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REACTIVE POWER BASED ANTI-ISLANDING SCHEME FOR SYNCHRONOUS DISTRIBUTED GENERATORS

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Abstract- Identification of intentional and unintentional islanding situation of the dispersed generators is one of the important protection concerns in both traditional and smart grids. Regarding the safety and reliability problems of the distribution networks an exact diagnosis index is required to discriminate loss of main network from existing occurrences of parallel operation. Hence, this paper presents a new passive-based islanding detection method, according to change in $\partial V_{DG}/\partial Q_{DG}$ index. The proposed methodology can be used in both traditional and smart grids. This technique has been applied on two sample network to evaluate the performance of the proposed method with different scenarios, including the islanding and non-islanding occurrences. At the end, the proposed method has been compared with the ROCOV relays. Simulation results show that the proposed method has smaller NDZ than the ROCOV relays and can be used as an effective alternative instead of the ROCOV relays.

Keywords: Islanding detection, Synchronous Distributed Generation (SDG), Passive methods, Non-Detection-Zone (NDZ).

I. INTRODUCTION

Distributed generation (DG) is the electricity generation at the distribution networks. Nowadays distributed generation has been broadly used in the distribution power systems due to secure of electricity supply to customers, deregulation of the electricity market, increased power reliability and decreased environmental concerns [1, 2]. Capability of islanding identification for the connection of distributed generators to distribution networks is an important issue. According to IEEE standard 1547-2003, islanding situation is defined as a condition in which a portion of an electric power system is solely energized and separated from the rest of the electric power system [3]. Failure to islanding detection can be lead to several negative impacts to the generators and connected loads.

Disadvantage of islanding situation are [1, 4]:
1. Equipment damaging due to grid cannot control of its frequency and voltage.
2. Safety hazards to utility workers and customers.

Therefore islanding situation must be detection as soon as possible. Until now many islanding detection methods have been proposed. These methods can be classified into two ma-in categories. Remote techniques such as power line communication [5] and supervisory control and data acquisition [6] don't have non detection zone (NDZ) and more reliable than local techniques but more expensive. NDZs are defined as a loading condition for which an islanding detection method would fail to operate in a timely manner [2]. Local techniques can be classified into two major groups: active methods and passive methods. According to the active methods islanding situation is detected based on adding a perturbation signal into the system. The perturbation signals in parallel operation no significant effect on the detector signals but in the case of loss of main, these detector signals is amplified due to same perturbations.

Passive methods are based on measuring local parameters of DG and comparing it with preset value. Passive techniques which have been recently proposed include over/under frequency/voltage protections (OFP/UFP and OVP/UVP) and rate of change of frequency over the time [7-9]. Vector surge relay and wavelet transform are the other main methods, which are explained in [10-12]. The more information on active and passive methods could be found in [1]. This paper presents a new passive-based islanding detection method on the foundation of change in $\partial V_{DG}/\partial Q_{DG}$ index. The proposed methodology can be used in both traditional and smart grids. In the smart grids, the whole operations are based on digital technology. Thus, the aforementioned index can be computed by discretization of the continuous signals.

The rest of the paper is organized as follows: overview of ROCOV relay is described in section II. In section III, proposed methodology is introduced. Section IV shows the simulation results and in sections V conclusion is represented.

II. OVERVIEW OF ROCOV RELAY

The rate of change of voltage over time, which is known as ROCOV index is one of the islanding detection methods for DGs in the distribution networks.

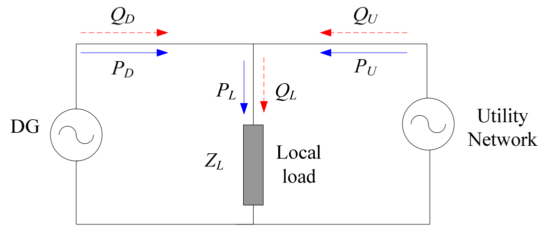

Figure 1. Equivalent circuits of a DG parallel with the grid.

Although this method is very simple for implementation but in small reactive power mismatches has wrong performance. This weakness of ROCOV index is formulated in the rest of content. From Figure 1, the reactive power generation of DG can be achieved as:

$$Q_D = |V_D||I_D|\sin(\varphi) \quad (1)$$

where, V_D, I_D and φ are voltage and current of DG and difference phase angle between DG's voltage and current, respectively. In the islanding conditions the mentioned equation is converted to the following relations:

$$Q_D = |V_D||V_L||Y_L|\sin(\varphi) \quad (2)$$

where, $|Y_L|$ and $|V_L|$ are amplitude of the local load admittance and voltage, respectively. The partial derivative of Q_D can be achieved, as follows:

$$\frac{\partial Q_D}{\partial |V_L|} = |V_D||Y_L|\sin(\varphi) \quad (3)$$

For any deviation in V_L, the aforementioned equation is converted to the following equation:

$$\frac{\Delta Q_D}{|V_D|} = \Delta|V_L|.B_L \quad (4)$$

where, B_L is the imaginary part of Y_L. Finally, rate of change of voltage is expressed, as follows:

$$\frac{\Delta|V_L|}{\Delta t} = \frac{1}{|V_D|.B_L}\frac{\Delta Q_D}{\Delta t} \quad (5)$$

From (5), it can be seen that ROCOV index is directly depends on the reactive power imbalance. Thus, when the reactive power imbalance has a large value, this causes transient state in the terminal voltage, so ROCOV index exceeds its preset threshold value. In contrast, when the reactive power imbalance has small variations, then ROCOV index doesn't sense the threshold value and can't detect the islanding situation.

III. THE PROPOSED METHODOLOGY

In the distribution networks for islanding detection methods based on passive techniques commonly, parameters such as frequency, voltage, active power and etc are used. These techniques either in direct (itself of signal) or indirect (existing energy in the harmonics of the signal) forms use the aforementioned parameters. The active power imbalance is a detection criterion of those methods which are based on frequency and active power. It means that, the detection procedure is carried out with regard to differ between active power generated by DG and active power consumed by loads.

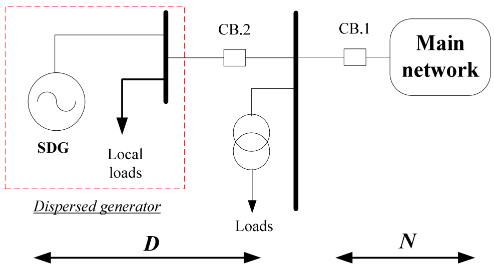

Figure 2. Overall schematic of main network and distributed generating unit

On the other hands, the reactive power imbalance is the detection criterion of the voltage based methods. Moreover, the majority of existing loads in the distribution networks are inductive-resistive types. It means that, when islanding situation occurs, both active and reactive power imbalances are created. So, to detect and analyze of the islanding phenomenon, this article uses from reactive power imbalances. In fact, the rate of change of DG's voltage over its reactive power is used as a detection index.

From (2), the rate of change of DG's reactive power over its voltage is expressed, as follows:

$$\frac{\partial Q_D}{\partial V_D} = |V_L||Y_L|\sin(\varphi) \quad (6)$$

For any deviation in Q_D, the aforementioned equation is converted to the following relation:

$$\frac{\Delta|V_D|}{\Delta Q_D} = \frac{Z_L}{|V_L|.\sin(\varphi)} \quad (7)$$

From (7), it can be seen that the proposed index is completely independent of the reactive power imbalance. For more analysis, this index must be achieved in both islanding and non-islanding situations. Figure 2 represents an overall schematic of grid-connected distributed generator, which N represents main network and D represents distributed generator and local loads. To obtain the aforementioned index, so, in the normal operation (i.e., CB_1 and CB_2 are normally closed) the following relation can be written:

$$Q_N + Q_D = -Q_L \quad (8)$$

Rate of change of (8) over voltage of distributed generator can be achieved as follows:

$$\frac{\partial}{\partial V_D}(Q_N + Q_D) = -\frac{\partial Q_L}{\partial V_D}$$
$$\frac{\partial Q_N}{\partial V_D} + \frac{\partial Q_D}{\partial V_D} = -\frac{\partial Q_L}{\partial V_D} \quad (9)$$

To obtain the mentioned indicator, (10) should be solved in both islanding and parallel operation. Now consider this scenario when the both sides are not connected together. In this situation, the both sides operate independently and we can write the following equation in the DG side:

$$\frac{\partial Q_N}{\partial V_D} = 0$$
$$\frac{\partial Q_D}{\partial V_D} = -\frac{\partial Q_L}{\partial V_D} \quad (10)$$

Next, consider the parallel operation, which the both sides are electrically connected. In this situation, if there is a load change of ∂Q_L occurs in D side, the following equation should be satisfied:

$$\partial V_N = k.\partial V_D \quad (11)$$

The above equation means that, in parallel operation the main network voltage and DG voltage have proportional relation. Where, the k is constant coefficient. By substituting (12) into (10), the following equation can be formulated:

$$\frac{\partial Q_D}{\partial V_D} = -\left(\frac{\partial Q_N}{\partial V_D} + \frac{\partial Q_L}{\partial V_D}\right) \Rightarrow \frac{\partial Q_N}{\partial V_D} = k.\frac{\partial Q_N}{\partial V_N}$$
$$\Rightarrow \frac{\partial Q_D}{\partial V_D} = -\left(k.\frac{\partial Q_N}{\partial V_N} + \frac{\partial Q_L}{\partial V_D}\right) \quad (12)$$

As compared (10) with (12), it discloses that with the same loading variations of D side, the computed value of $\partial V_D / \partial Q_D$ under various situations can be different. From this viewpoint, the mentioned index can be used as an effective indicator.

Figure 3 depicts the calculation procedure of the proposed method. In this paper, to achieve the detection index, the whole under study signals should be converted to the discrete signals. To reach the mentioned aim, this article uses zero-order-hold (ZOH) filter. After discretization process, calculation of detection index is started (Figure 4). When the amplitude of detection index (D) is larger than preset threshold value, the number of counter (N) is incremented by one. The islanding situation is detected when the value of N exceed from N_{th}; where, N_{th} is threshold value of counter.

To acquire the threshold value (D_{th}), other form of (7) is used, as follows:

$$\left|\frac{\partial V_D}{\partial Q_D}\right| = \frac{S_b \sin(\theta)}{Q_L V_L \sin(\varphi)} = D \quad (13)$$

where, S_b and θ are power rate of DG and phase angle of loads, respectively. Figure 5, shows the variations of detection index versus load reactive power. Regarding this figure, for any DGs with reactive power from 0 to 30 MVar, the value of detection index is larger than 1. So, in this article the threshold of detection index (D_{th}) has been adjusted to 1. In the case of counter threshold, the large value of N_{th}, causes the more reliability of the proposed method but makes large value in the detection time. So, in this study N_{th} = 8 in considered.

IV. SIMULATION RESULTS AND DISCUSSION

To validate the effectiveness of the proposed method, various islanding and non-islanding occurrences have been applied on the case study systems as shown in Figures 6 and 7. In [8] and [13], all information about first and second case study systems has been presented. All simulations have been carried out in the Matlab/SimPowerSystem software environment. At first stage, loss of main network occurrence or islanding condition is evaluated. It should be note that all of the occurrences have been applied at 2 sec.

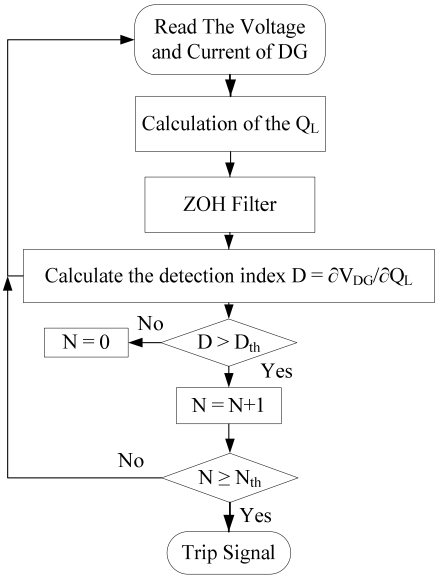

Figure 3. Flowchart of the proposed method

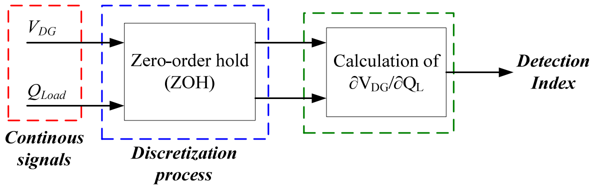

Figure 4. Discretization process of signals

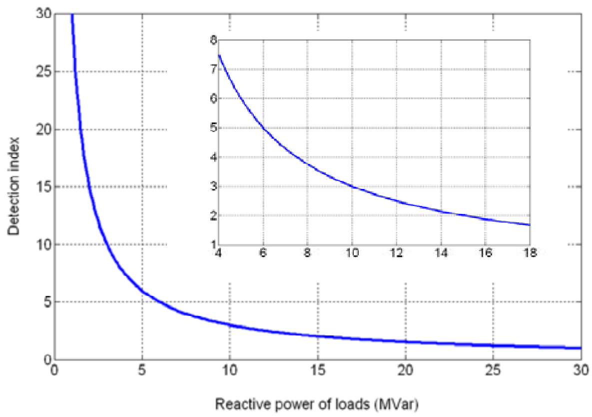

Figure 5. Variations of detection index versus reactive of local loads

Figures 8-10 show the detection index variations in islanding conditions with different active and reactive power imbalances in first case study system. Regarding many islanding and non-islanding events, the threshold value of ROCOV relay has been adjusted to 2 pu/s. Moreover, this relay is supported by under voltage relay in different short circuit faults. Figures 11-13, depict the islanding conditions for second case study system. From Figures 8-13, it can be seen that the proposed method can detect the islanding, even in small reactive power mismatches, while the ROCOV relay has poor performance in this situations. The proposed method has very good performance, up to 28% and 20% of reactive power imbalances in first and second systems, respectively.

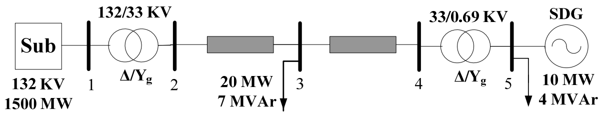

Figure 6. Single line diagram of first case study system

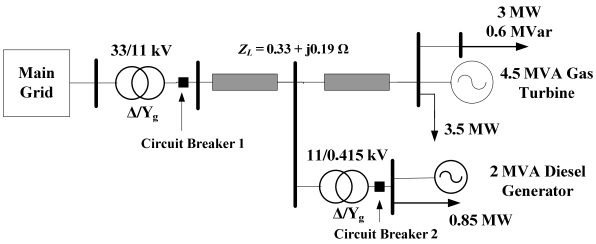

Figure 7. Single line diagram of second case study system

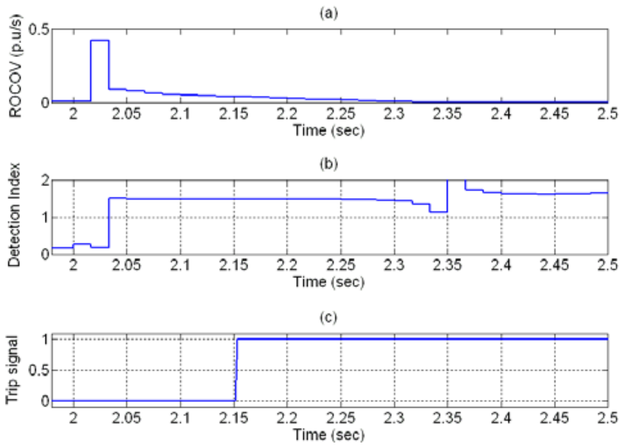

Figure 8. Effect of the both 5% of reactive and 2.5% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

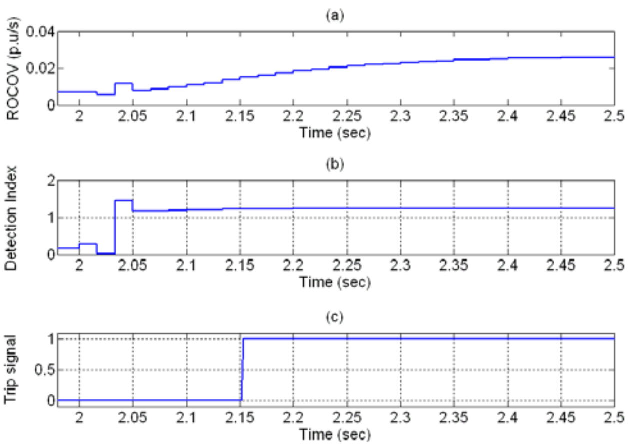

Figure 9. Effect of the both 0% of reactive and 3.3% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

On the other hand, for larger than the mentioned values, the ROCOV relay detects the islanding faster than the proposed method. As for the results of the ROCOV relay shown in Figure 10, although the detection time is smaller than the proposed approach (activated at 2.0206s) but the merit of the proposed method is appeared by the capability of islanding detection even though the reactive power imbalance is very small (Figures 9 and 11).

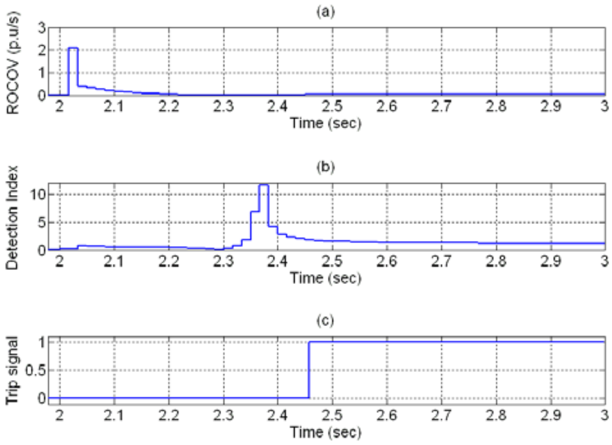

Figure 10. Effect of the both –28% of reactive and 13% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

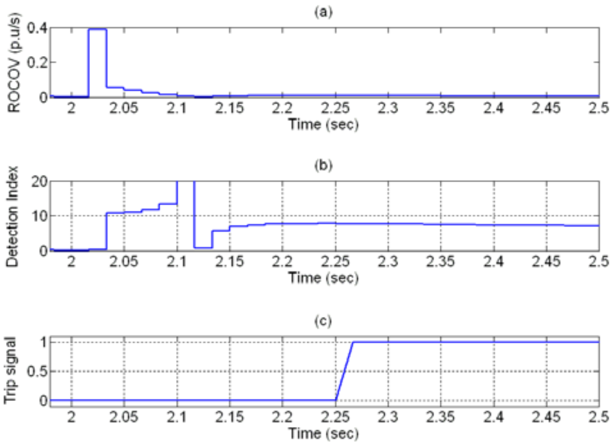

Figure 11. Effect of the both 1% of reactive and 1% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in second system

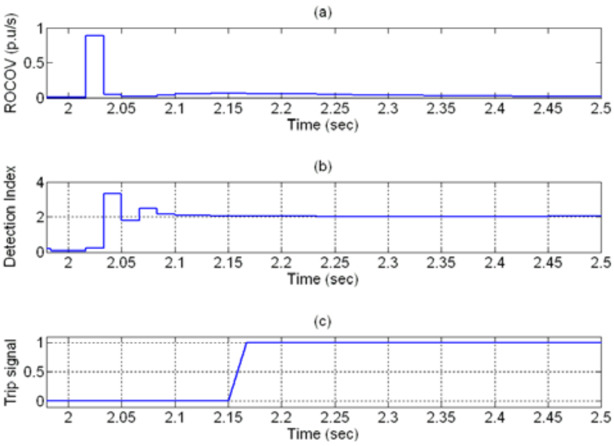

Figure 12. Effect of the both –7% of reactive and 4% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in second system

Figures 9 and 11, show the effect of zero and one percentage of reactive power imbalances in the both proposed approach and ROCOV relay performance in first and second case study systems, respectively. For these scenarios, variations for the rate of change of voltage are very small than the preset threshold value.

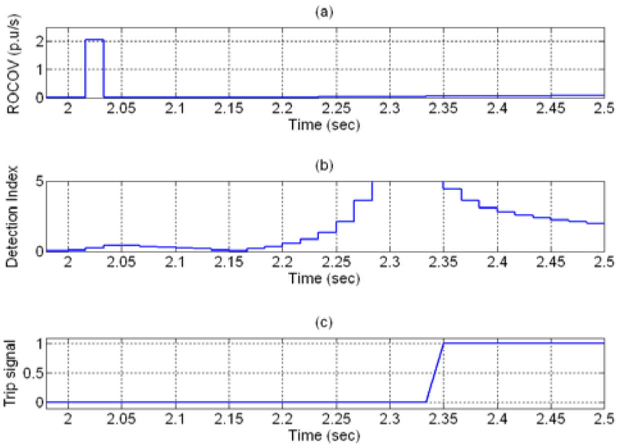

Figure 13. Effect of the both –20% of reactive and 26% of active power mismatches in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in second system

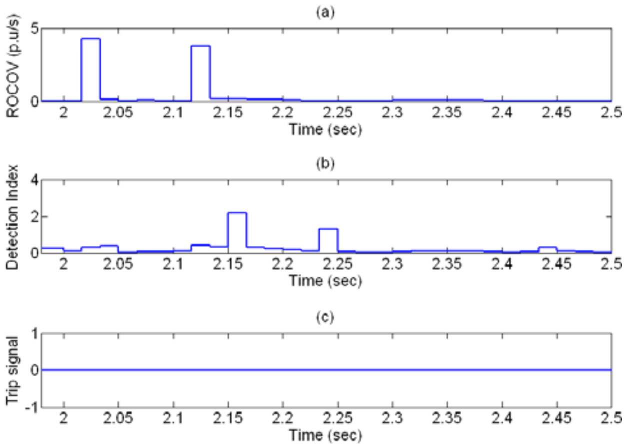

Figure 14. Effect of the double line (a and b) fault with R_f = 10 ohm in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

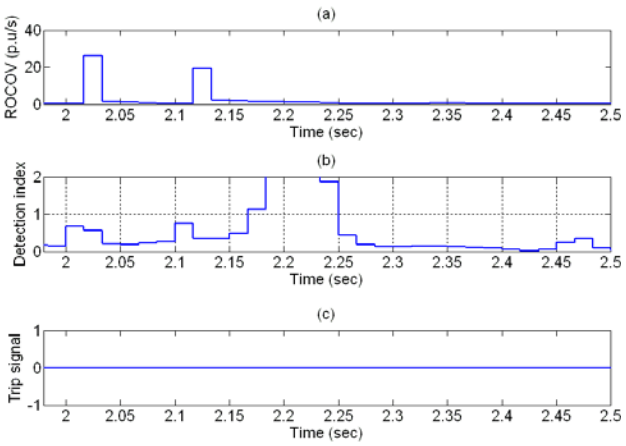

Figure 15. Effect of the three phases fault with R_f = 1 ohm in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

Thus, the ROCOV relay cannot detect the islanding situation. The capability of the proposed method is identified in these situations by the detection of islanding event at 2.150 sec and 2.165 sec for first and second case study systems, respectively.

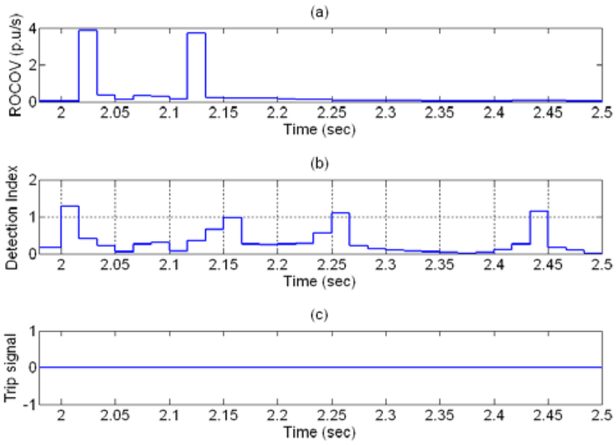

Figure 16. Effect of the single line to ground fault with R_f = 5 ohm in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system.

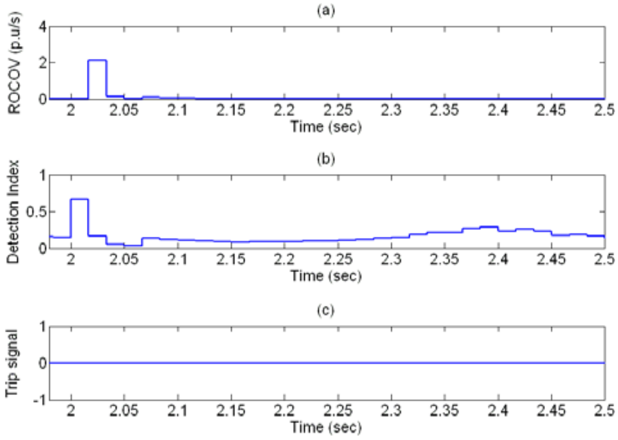

Figure 17. Effect of the 25 MVar capacitor bank switching in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

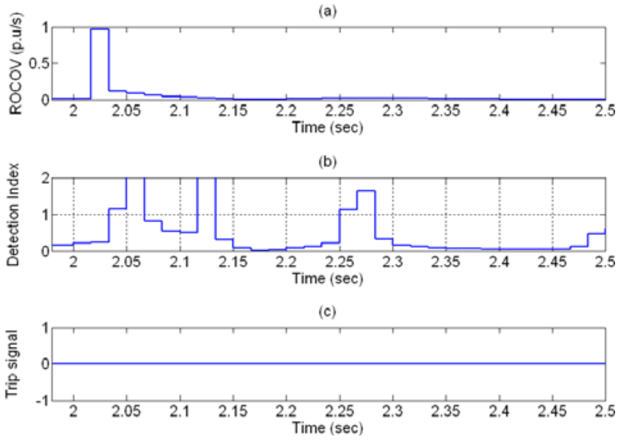

Figure 18. Effect of the load disconnecting (20 MW and 10 MVar) in (a) ROCOV relay, (b) proposed method and (c) trip signal of proposed method in first system

Consequently, the reliability of proposed approach is ensured in the loss of main occurrence by applying these tests. At the next stage, the proposed method is assessed when the system encounters with the parallel operation occurrences. These occurrences include short circuit faults (3-phase, double line and single line to ground), capacitor bank switching and sudden load change.

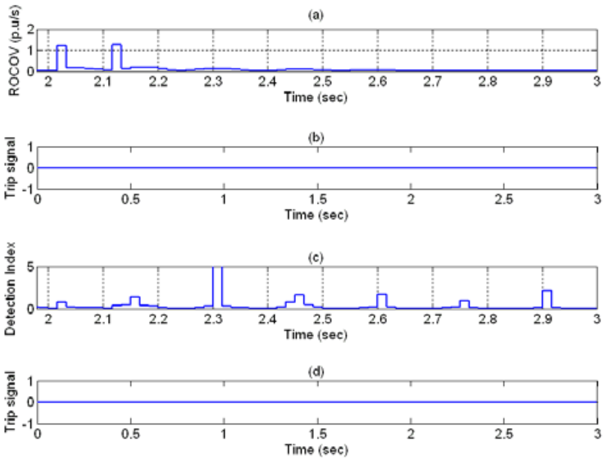

Figure 19. Effect of the three phases fault with R_f= 10 ohm in (a) ROCOV relay, (b) trip signal of ROCOV relay, (c) proposed method and (d) trip signal of proposed method in second system

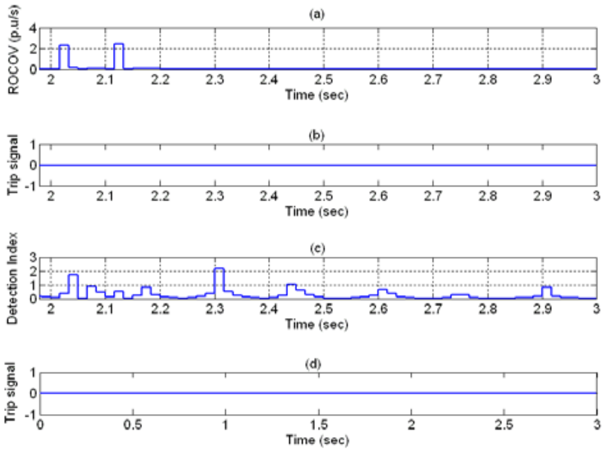

Figure 20. Effect of the double line (a and c) with R_f= 10 ohm in (a) ROCOV relay, (b) trip signal of ROCOV relay, (c) proposed method and (d) trip signal of proposed method in second system

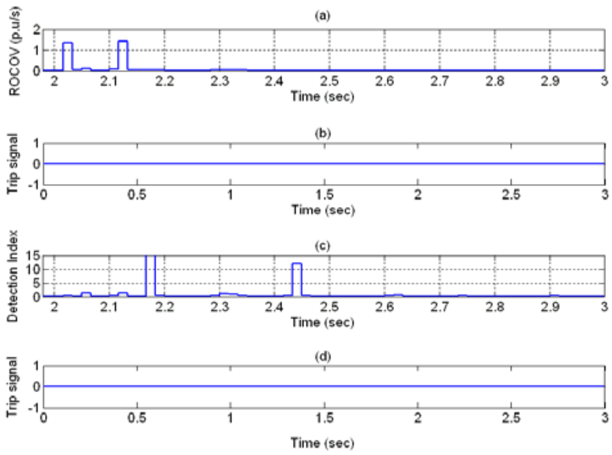

Figure 21. Effect of the single line to ground fault with R_f= 5 ohm in (a) ROCOV relay, (b) trip signal of ROCOV relay, (c) proposed method and (d) trip signal of proposed method in second system

Short circuit faults: the short circuit faults are the major occurrences, which may be occurred in the power system. An islanding detection method has a strong performance if it can distinguish between islanding and non- islanding occurrences.

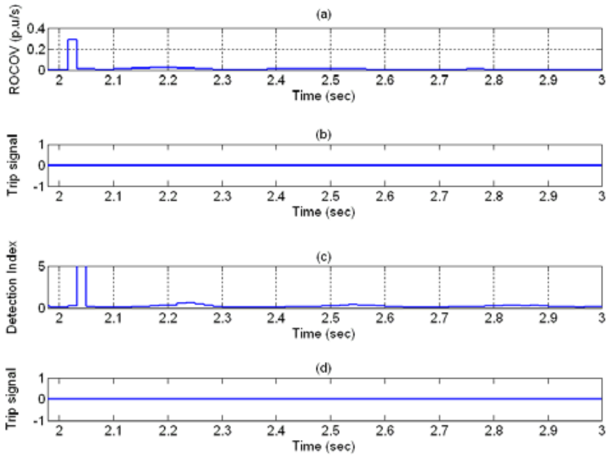

Figure 22. Effect of the load disconnecting (10 MW and 4 MVar) in (a) ROCOV relay, (b) trip signal of ROCOV relay, (c) proposed method and (d) trip signal of proposed method in second system

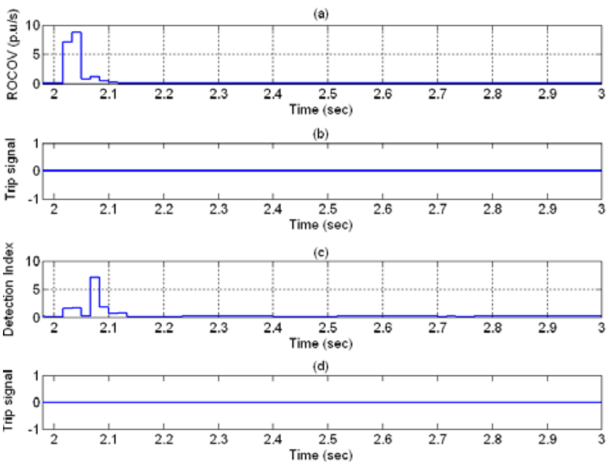

Figure 23. Effect of the 10 MVar capacitor bank switching in (a) ROCOV relay, (b) trip signal of ROCOV relay, (c) proposed method and (d) trip signal of proposed method in second system

The three phases, double line and single line to ground faults are main faults, which the system may be encountered with those. Figures 14-16 and 19-21, show the variations of detection index and ROCOV relay when the different faults are happen. In this study, from 5% to 50% of voltage sag for different faults with lasting of six cycles is considered. Regarding the Figure 15, a 50% of voltage sag hasn't effect on the performance of detection index. In this figure, although the detection index at the some instants exceeds from its preset threshold but the number of counter (N_{th}) stays in 4 and it is smaller than 8. Hence, the reliability of the proposed method was successfully tested when the short circuit faults was occurred.

Capacitor bank switching: In the capacitor bank switching test case, a 138.8% and 150% increase of reactive power have been investigated for first and second case study systems. These values are near to 25 MVar and 10 MVar, respectively. Figure 17 depicts the effect of 25 MVar capacitor bank switching on the performance of detection index. Regarding the Figure 17, for 138.8% increase of reactive power, the detection index never touch the threshold value.

In Figure 23, although the detection index (D_{th}) exceeds its pre-set value but number of counter (N) is smaller than the counter threshold value (N_{th}). Thus, these non-islanding disturbances weren't selected as an islanding event.

Sudden load change: at this section, switching effect of composite loads on the performance of detection index is evaluated. These composite loads are comprised of 20 MW and 10 MVar (inductive and resistive loads) for first system and 10 MW and 4 Mvar for second one. Figures 18 and 22, show the results of detection index with the mentioned scenario. According to these figures, it should be note that although detection index in some instants exceeds from threshold value but number of counter is smaller than the N_{th}. As a result, the capability of the proposed approach is not affected by the load change and the reliability of the method is ensured.

V. CONCLUSIONS

This paper proposes a new islanding detection method based on the rate of change of DG's voltage over reactive power. In fact, the proposed method by monitoring of both voltage and reactive power of DG calculates the detection index and detects the islanding situation. To implement the proposed method by digital metering devices, the under study signals should be converted to the discrete type. To convert the continuous signals to the discrete signals this study uses from the zero order hold filter. After discretization process and calculate the detection index, the proposed approach was successfully tested under different islanding and non-islanding occurrences on two different power system. Simulations results demonstrate the effectiveness of the proposed method even though the zero percent of the reactive power mismatch whereas the ROCOV relay cannot detect this situation. Thus, the proposed method has smaller NDZ than the ROCOV relays and can be used as an effective alternative instead of the ROCOV relays.

NOMENCLATURES

Q_D: Generated reactive power of DG
V_D: Terminal voltage of DG
I_D: Current of DG
Q_L: Consumed reactive power of local loads
V_L: Terminal voltage of local loads
I_L: Current of local loads
φ: Phase angle difference between voltage and current of DG
θ: Phase angle difference between voltage and current of local loads
Y_L: Admittance of local loads
B_L: Imaginary part of Y_L
ΔQ_L: Deviation of local loads reactive power
ΔV_L: Deviation of local loads terminal voltage
ΔQ_D: Deviation of DG reactive power
ΔV_D: Deviation of DG terminal voltage
ΔQ: Reactive power imbalances
ΔP: Active power imbalances
∂: Symbol of variations
Q_N: Injected reactive power of main network
V_N: Thevenin voltage of main network
D: Detection index
D_{th}: Threshold of detection index
N: Number of counter
N_{th}: Threshold of counter

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