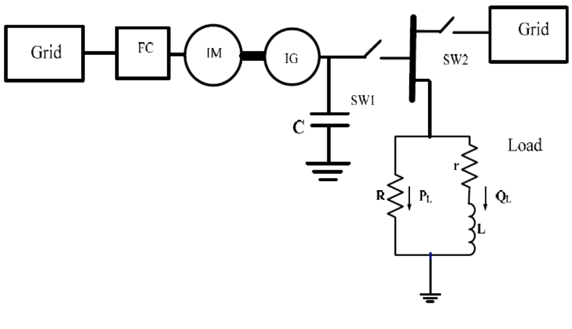

Fig 2.single line diagram of implementation system in order to islanding condition detection

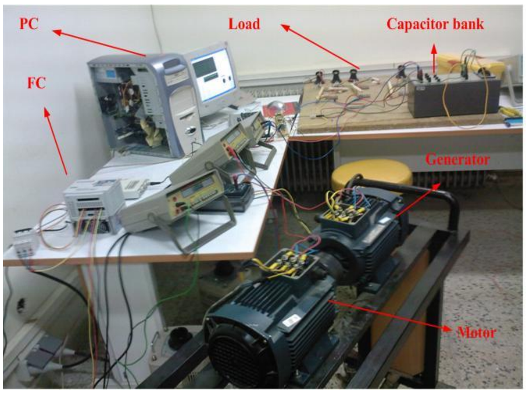

Fig 3: Implementation system in order to islanding condition detection

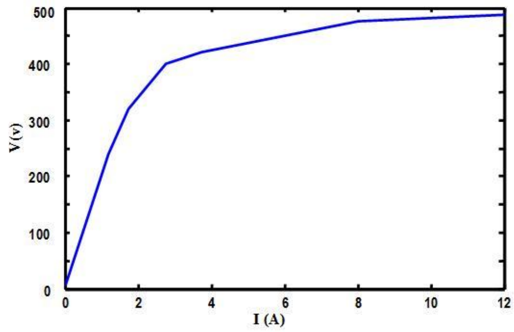

Fig 4.Motor and Generator saturation curves.

Voltage and Frequency of DG should be remaining in admissible values in both grid-connected and islanded modes. In grid-connected mode, the voltage magnitude and frequency of the local load, at PCC, are regulated by the grid.

Table.1
Parameters of implemented system

Parameters	Value	
Induction Motors	Sn	2 kVA
	Vn	400 V
	f	50 Hz
	PF	0.78 Lag
	Rs, Rr	2.3541 Ω
	Lr,Ls	0.01678 H
	Lm	0.275 H
Local Load	R	180 Ω
	L	Inf
Capacitor	C	36.75 F

3. Mathematical model

This section gives a brief overview of state space model, step time response of study systems.

By considering balanced condition for islanded system (Fig. 1), the circuit model of self excited induction generator with fixed wind speed simple model model are shown in fig 1. From of this figure, it is obvious that the model of two systems can be described as same. Therefore in this section the mathematical model of switching based DG is described and generalized for other systems. It is assumed that the DG unit and the local load are balanced three-phase subsystems within the island. In balanced three-phase subsystems within the island, the state-space model of switching based DG system in the $\alpha\beta$ -frame, dynamic model is:

Place of Fig.5

The state space model of the study systems in islanding mode described as standard form:

$$\dot{X}(t) = AX(t) + BU(t) \qquad (1)$$
$$Y(t) = CX(t) + DU(t)$$

Which, the ABCD matrix of state-space model can be defined as follow:

$$A = \begin{bmatrix} -\frac{R_t}{L_t} & \omega_0 & 0 & -\frac{1}{L_t} \\ \omega_0 & -\frac{R_l}{L} & -2\omega_0 & (\frac{R_l C\omega_0}{L} - \frac{\omega_0}{R}) \\ 0 & \omega_0 & -\frac{R_l}{L} & (\frac{1}{L} - \omega_0^2 C) \\ \frac{1}{C} & 0 & -\frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \qquad (2)$$

$$B^T = \begin{bmatrix} \frac{1}{L_t} & 0 & 0 & 0 \end{bmatrix} \qquad (3)$$

$$C = [0 \quad 0 \quad 0 \quad 1] \qquad (4)$$

$$D = [0] \qquad (5)$$

$$X^T = [i_{td} \quad i_{tq} \quad i_{Ld} \quad v_d] \qquad (6)$$

With considering $u(t) = v_{td}$, figure 6 shows the step response of system in the islanding mode. The response time constant of the islanding system is selected as the analyzing time of wavelet analysis window.

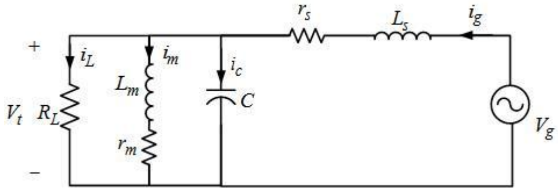

Fig 5: Simple model of case study

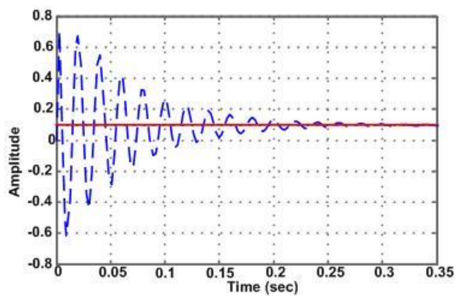

Fig. 6: Step response of wind turbine system

From of Fig. 6, the transient response time of switching based DG is about 0.04 seconds, and wind turbine about 0.2 second. We consider 0.2 seconds of histogram of ROCOPS data for wind turbine to achieve reliable detection from the step response process.

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4. Proposed Technique

Here a new algorithm for detection of islanding is based on Rate of Change of positive sequence (ROCOPS) of load voltage and thresholding method is proposed.

4.1. Thresholding Method

We introduce a measure for calculating the difference between two ROCOPS signals magnitude for islanding and non-islanding conditions and call it IROCOPS and NIROCOPS, respectively.

For each possible of the islanding cases the ROCOPS values are calculated and reported. Similarly for each possible of the non-islanding cases the ROCOPS values are calculated and reported.

The average value of ROCOPS is greater than the average value of all ROCOPS. This difference between islanding and switching values is motivated us to introduce an approach to classify an unknown condition, based on the calculation of ROCOPS (for known islanding or non-islanding cases), into islanding cases or non-islanding cases.

Suppose that we have NI known islanding cases and NN known non-islanding cases, these cases are the training cases of the proposed method, and then we can calculate (NI×NN) possible ROCOPS values. All of the ROCOPS values are sorted and the magnitude of them is considered. It is expected that the magnitude of ROCOPS will be separated in islanding and non-islanding conditions. Thus, a proper threshold value, we call it k*, separate the ROCOPS magnitudes into two groups.

The value of k* can be found by an appropriate thresholding method such as Otsu method [?]. For an unknown case if its ROCOPS is accessible, by Comparing of the value of k* with threshold we can determine the condition of the unknown case.

4.2. ROCOPS Method

Under balanced conditions, each three-phase variable xabc (t) can be transferred to a stationary reference frame system by applying the following transformation [14]:

$$x_p = x_a e^{j0} + x_b e^{-j\frac{2\pi}{3}} + x_c e^{+j\frac{2\pi}{3}} \tag{7}$$

x_p is positive sequence of x. Therefore, the vabc in stationary reference frame is:

$$v_p = v_a e^{j0} + v_b e^{-j\frac{2\pi}{3}} + v_c e^{+j\frac{2\pi}{3}} \tag{8}$$

We propose a new algorithm that employs ROCOPS to detect the islanding event. Figure 7 shows algorithm of the proposed method. In the first step, the voltage of load voltage is measured and ROCOPS is calculated afterwards. The ROCOPS is calculated as given in equations (9).

$$ROCPS = \frac{\partial v_p}{\partial t} \tag{9}$$

In next step, ROCOPS have been compared with their threshold values. If the value of any of this parameter exceeds the threshold value, islanding has been happened when the ROCOPS is higher from threshold value.

In this study system in first, voltage signal of the load is measured. And then this voltage signal passed from the low-pass filter in order to expurgate the high frequency harmonics of voltage signal. Then, with ROCOPS given of this signal and comparison with threshold value, it is detected that the islanding is occurred or not. Fig 7 shows the proposed algorithm of this method.

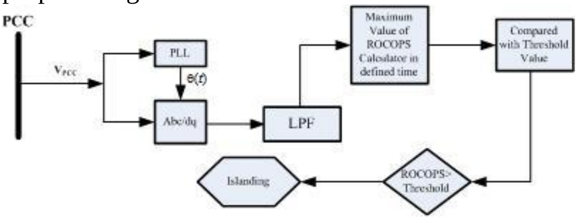

Fig 7. Proposed algorithm in order to islanding detection

5. Experimental and Simulation Results

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

5.1 Islanding Scenario test (Case 1)

In this case, the load as shown in Fig. 1 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. Fig. 8 shows the dynamic response of the system prior, during and subsequent to the islanding event. Fig. 8(a) shows the frequency changing of the load and demonstrates that it has no main change prior to the islanding and after the islanding condition. Fig. 8(b) shows the instantaneous voltage of phase-a at the PCC and Fig 8(c) depict the ROCOPS of load voltage. According to these figures, at t=2.03 s, the ROCOPS increases from threshold value. Therefore, the proposed method detects the islanding. In Fig. 9, the experimental results for the nominal load are depicted. In the experimental case islanding occurred at t=3.8s. Fig. 9(a) shows the frequency changing of the load and demonstrates that is almost fixed prior to the islanding. Fig.9 (b) shows the instantaneous voltage of phase-a at the PCC. According to these figure the voltage of utility is fixed before islanding, and after islanding. Fig. 9(c) shows the ROCODPS. As shown, the ROCOPS is exceed from the threshold value at t = 3.93s, which leads to islanding detection after 0.13 s.

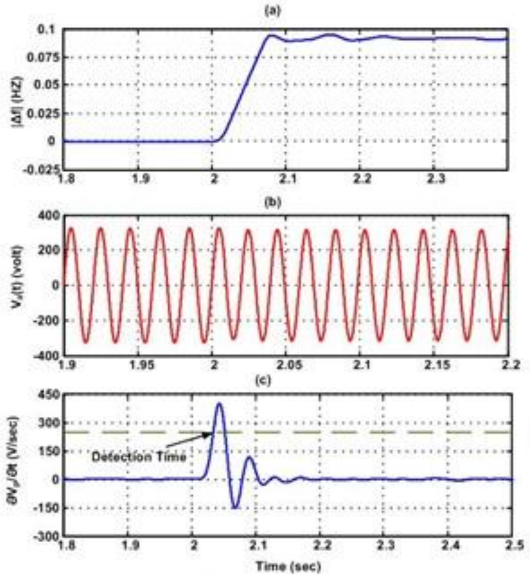

Fig 8: dynamic response of simulation system, a)frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

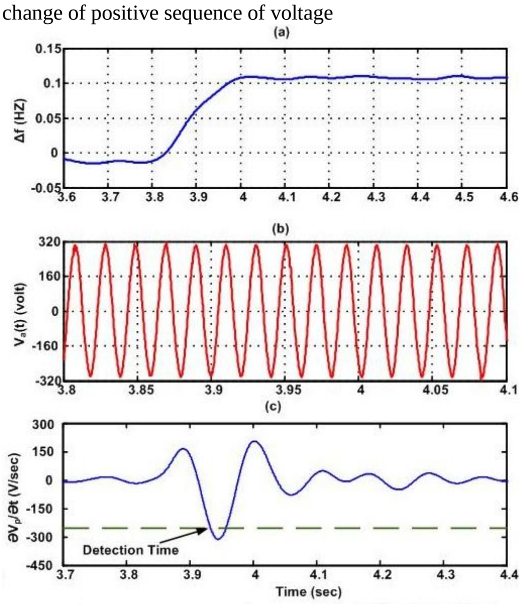

Fig 9: dynamic response of experimental system, a)frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

5.2 Islanding Scenario test (Case 2)

The system shown in Fig. 1 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. As shown, the ROCOPS is exceed from the threshold value at t = 2.02s, which leads to islanding detection after 0.02 s.. 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. Fig. 10 shows the results of this condition in the simulated system. According to Fig. 10(b), the value of the voltage is decreased after islanding, and the frequency of the system, as shown in Fig. 10(a), is increased.

The results for the experimental system are depicted in Fig. 11. Fig. 11(a) shows the frequency changing of the load. Fig. 11(c) shows the ROCOPS value. In this case, at t = 2.7s, islanding occurs and is detected at t = 2.81 s. Fig. 11(b) shows the instantaneous voltage of phase-a at the PCC. The voltage of utility is decreased after islanding.

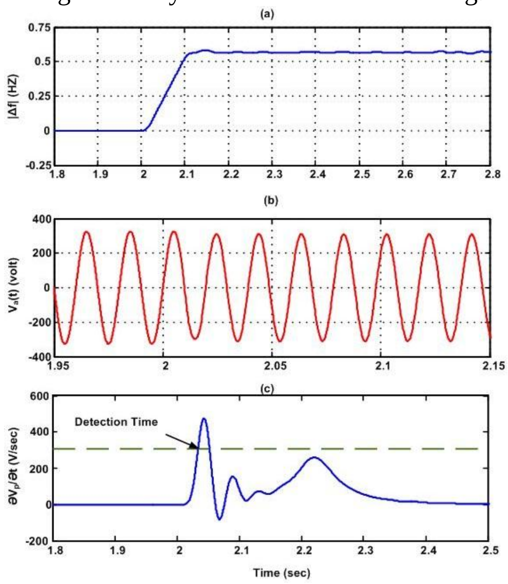

Fig 10: dynamic response of simulation system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

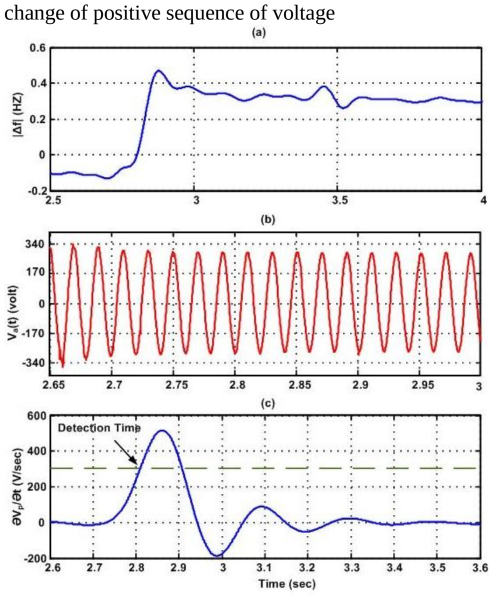

Fig 11: dynamic response of experimental system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

5.3 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 Fig. 12, and the experimental results of this condition are shown in Fig. 13.

At t = 1.5 s, the induction motor was started. Then the RMS voltage of the PCC decreased the values of frequency and voltage nearly fixed, as shown in Fig. 12(a) and Fig. 12(b) respectively, Fig. 12(c) shows the ROCOPS value does change but the value does not exceeds from threshold value at 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 = 1.2 s, and the voltage of the PCC decreased at this time as shown in Fig. 13 (b). The voltage of grid in this study is 375 V and, at the instant of switching, decreased to 360 V. According to Fig. 13 (c) it is obvious that the experimental results and simulation results prove the reliability of the proposed method.

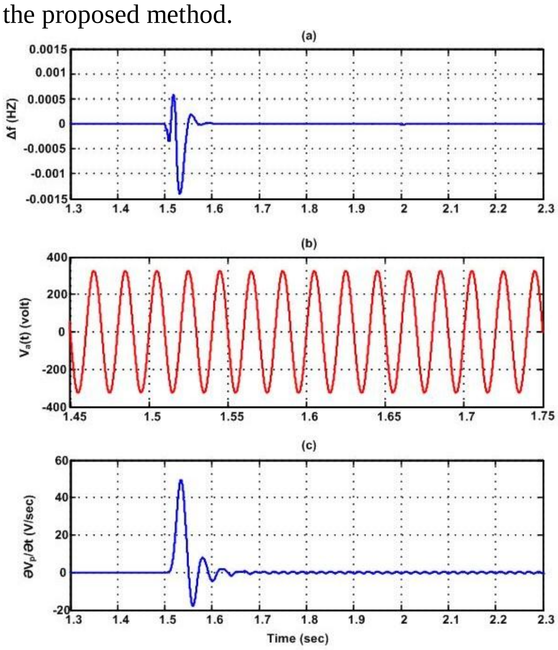

Fig 12: dynamic response of simulation system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

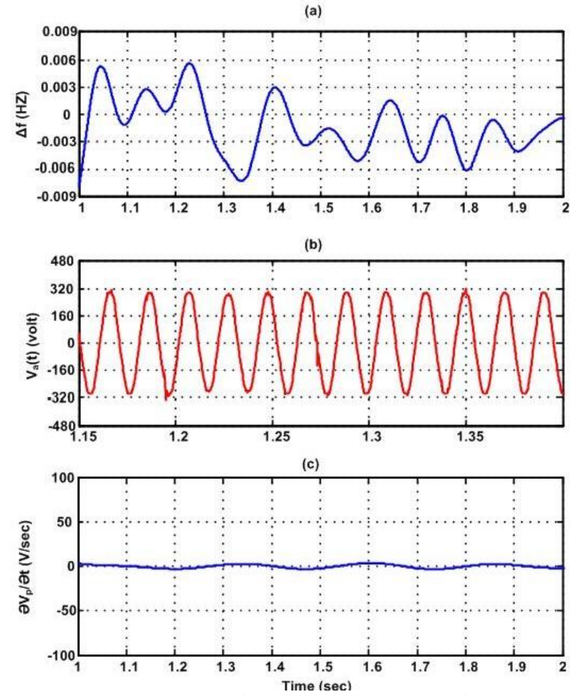

Fig 13: dynamic response of experimental system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

5.4 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 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 Fig. 14. At the switching time, the voltage and frequency are almost constant. Fig. 14 (c) shows that the ROCOPS does not change in this condition. The results show that ROCOPS does not have any sensitivity to the switching condition, and the proposed method works perfectly.

The experimental results are described in Fig. 15. A 2kvar capacitor bank was switched at t = 2 s. As shown in Fig 15(c), ROCOPS does change but the value does not exceed from threshold value at this time. Therefore, the results confirm the simulation results.

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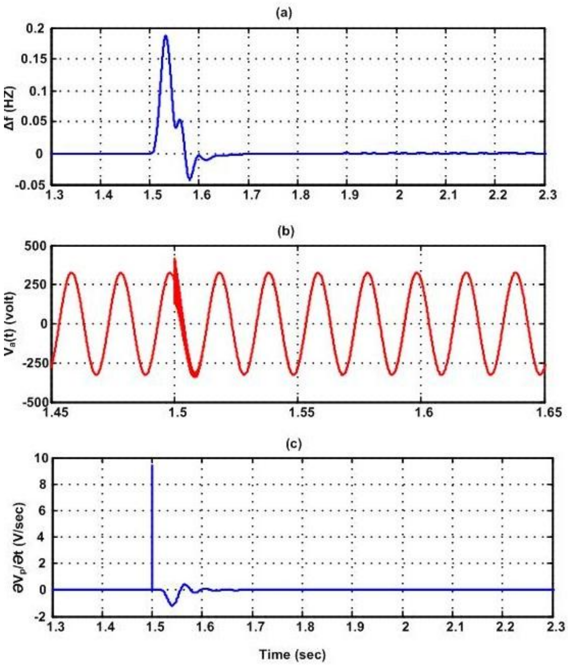

Fig 14: dynamic response of simulation system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

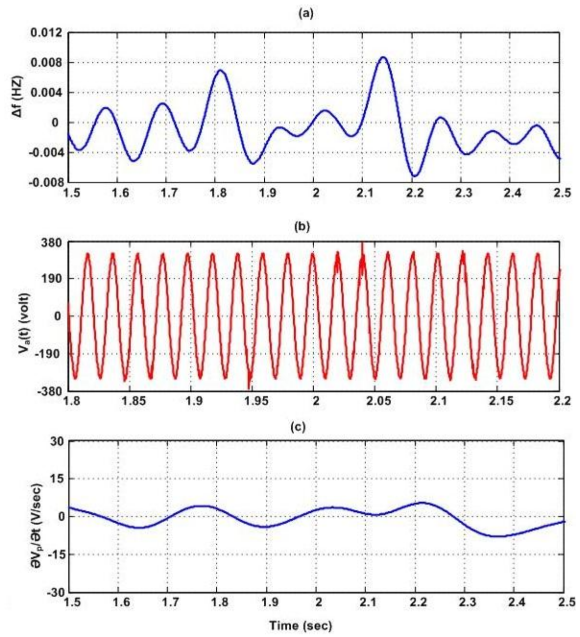

Fig 15: dynamic response of experimental system, a) frequency deviation of PCC voltage b) instantaneous voltage c) rate of change of positive sequence of voltage

Conclusion

Following the increased number and enlarged size of distributed generating units installed in a modern power system, the protection against islanding has become extremely challenging nowadays. Islanding detection is also important as islanding operation of distributed system is seen a viable option in the future to improve the reliability and quality of the supply. In this paper, A new technique for islanding detection of distributed generation is proposed based on ROCOPS method. The main emphasis of the proposed scheme is to reduce the NDZ and this technique using thresholding method can also overcome the problem of setting the detection thresholds inherent in the existing techniques. By case studies with numerical simulations and implemented system, the proposed approach was verified with feasibility, flexibility and robustness.

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