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A passive islanding detection strategy for multi-distributed generations

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ABSTRACT

Islanding operation is an undesirable event because it can harm the personnel and damage the connected loads. Therefore, islanding operation should be detected and the islanded distributed generation units should be isolated from the rest of the distribution network. This paper presents a simple islanding detection method that is suitable for multiple distributed generation units. The proposed method is based on the concept of the main bus and uses an index called the voltage index to detect islanding operation for large power mismatches. However, for small power mismatches, the line current measured at the main bus is used to disconnect the loads connected to the bus in order to transfer small power mismatches to large power mismatches to detect islanding operation. The simulation results clearly reveal that the proposed method is effective in islanding operation detection and has no non-detection zone. Wind farms power generation system is presented in this paper as an example of distributed generation units.

1. Introduction

Distributed generation (DG) is a small-scale generation that can support increase in the total load demand without investment in the expansion of distribution network by installing the DG units close to the loads. DGs generally refer to renewable distributed energy resources, including wind farms, micro-hydro turbines, photovoltaic (PV), and other generators that are supplied with biomass or geothermal energies [1]. Integration of large numbers of DGs of smaller capacity into utility, which are dispersed according to the availability of renewable energy resources, is resulting in important changes to the topology of the power system. These changes may ultimately convert the power system from vertically to a horizontally-operated power system [2].

Integrating DG into utility has many benefits such as improvement of the power system efficiency, increase the system flexibility, reduction in the power loss and reduction in the environmental pollution. However, this increasing penetration level of DGs has raised many technical concerns such as protection coordination, islanding, safety, system stability, reliability, supply security and voltage regulation [1–4,31]. One of the important concerns that should be taken into account is the islanding operation. Islanding is a situation in which part of the distribution network is isolated from the utility grid and the loads still energized by the local DG units.

Islanding operation is undesirable situation because it leads to safety hazards for personnel and power quality problems for loads. Moreover, islanding operation may lead to damage to the power generation and power supply facilities as a result of unsynchronized reclosure [1–4]. Considering the severe consequences that islanding operation can cause, IEEE STD 1547–2008 specified a delay of two seconds for the DG unit to detect the islanding situation and isolate itself from the distribution system [4].

Until now, several islanding detection methods have been proposed. The islanding detection methods can briefly be divided into two categories, remote methods, where the detection is based on the utility side, and local methods, where the detection is based on the DG side. The performance of each detection scheme is evaluated according to its non-detection zone (NDZ). The NDZ represents the interval in which the detection scheme fails to detect islanding situation once islanding occurred [1,5].

Remote methods are schemes which rely on the communication between the utility and DG units. These techniques are highly reliable and more effective than the local techniques as they eliminate non-detection zone (NDZ). However, they can suffer with communication problems and its implementation implies very high costs [5,6]. The common remote islanding detection techniques are: Power Line Carrier Communication, Supervisory Control and Data Acquisition and Signal Produced by Disconnect [6].

The local methods can be further classified into active and passive methods. Passive methods rely on available local measurements such as voltage, frequency, harmonic distortion, etc. measured on the DG site [1]. The general concept of passive methods is that if the measurements are outside the predetermined thresholds, the protective relay at DG site decides to disconnect the DG [1,7]. Passive methods are preferred due to their smooth implementation and practical solutions as well as

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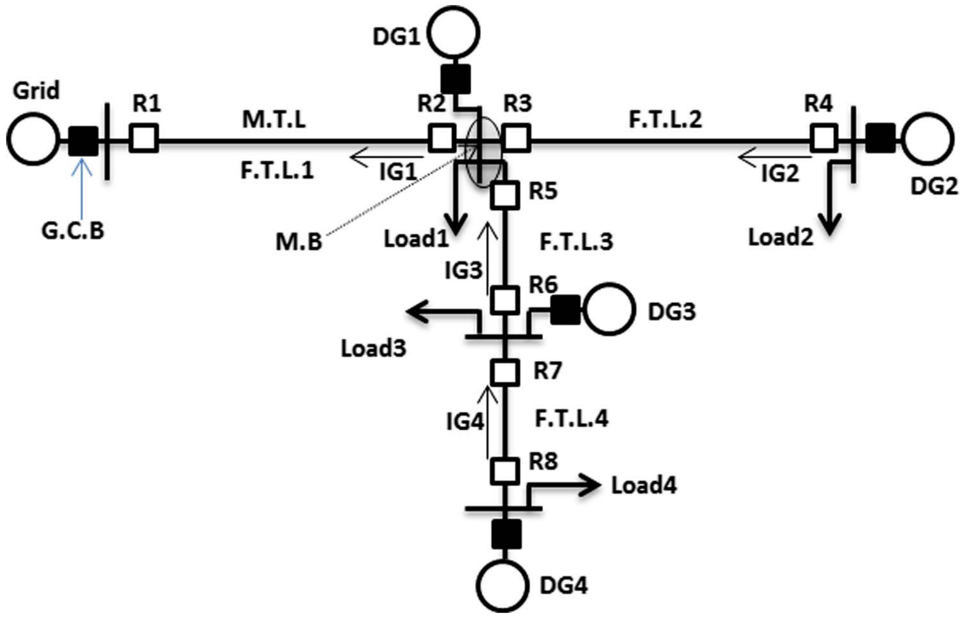

Fig. 1. The distribution system under consideration.

Table 1
The parameters of the model under consideration.

Grid	2500 MVA:120 kV; 60 Hz.
Grid transformer	Step down; 50 MVA; (120/25) kV
DG unit	5 MVA; 575 V; 60 Hz
DG transformer	Step up; 10 MVA; (575/25) kV
Transmission line	R1 = 0.1153 Ω/km; R0 = 0.413 Ω/km; X1 = 1.05 mH/km; X0 = 3.32 mH/km; C1 = 11.33 nF/km; C0 = 5.01 nF/km; Distance: M.T.L. = 50 km; F.T.L2 = 40 km; F.T.L3 = 15 km; F.T.L4 = 15 km;

Table 2
Abbreviations of the scheme.

G.C.B.	Circuit breaker of the grid
M.B.	The main bus of the system
R1	Protective relay no. 1
M.T.L.	Main transmission line
F.T.L1	Front transmission line no. 1
DG1	Distributed generation unit no. 1
IG	The line current of the front transmission line (rms value)

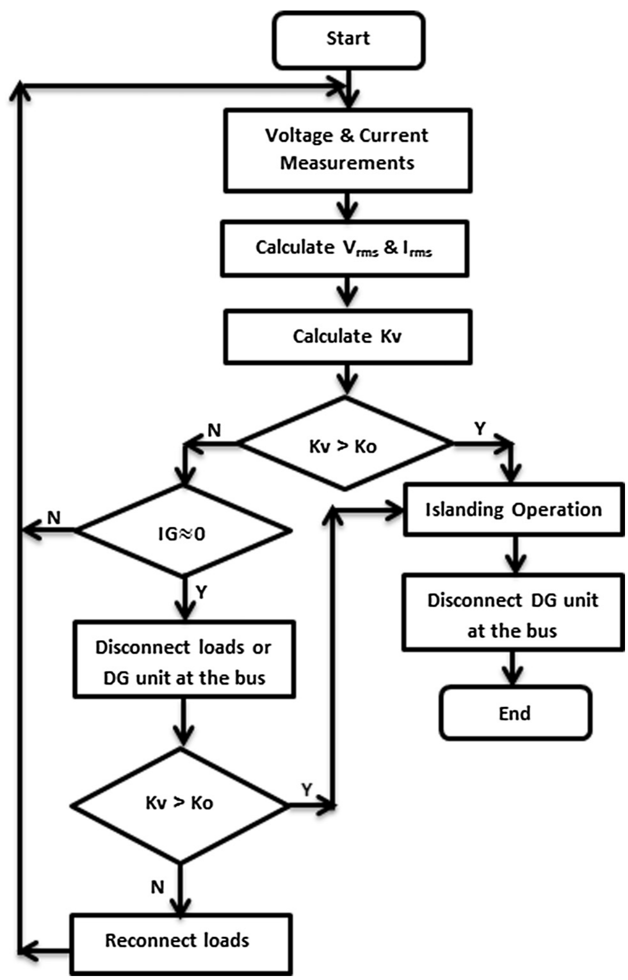

Fig. 2. The flowchart of the proposed strategy for islanding detection.

they do not produce any changes in the power quality [7,8]. Passive methods have some drawbacks such as having a large NDZ and specified threshold values with difficulty [7,9]. The common passive methods include over/under voltage, over/under frequency, over current, voltage phase jump, rate of change of frequency, rate of change of power, and harmonic distortion schemes. A comprehensive survey on passive methods is presented in [6,7,10].

Recently, some different approaches based on combining the passive methods with computational intelligence and modern signal processing methods have been done in order to reduce the non-detection zone and improve the performance of the passive methods. Different approaches based on artificial neural network and fuzzy logic have presented in [1,11–15]. Many researchers have proposed different techniques based on wavelet transform, wavelet packet transform and s-transform (ST) for islanding detection [16–23].

Active methods use disturbing signals in order to cause power mismatches, so that certain system parameters (such as voltage and frequency) drift, when the islanding operation occurs. Active methods have the ability to reduce, even eliminate, the non-detection zone and detect islanding situation accurately compared to passive methods [1,5,7]. However, next to the injection of unwanted perturbations in the distribution system, this external disturbance degrades the output

Table 3
Summary of possible cases of operation.

k_V	I_G	Description of the operation	Action
$k_V > k_o$	Any value	Islanding operation at a large power mismatch	Disconnect DG
$k_V < k_o$	$I_G \approx 0$	Islanding operation at a small power mismatch or Normal operation at power match	1- nitiate LDS 2- monitor k_v
$k_V < k_o$	$I_G > 0$	Normal operation, load changes…etc.	No action

power quality of the distribution system [1,5]. Moreover, the main drawback of the active methods is the poor performance in the presence of multiple inverters [5]. A comprehensive survey on active detection methods is discussed in [6–10,24–27]. The hybrid methods are a combination of passive and active schemes.

This paper aims to propose a strategy that can detect islanding operation accurately for multi-distributed generations. The proposed strategy is based on an index called the voltage index to detect islanding operation. The voltage index depends on the changes of the system voltage. This strategy is able to detect islanding situations under any condition even under the NDZ, the worst case, where other methods failed. The proposed strategy is simple, straight forward and easy to implement with small computational time. This paper is organized as follows: In Section 2, the power system under consideration in this study is described. The proposed method details are presented in Section 3. Section 4 illustrates the simulation results and performance of the proposed method. Finally, discussion and conclusions are given in Sections 5 and 6 respectively.

2. Model description

Wind farm power generation system is presented in this paper as an example of distributed generation units. The electrical power system depicted in Fig. 1 consists of four wind farms (each one 5 MVA) connected to a 25 kV distribution system. Each wind farm operates at 575 V and is connected to a transformer rated at 10 MVA, to step up the voltage to 25 kV. The utility grid is connected to the 25 kV distribution system by a 50 MVA, 60 Hz, 120/25 kV step down transformer. Wind turbines using a doubly-fed induction generator (DFIG) composed of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator windings are connected directly to the utility grid while the rotor is fed at variable frequency via the AC/DC/AC converter. The model under study is modeled using Matlab/Simulink software environment. The islanding operation is simulated by opening the circuit breaker of the grid (G.C.B.) at t = 0.6 s. The parameters of the model under consideration are mentioned in Table 1 and the abbreviations of the scheme are given in Table 2.

3. Methodology

In order to reduce NDZ and improve the accuracy of the islanding detection methods, this paper presents a passive islanding detection method (IDM) for multiple DG units. The proposed strategy depends on a main parameter called the voltage index to detect islanding operation. Also, the proposed strategy uses the line current ($I_{G\text{-}rms}$) of the front transmission line (F.T.L.) at each DG bus as a secondary parameter to initiate the load disconnection strategy (LDS) at certain case. Also, the proposed method introduces and defines the concept of main bus in this study. As illustrated in Fig. 1, the main bus (M.B.) is the bus that links the grid and rest of the distribution network including DG units and loads through the main transmission line (M.T.L.). In other words, M.B. is the point of the common coupling (PCC) of the entire distribution network (including DG units and loads) to the grid. The following sections explain the voltage index and the proposed strategy.

3.1. The voltage index K_v

This methodology is proposed based on the hypothesis that certain system parameters (such as voltage and frequency) drift, when the

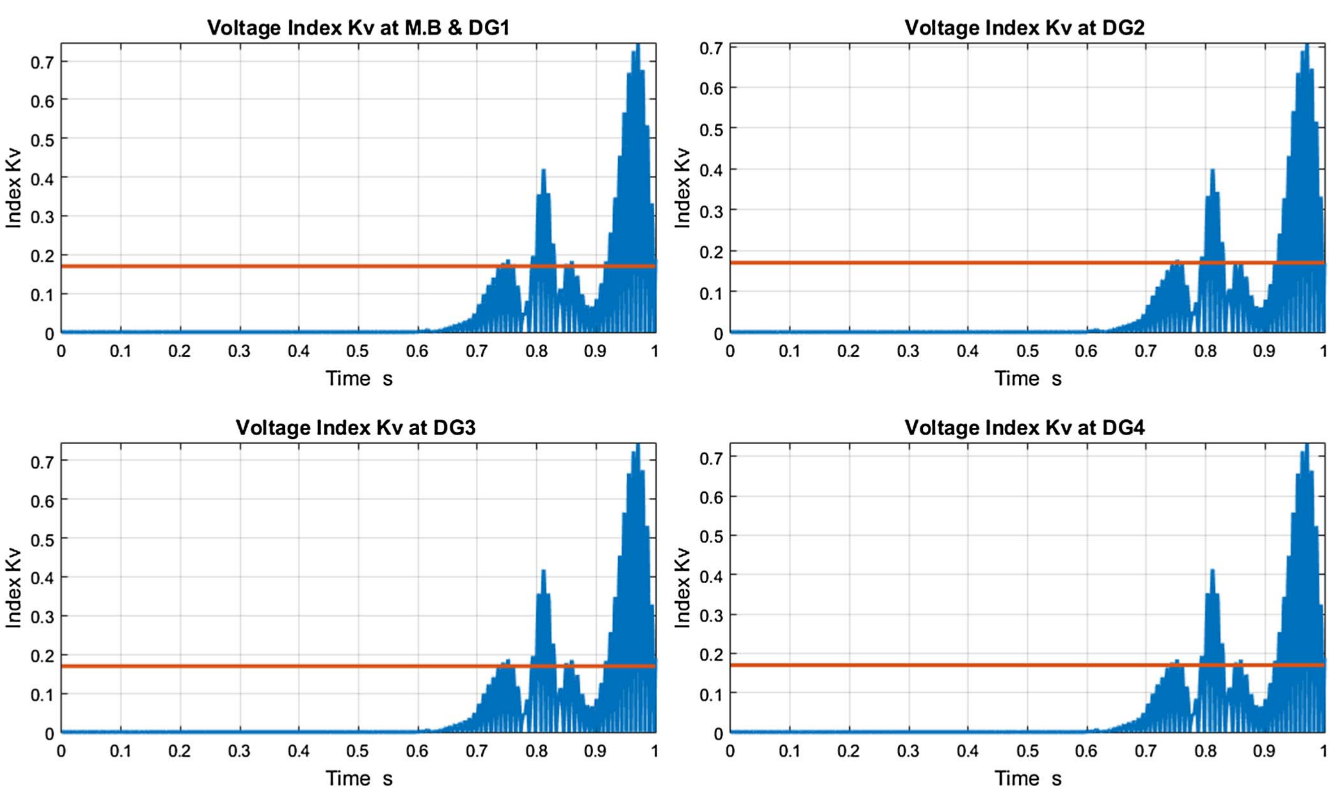

Fig. 3. The voltage index at DG units during islanding operation at a large power mismatch.

Table 4
Maximum detection time for different loads at large active power mismatches.

Total load demand		Power mismatch		Maximum detection time T < 2 s
Active power P	Reactive power Q	Active power P	Reactive power Q	
11 Mw	6 Mvar	7 Mw	3 Mvar	0.15 s
13 Mw	7 Mvar	5 Mw	2 Mvar	0.23 s
12 Mw	9 Mvar	6 Mw	0	0.22 s
14 Mw	9 Mvar	4 Mw	0	0.26 s

islanding operation occurs. When the grid is connected, the system parameters change in very short limitations. However, when the grid is disconnected from DG units, the system parameters have significant changes.

The phase voltage signals measured at the DG site are used to calculate the average value of the voltage (V_{av}) for each phase. The average value is calculated over one cycle of the fundamental frequency (60 Hz) according to the following equation.

$$V_{av}(k) = \frac{1}{N}\sum_{k=r}^{r+N-1} V(k) \tag{1}$$

Where N is number of samples/cycle and r is the starting sample (r = 1, 2, 3 …). In this study a sampling frequency of 200 kHz having 3333 numbers of samples N in one cycle on the 60 Hz base frequency is considered. Change of the average value of voltage signal V_{av} depends on the change in the system frequency. In other words, during normal operation, number of samples/cycle is N which is a constant value at 60 Hz. However during transient events such as islanding operation, number of samples/cycle is less or more than N due to change of the system frequency which in turn leads to a significant change in the average value of the voltage.

During normal operation, V_{av} is zero or almost zero as no significant change is detected in the system frequency. However during islanding operation V_{av} has a considerable value due to change of the system frequency.

A new term called accumulative average of voltage (*AAV*) is introduced and defined according to the following equation.

$$AAV(k) = \sum_{k=r}^{k=r+N-1} abs(V_{av}(k)) \tag{2}$$

where k is a moving summation parameter.

AAV is the sum values of the change of average voltage for one moving cycle with respect to time and represented as an absolute value.

The voltage index K_v is defined as the multiplication of *AAV* and the change in the system voltage ΔV. The index K_v is given by Eq. (3):

$$K_V = |(V_b - V_s)| \times \text{AAV} \tag{3}$$

where $\Delta V = |(V_b - V_s)|$ in per unit (pu).

V_b and V_s are the rms values of the base voltage of the system and the operating voltage at the DG bus, respectively. The voltage index proposed in this paper is formulated by the authors.

The entire process is based on the moving window concept where the one-cycle window is moved continuously by one sample. In this paper, the definition of the voltage index is different from any similar definitions in the present islanding detection techniques. The proposed voltage index is more sensitive than normal voltage measurements as according to Eq. (3), the voltage index K_v consists of two parts. The first part $\Delta V = |(V_b - V_s)|$ represents the change in the system voltage at DG bus. The second part *AAV* represents the accumulative change in the average value of the voltage signal at DG bus which in turn depends on the change in the system frequency as mentioned before.

3.2. The proposed strategy

The proposed strategy follows the flowchart shown in Fig. 2. The proposed strategy depends on the voltage index as a main index to detect islanding operation. Also, the line current (I_G) in the front transmission line (F.T.L.) is only used as a secondary index to initiate the load disconnection strategy LDS in order to discriminates between

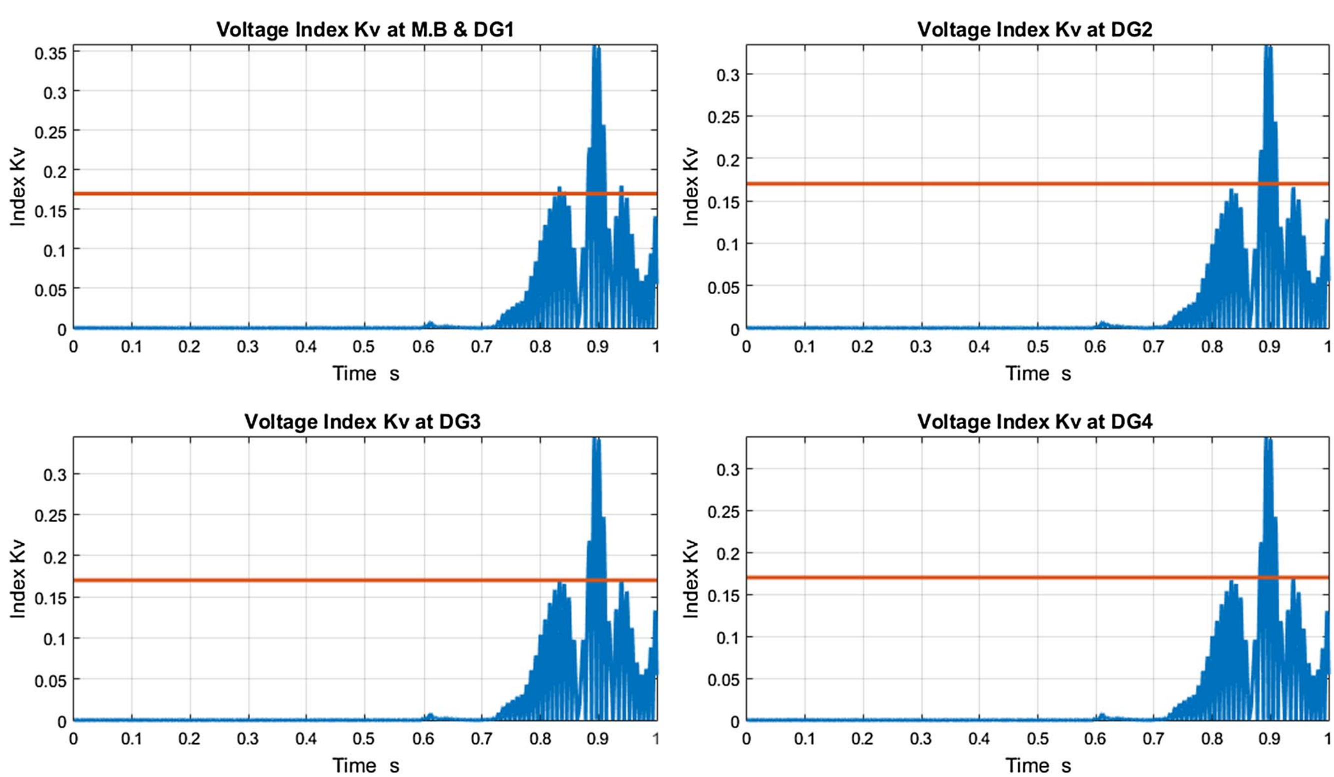

Fig. 4. The voltage index at DG units during islanding operation at a small power mismatch.

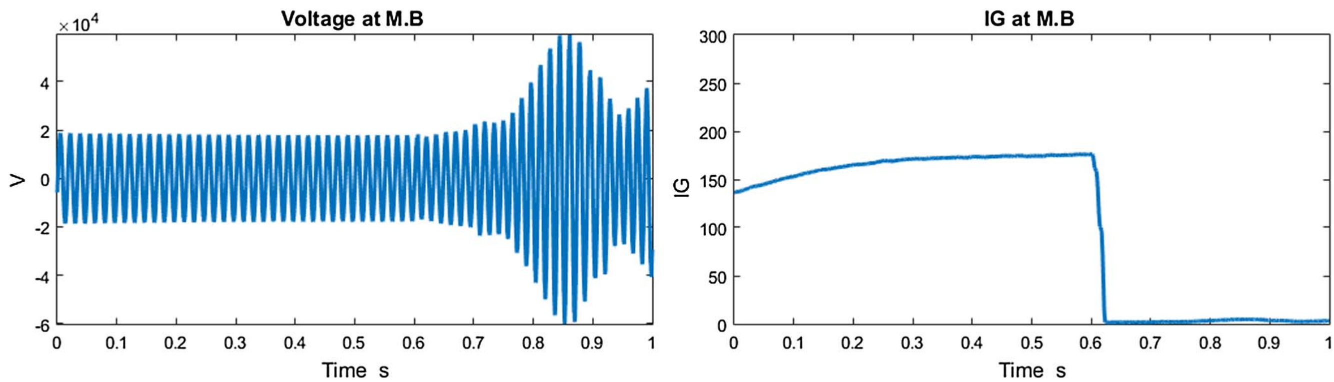

Fig. 5. The phase voltage V_a at M.B. and the current I_{G1} in M.T.L.

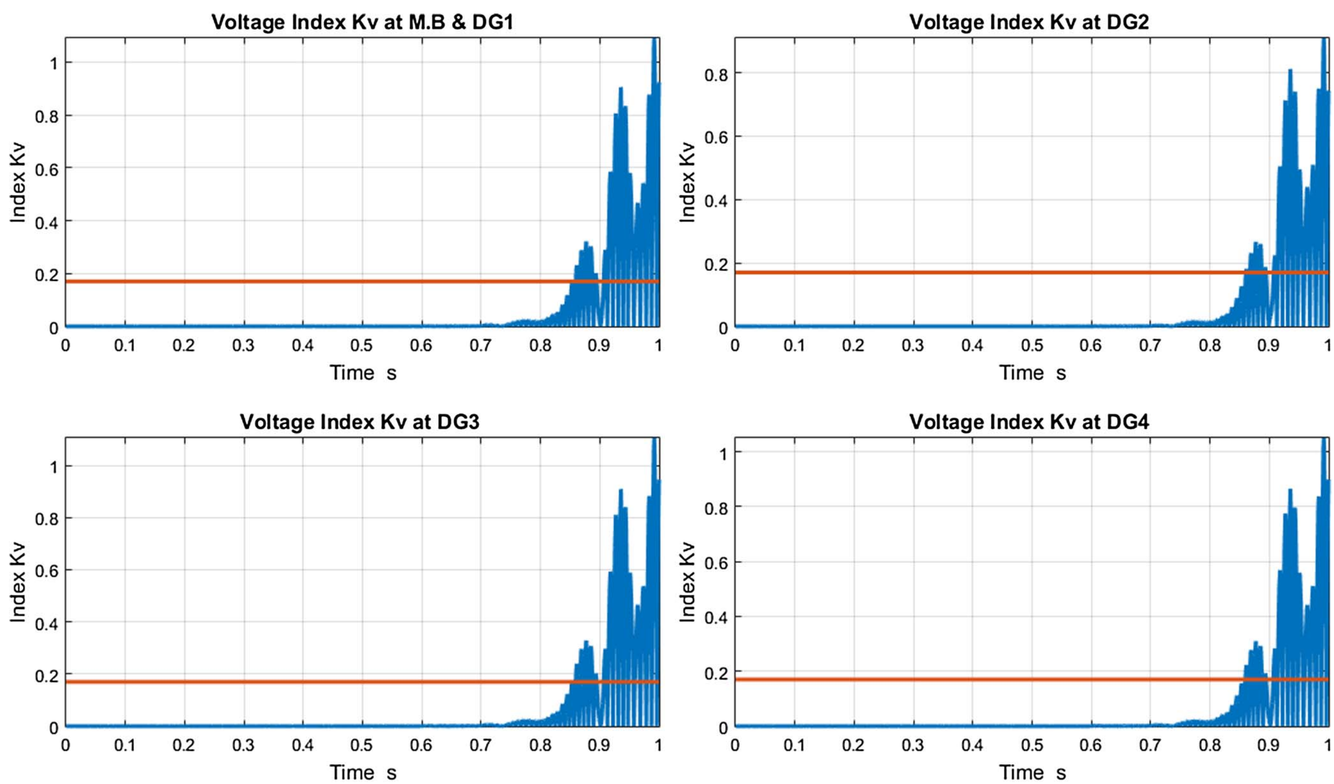

Fig. 6. The voltage index at DG units during islanding operation at a small power mismatch with capacitive load.

Table 5
Detection times for different loads at small active power mismatches.

Total load demand			Power mismatch		Maximum detection time T < 2 s
Active power P	Reactive power Q (L)	Reactive power Q (C)	P	Q	
17 Mw	9 Mvar	0	1 Mw	0	0.28 s
18 Mw	6 Mvar	0	0	3 Mvar	0.28 s
17 Mw	9 Mvar	−5 Mvar	1 Mw	−4 Mvar	0.25 s
18 Mw	6 Mvar	−5 Mvar	0	−8 Mvar	0.28 s

normal operation and islanding operation at a small power mismatch. LDS disconnects the loads connected to M.B. for a certain time.

3.2.1. Case 1

For a large active power mismatch between DG units and the total load demand, loss of mains (islanding operation) is detected when the voltage index (K_v) exceeds a predetermined threshold (k_o).

3.2.2. Case 2

For a small active power mismatch, the voltage index does not exceed the threshold (k_o) at all buses, but the line current I_{G1} in the main transmission line (M.T.L.) at the main bus is almost zero. In this case, the protective relay (R2) at M.B. initiates the load disconnection strategy (LDS). The time required to disconnect the loads connected to the bus is about 5 cycles (84 ms) .The target behind LDS is to protect the loads and transfer the islanding situation from a small active power mismatch to a large active power mismatch between the total load demand and DG units, which in turn results in a significant change in the voltage index at all buses due to loss of grid. The protective relays at other DG buses observe this change and issue trip signals to disconnect the DG units connected to those buses.

3.2.3. Case 3

In case of the grid contribution is very weak, the line current I_{G1} in the main transmission line (M.T.L.) at the main bus is almost zero. Therefore, the protective relay (R2) at M.B. initiates the load disconnection strategy and K_v is monitored. In this case K_v does not exceed

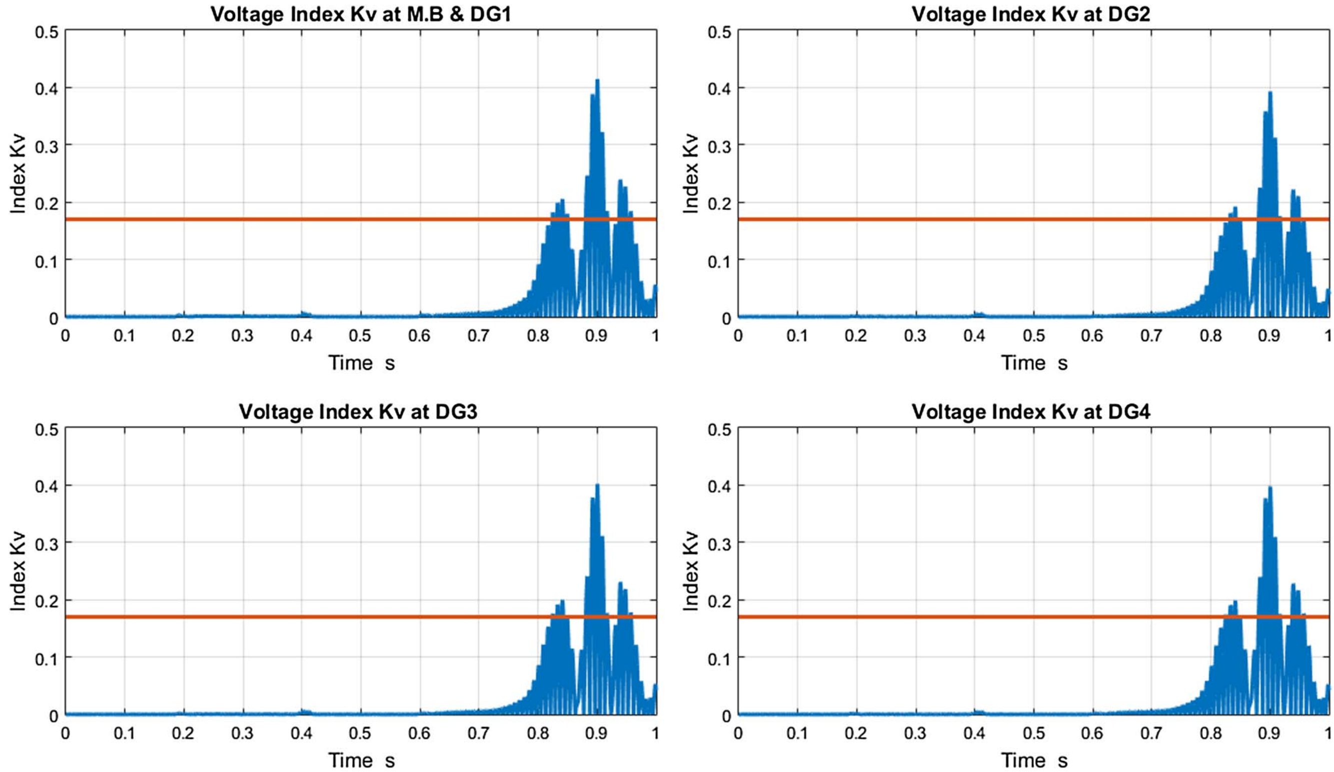

Fig. 7. The voltage index at DG units during a switching of a large load change and islanding operation.

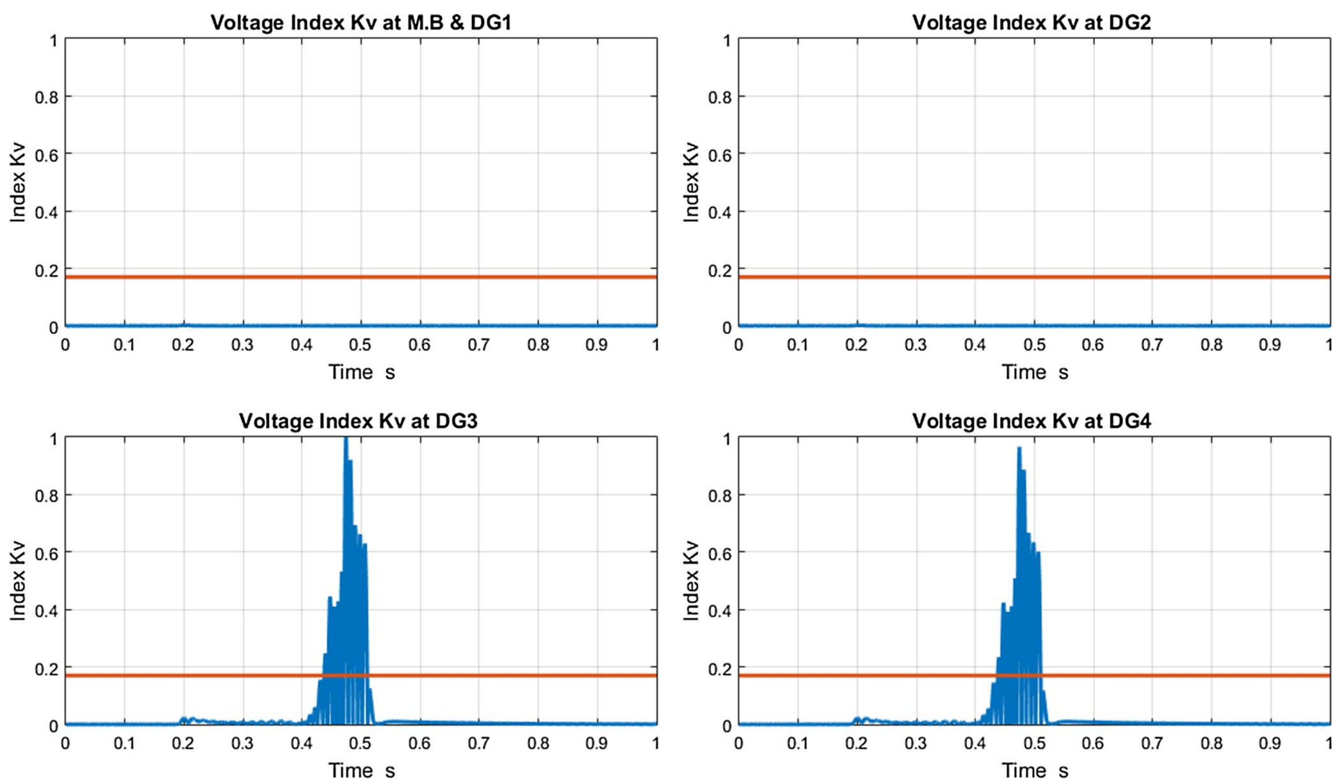

Fig. 8. The voltage index at DG units during separation of DG3 and DG4.

the specified threshold and the situation will be defined as a normal operation and the loads will be reconnected to the network.

3.2.4. Case 4

When one or more DG units are separated form rest of the distribution network (including the grid) and continue feeding the local loads, in such a situation one of the previous cases (case1 or 2) occurs. The islanding operation is detected if the voltage index (k_v) exceeds the specified threshold (k_o). Table 3 shows a summary of the flowchart for the possible cases under consideration.

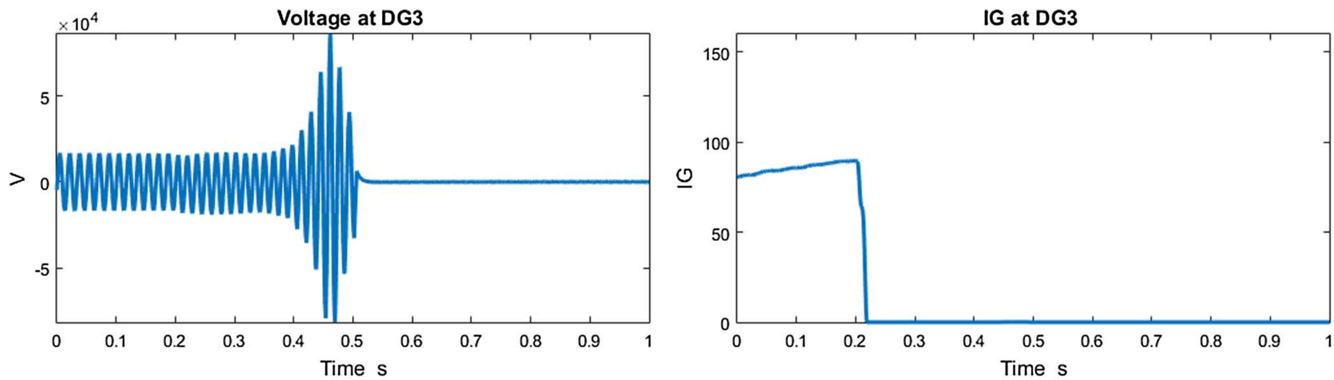

Fig. 9. The phase voltage V_a at DG3 and the current I_{G3} in F.T.L3 during separation of DG3 and DG4.

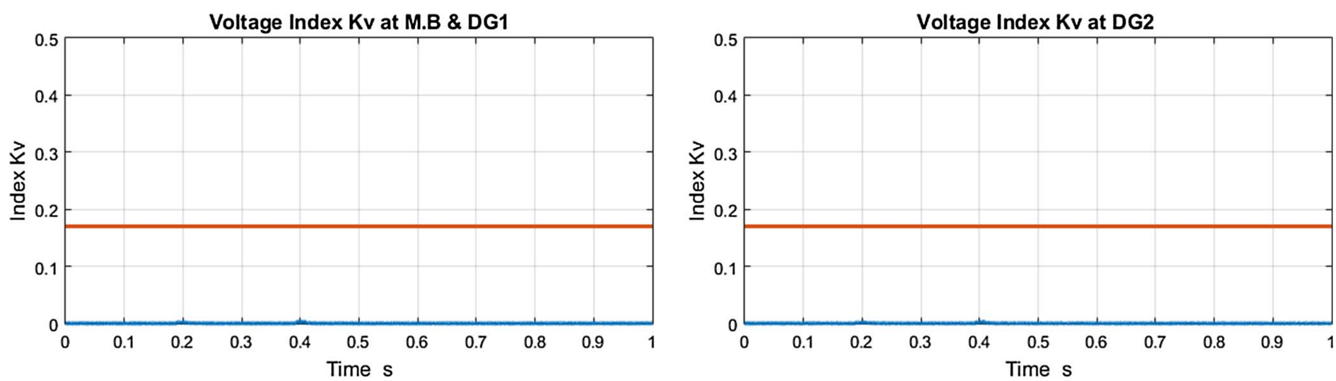

Fig. 10. The voltage index at main bus and bus2 during DG3 and DG4 tripping.

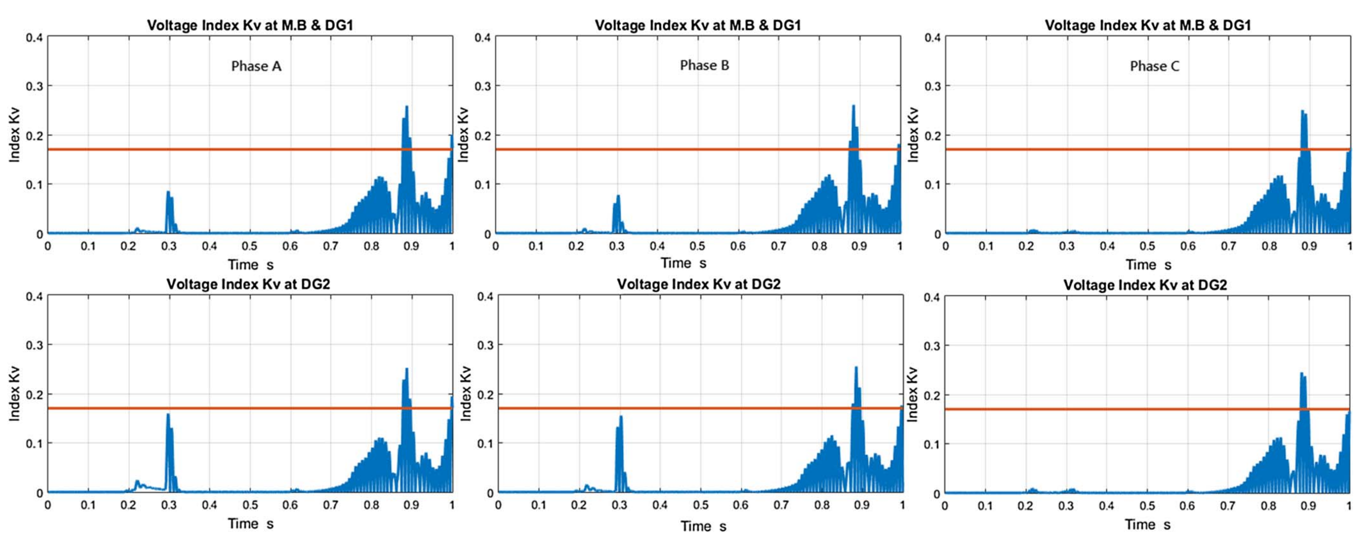

Fig. 11. The voltage index at all DG1 and DG2 during a double line to ground fault.

3.3. The threshold k_o

According to IEEE STD 1547, the voltage is allowed to be between 0.88 pu and 1.1 pu of the base voltage of the system. Also, the system frequency is allowed to be between 59.3 Hz and 60.5 Hz where the fundamental frequency is 60 Hz. In order to determine the threshold k_o, consider the maximum allowed changes in the voltage and frequency which occur at the lower limits. The threshold k_o is given as follows:

$$k_o = \Delta V \times AVV = \Delta V \times N \times V_{av} \quad \text{at } V = 0.88 \text{ pu and } f = 59.3 \text{ Hz Lower limits}$$

$$k_o = \Delta V \times N \times \left[\frac{1}{N} abs\left(\sum_{k=1}^{n} V(k)\right)\right] = \Delta V abs\left(\sum_{k=1}^{n} V(k)\right)$$

where n is number of samples corresponding to f = 59.3 Hz. $n = \frac{59.3}{60} \times N = 3294$ sample. $\Delta V = 1–0.88 = 0.12$ pu, and N = 3333 sample/cycle.

Consider the continuous form of the voltage signal is $v(t) = V_m \sin(\omega t)$ and the discrete form of the voltage signal is V(k) = [V(1) V(2) V(3) V(3) ……… V(n)…. V(N)]. By converting v(t) into samples using Matlab software, we get $k_o = 0.17$ pu.

Another way to calculate the threshold k_o by using the continuous form of the voltage signal. The threshold k_o is given as follows:

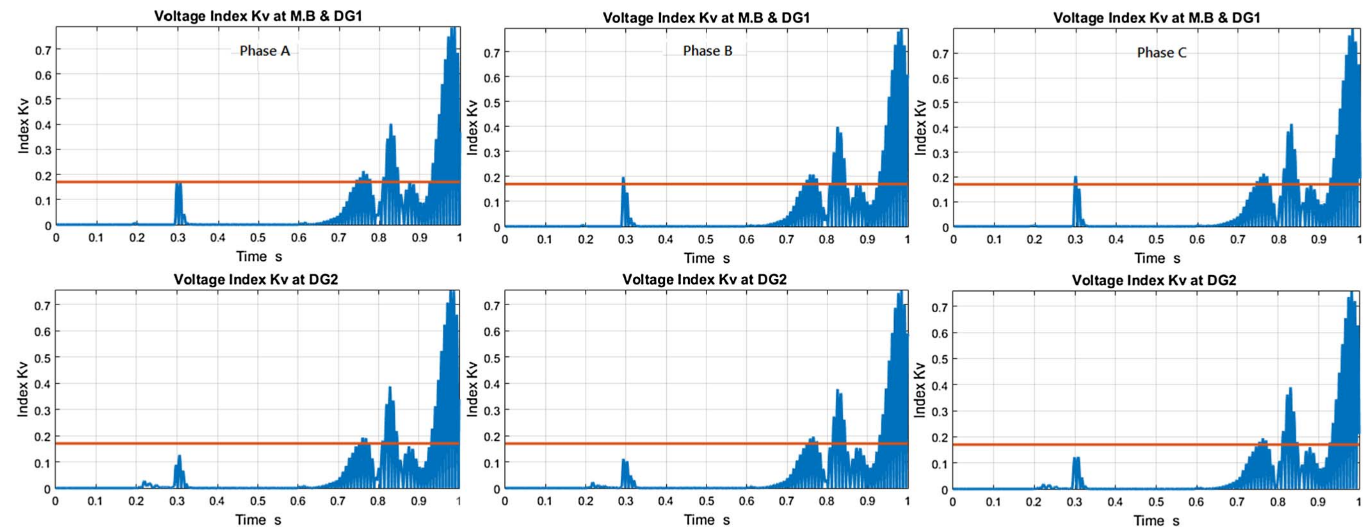

Fig. 12. The voltage index at all DG1 and DG2 during a symmetrical fault.

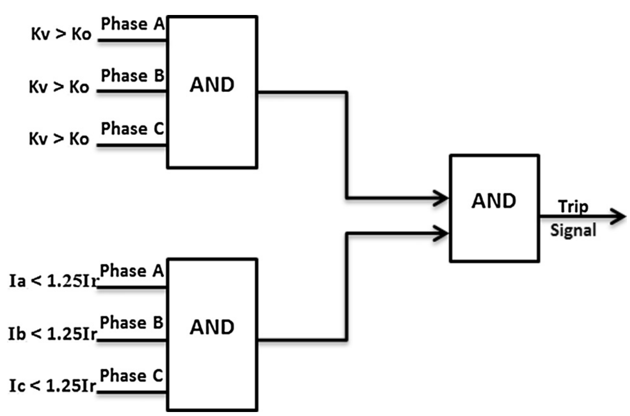

Fig. 13. A logic block diagram for islanding detection strategy.

$$k_o = \Delta V \times AVV = \Delta V \times N \times V_{av} = \frac{\Delta V \times N}{2\pi}\int_0^{\theta} V_m \sin(\omega t)\, d\omega t$$

Where θ is the angle corresponding to $f = 59.3$ Hz, $\theta = \frac{59.3}{60} \times 2\pi = 1.976\pi$ rad, $\Delta V = 0.12$ pu, $V_m = 1$ pu and N = 3333 sample/cycle. Using the previous data, we get $k_o = 0.17$ pu.

4. Simulation results

Simulations are conducted with MATLAB/SIMULINK software in order to evaluate the performance of the proposed method. The proposed method is validated on the power system under consideration shown in Fig. 1. Different events, such as islanding operation, load changes, capacitor bank switching, DG tripping, etc. have been simulated to demonstrate the effectiveness of the proposed method. The islanding situation is simulated in all simulations by opening the circuit breaker G.C.B. shown in Fig. 1 at t = 0.6 s. The following sections explain the study cases.

4.1. Islanding operation at a large active power mismatch

In this case, the utility grid is disconnected form the distribution system and the DG units (18 Mw & 9 Mvar) continue supplying the loads (11 Mw & 6 Mvar). The islanding operation occurs when there is a power mismatch of 7 Mw and 3 Mvar between the total load demand and the total generation of DG units.

Simulation results illustrated in Fig. 3 show that, when the islanding operation occurs at t = 0.6 s, the DG units attempt to keep supplying the loads within the specified limits for about 0.1 s but the voltage index starts exceeding the threshold (k_o) at each DG bus. Therefore, the protective relays send trip signals to disconnect the DG units. In case of large active power mismatches, the islanding operation is easily and rapidly detected by the proposed method. In this case, the maximum detection time of the islanding situation among the protective relays is almost 0.15 s (9 cycles). Simulations have also been done for different power mismatches and the results are expressed in Table 4.

4.2. Islanding operation at a small active power mismatch

In this case, the utility grid is lost at t = 0.6 s and the DGs continue feeding the loads (17 Mw & 9 Mvar) at a small active power mismatch between the total load demand and DGs generation. Under this situation, simulation results illustrated in Figs. 4 and 5 show that a small change is detected in the voltage index K_v between t = 0.6 s and 0.7 s, because the DG units keep supplying the loads within the specified limits. However, the line current (I_{G1}) in the front transmission line (M.T.L.) at the main bus is zero as shown in Fig. 5. Therefore, the protective relay (R2) initiates LDS. a trip signal is sent at t = 0.7 s to disconnect load L1 connected to the main bus in order to transfer the situation to a large active power mismatch, which in turn results in a significant change in the voltage index at all buses due to loss of grid. As illustrated in Fig. 4, after t > 0.8 s the voltage index K_v starts exceeding the threshold k_o. The protective relays at other DG buses detect this change and issue trip signals to disconnect the DG units. In this case, the detection time of the islanding situation is between 0.22 s and 0.28 s.

In order to test the performance of the proposed strategy under a capacitive load, a capacitor bank of 5 Mvar has been connected to the distribution system at load L3. Simulation results of Fig. 6 are the same as previous simulations of Fig. 4. Simulations have also been done for different active power mismatches and the results are expressed in Table 5.

4.3. Load increment and decrement

In addition to effective detection under islanding conditions, the proposed strategy is designed to work properly in non–islanding conditions as well. The response of the proposed strategy in non–islanding statuses is also tested by simulating the system under consideration for a large load switching (100% increase at t = 0.2 s and 100% decrease at t = 0.4 s). In this case, a load increment and decrement of 13 Mw and 5 Mvar is simulated when the total load demand is 13 Mw and 5 Mvar.

Table 6
Summary of islanding detection methods and their performances.

Method type		Concept	NDZ	Detection time	Disadvantages	System type	Power quality degradation
Passive method	The proposed strategy	Voltage and frequency variation	Zero	Small	NO	All types of DG configuration	NO
Hybrid method	Two level Islanding detection method [28]	Wavelet entropy algorithm and active frequency drift	Almost zero	Small	It is only applied for Inverter based system	Single or multi inverter system	Yes
Passive method	Deep learning islanding detection method [29]	Wavelet entropy is combined with deep neutral network	Almost zero	Small	Detection accuracy increases with bigger sample size	Single inverter system	NO
Hybrid method	Grid impedance estimation method [30]	Grid impedance estimation and the resonance injection	Zero	Small	The method application is more difficult for parallel-inverters	Multi inverters system	Yes
Passive method	Islanding detection algorithm [31]	Hilbert–Huang transform and extreme learning machine	Almost zero	Small	The method needs a massive set of data to train and test the classifier	All types of DG configuration	NO

Fig. 7 shows that when the sudden load is connected to the distribution system at M.B. at t = 0.2 s and disconnected at t = 0.4 s, no considerable changes are detected in the voltage index due to the presence of a strong power supply (the grid) and no action is done. Such load switching events do not have any effect on the proposed strategy. Also at t = 0.6 s, Fig. 7 shows an islanding operation to demonstrate the change in the voltage index during load changes and islanding operation. If the large load switching is replaced by switching of a capacitor bank of 5 Mvar, similar results to those of Fig. 7 are obtained.

4.4. Islanding operation due to separation of some DG units at a small power mismatch

This case represents a separation of two DG units (DGs 3&4) form rest of the distribution network while DG1 and DG2 are still connected to the system. The proposed strategy has also been designed to work and detect islanding under these circumstances. As illustrated in Figs. 8 and 9, when DG3 and DG4 units (9 Mw & 4.5 Mvar) are disconnected from the network at t = 0.2 s, by disconnecting F.T.L3, and continue supplying the local loads (L3 & L4 = 9 Mw & 4 Mvar) at active power match, the voltage index values at DG3 and DG4 do not exceed the threshold because DG units (3 &4) have the ability to continue supplying the loads within the allowed limits without changing the system parameters. On the other hand, the protective relay R6 at DG3 notices that the line current I_{G3} in the front line (F.T.L3) at DG3 is zero, therefore the protective relay R6 disconnects the load L3 and the voltage index is monitored. Simulation results of Figs. 8 and 9 show that, when the load L3 is disconnected at t = 0.4 s, a significant change in the voltage index is detected at DG3 and DG4. Therefore, the protective relays R6 and R8 discriminate this case as an islanding situation and send trip signals to disconnect DG3 and DG4 at t = 0.5 s. In this case, the detection time of the islanding situation is 0.23 s.

4.5. DG unit tripping

In this case, the performance of the proposed strategy will be further tested for DG tripping. DG tripping case is simulated at a small power mismatch between the total load demand and DG units. This case is simulated by tripping DG3 at t = 0.2 s and DG4 at t = 0.4 s. Fig. 10 illustrates that when DG3 (or DG4) is tripped, no considerable changes are detected in the voltage index at other DG buses due to the presence of the grid. Hence, no action is done. Such events have no effect on the proposed strategy.

4.6. Unsymmetrical faults

To further test the ability of the proposed strategy, unsymmetrical fault is simulated at a small power mismatch between the load demand and DGs. A double line to ground fault (ABG) starts at t = 0.2 s and is cleared after 6 cycles at t = 0.3 s without any circuit breaker operation. The fault occurs at the middle of the transmission line F.T.L2 that links DG1 and DG2. As illustrated in Fig. 11, when a double line to ground fault (ABG) occurs, remarkable changes in the voltage index of the faulty phases are detected at all buses but they are lower than the threshold. Since the result of the logic operation AND of the three phases is zero, no trip signals will be issued to disconnect the DG units. Such types of unsymmetrical faults have no effect on the proposed strategy. Also Fig. 11 shows an islanding condition at t = 0.6 s to demonstrate the change in the voltage index during unsymmetrical fault and islanding condition.

4.7. Symmetrical faults

Symmetrical faults have been proposed to investigate the influence of this type of faults on islanding detection. The simulations are performed in the condition that a three phase to ground fault at M.B. starts at t = 0.2 s and is cleared at t = 0.3 s without any circuit breaker operation. As illustrated in Fig. 12, when the symmetrical fault occurs, significant changes in the voltage index are detected at all buses but the voltage index exceeds the specified threshold only at the faulty bus (DG1). Since the result of the logic operation AND of the three phases is one at DG1 only, a trip signal will be issued to disconnect the DG units. Such type of faults leads to a misoperation for the proposed strategy. To avoid such type of faults, a further condition will be added to the proposed strategy. If the currents of the three phases exceeds 1.25 of the rated current (I_r) of the DG unit, the protective relay discriminates this case as symmetrical fault and does not issue a trip signal to disconnect the DG unit. Fig. 13 shows a logic block diagram for the proposed strategy after this modification. Again, our goal is to find a method is to detect islanding operation not faults. Also, Fig. 12 illustrates an islanding condition at t = 0.6 s to demonstrate the change in the voltage index during symmetrical fault and islanding situation.

5. Discussions

From the results of simulation for the study cases under consideration, it is noted that for islanding situation at large active power mismatches, the proposed strategy can easily detect islanding operation by monitoring the voltage index at the DG units. As illustrated in Fig. 13, the trip signal is sent to disconnect the DG unit when the result of the logic operation AND is one. However, for small active power mismatches, the proposed strategy can detect islanding operation by initiating the load disconnection strategy at M.B. Disturbances such sudden load changes or DG tripping or capacitor switching have no effect on the proposed strategy. Symmetrical and unsymmetrical faults lead to significant changes in the voltage index and currents, but the strategy has been modified as shown in Fig. 13 to avoid misoperation due to such faults. Finally, no event can mislead to the system, so the proposed strategy has no NDZ and can be used for multiple DG systems. A summary of islanding detection methods (including the proposed strategy) and their performances with respect to detection time, index of non-detection zone, and effect on power quality has been shown in Table 6.

6. Conclusion

A new passive islanding detection strategy has been proposed in this paper for multi-DG units. Wind farms power generation system has been presented as an example of distributed generation units. The proposed method is based on the concept of the main bus and the voltage index. The strategy is tested on a distribution system having four DG units of 5 MVA each. Example simulations are performed at different P-Q values in order to indicate the differences between the islanding operation and other events that may exist in the power systems and may cause misoperation for traditional techniques. The simulation results show that the proposed method can efficiently detect islanding operation. Furthermore, the proposed strategy has no NDZ and the detection time is less than 0.3 s. Also this strategy can be applied for any type of DG units such as PV systems. The algorithm is very simple and easy to implement besides it does not influence the power quality of the distribution network.

References

[1] Abd-Elkader AG, et al. Islanding detection method for DFIG wind turbines using artificial neural networks. Electr Power Energy Syst 2014;62:335–43.
[2] Manditereza PT, Bansal R. Renewable distributed generation: the hidden challenges–A review from the protection perspective. Renew Sustain Energy Rev 2016;58:1457–65.
[3] Laghari JA, et al. A new islanding detection technique for multiple mini hydro based on rate of change of reactive power and load connection strategy. Energy Convers Manage 2013;76:215–24.
[4] IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE Std 1547–2003, 2003: p. 1–28.
[5] Papadimitriou CN, et al. A novel islanding detection method for microgrids based on variable impedance insertion. Electr Power Syst Res 2015;121:58–66.
[6] Karimi M, et al. Photovoltaic penetration issues and impacts in distribution network – A review. Renew Sustain Energy Rev 2016;53:594–605.
[7] Bayrak G, Kabalci E. Implementation of a new remote islanding detection method for wind–solar hybrid power plants. Renew Sustain Energy Rev 2016;58:1–15.
[8] Bayrak G. A remote islanding detection and control strategy for photovoltaic based distributed generation systems. Energy Convers Manage 2015;96:228–41.
[9] Pinto SJ, Panda G. Wavelet technique based islanding detection and improved repetitive current control for reliable operation of grid-connected PV systems. Electr Power Energy Syst 2015;67:39–51.
[10] Khamis A, et al. A review of islanding detection techniques for renewable distributed generation systems. Renew Sustain Energy Rev 2013;28:483–93.
[11] Mohamad H, Mokhlis H, Bakar AHA, Ping HW. A review on islanding operation and control for distribution network connected with small hydro power plant. Renew Sustain Energy Rev 2011;15:3952–62.
[12] Heidari M, Seifossadat G, Razaz M. Application of decision tree and discrete wavelet transform for an optimized intelligent-based islanding detection method in distributed systems with distributed generations. Renew Sustain Energy Rev 2013;27:525–32.
[13] Chao KH, Yang MS, Hung CP. Islanding detection method of a photovoltaic power generation system based on a CMAC neural network. Energies 2013;6:4152–69.
[14] Khamis A, Shareef H, Mohamed A, Bizkevelci E. Islanding detection in a distributed generation integrated power system using phase space technique and probabilistic neural network. Neurocomputing 2015;148:587–99.
[15] Chao Kuei-Hsiang, Chiu Chia-Lung, Li Ching-Ju, Chang Yu-Choung. A novel neural network with simple learning algorithm for islanding phenomenon detection of photovoltaic systems. Expert Syst Appl 2011;38:107–15.
[16] Aljankawey AS, Liu Ning, Chang L. A new passive islanding detection scheme for distributed generation systems based on wavelets. In: Energy Conversion Congress and Exposition (ECCE) Conference, 2012 IEEE, 15–20 Sept. 2012; p. 4378–82.
[17] Widanagama N, Rajapakse Athula D. A pattern-recognition approach for detecting power islands using transient signals—Part II: performance evaluation. IEEE Trans Power Deliv July 2012;27(3).
[18] Kazemi Karegar H, Sobhani B, Kazemi H. Wavelet transform method for islanding detection of wind turbines. Renew Energy 2012;38:94–106.
[19] Ray Prakash K, Mohanty Soumya R, Kishor Nand. Disturbance detection in grid-connected distributed generation system using wavelet and S-transform. Electr Power Syst Res 2011;81:805–19.
[20] Shayeghi H, Sobhani B. Zero NDZ assessment for anti-islanding protection using wavelet analysis and neuro-fuzzy system in inverter based distributed generation. Energy Convers Manage 2014;79:616–25.
[21] Alshareef S, Talwar S, Morsi WG. A new approach based on wavelet design and machine learning for islanding detection of distributed generation. IEEE Trans Smart Grid 2014;5(4):1575–83.
[22] Heidarin Mehrdad, Seifossadat Ghodratollah, Razaz Morteza. Application of decision tree and discrete wavelet transform for an optimized intelligent-based islanding detection method in distributed systems with distributed generations. Renew Sustain Energy Rev 2013;27:525–32.
[23] Lidula NWA, Rajapakse AD. A pattern-recognition approach for detecting power islands using transient signals – Part II: performance evaluation. IEEE Trans Power Deliv 2012;27(3):1071–80.
[24] Reigosa D, Briz F, Blanco C, Garcia P, Manuel Guerrero J. Active islanding detection for multiple parallel-connected inverter-based distributed generators using high-frequency signal injection. IEEE Trans Power Electron 2014;29(3):1192–9.
[25] Al Hosani M, Qu Z, Zeineldin HH. A transient stiffness measure for islanding detection of multi-DG systems. IEEE Trans Power Deliv 2015;30(2):986–95.
[26] Gupta P, Bhatia RS, Jain DK. Average absolute frequency deviation value based active islanding detection technique. IEEE Trans Smart Grid 2015;6(1):26–35.
[27] Bakhshi R, Sadeh J. Voltage positive feedback based active method for islanding detection of photovoltaic system with string inverter using sliding mode controller. Sol Energy 2016;137:564–77.
[28] Shrivastava S, et al. Two level islanding detection method for distributed generators in distribution networks. Electr Power Energy Syst 2017;87:222–31.
[29] Kong X, Xu X, Yan Z, Chen S, Yang H, Han D. Deep learning hybrid method for islanding detection in distributed generation. Appl Energy 2018;210:776–85.
[30] Ghzaiel W, et al. Grid impedance estimation based hybrid islanding detection method for AC microgrids mathematics and computers in simulation 2017;131:142–56.
[31] Mishra M, et al. An islanding detection algorithm for distributed generation based on Hilbert-Huang transform and extreme learning machine. Sustain Energy Grids Netw 2017;9:13–26.