Chapter 6

Detection and Operation of Unintentional Islands in the Presence of Distributed Generation Units

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Additional information is available at the end of the chapter

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Abstract

The complexities and challenges for reliable operation of power system have increased due to various types of Distributed Generators (DG) in the Distribution Network (DN) to supply the increasing load demand. It necessitates a comprehensive approach in planning the system towards effective and reliable operation of the system. During the operation of the system, detection of unintentional islanding is critical as non-detection of islanding event could lead to cascaded failure of the system due to active or reactive power imbalance leading to frequency, angle or voltage instability. If undetected, the instability in the islanded part can cascade into the stable part of the system resulting in complete failure of the system. A robust Modified Islanding Detection Technique (MIDT) has been proposed for identifying the islanding event early and accurately in the distribution networks with DGs installed for multiple objectives and is compared with existing passive Islanding Detection Techniques (IDT). A rank-based load shedding scheme is proposed for stable and reliable operation of the identified island, which sheds only the most vulnerable loads in the island for regaining the frequency and voltage stabilities. The proposed MIDT and rank based load shedding schemes were tested on 11kV IEEE 118 Bus Test system.

Keywords: distributed generation, islanding, modified islanding detection technique (MIDT), rank-based load shedding, frequency stability, voltage stability, reliability

1. Introduction

Distributed generator (DG) is an electric power source connected directly to the distribution networks (DNs). The various definitions and technologies of DGs are described in Refs. [1, 2]. The importance of the DG units in the network is more profound with the emphasis on green energy technology and environmental concerns. DG plays a crucial role for the security, reliability, and efficiency of the modern power systems [3]. An exhaustive analysis of methods and models for optimal placement of DG units is given in Ref. [4]. The various techniques proposed for optimal placement of the DG units in the DNs, using various AI techniques for realizing the benefits of DGs like improvement of voltage profile, loss minimization, power transfer capability, uncertainties due to load and fuel prices, planning of dispatchable and non-dispatchable DG units, network security, reliability, etc. are described in Refs. [5–9].

The electrical isolation distribution system from the power system due to abnormal conditions, while being energized by the DG connected to it, is known as islanding [10]. During operation of the system, the detection of islanding event is critical in effective operation of the system. A comprehensive survey of islanding protection with renewable DG is reported in Ref. [11]. The islanding detection techniques are broadly classified into active and passive techniques [12]. Active islanding detection techniques introduce small perturbations in the system for detecting the islanding event. They have smaller nondetection zones (NDZ) but have large time of detection. As a result of the perturbations being introduced, the performance of the system degrades. Active techniques have been reported to work satisfactorily for single DG unit only and their response at multiple DG units is not guaranteed. The passive scheme utilizes local measurements of voltage and current signals. Many techniques ranging from usage of voltage variations and its derivatives, frequency variations and its derivatives, intelligent devices, etc. have been proposed for islanding detection in the presence of DGs in the system. The algorithms of passive scheme include under/over frequency and voltage, rate-of-change of frequency and power, vector surge, and harmonic distortion indices [13–18]. The passive methods have small time of detection and do not degrade the system power quality. However, the passive methods suffer from large NDZ.

The power mismatch may lead to collapse of the system, in the islanded part of the system, if proper corrective actions are not initiated timely. Load shedding is a commonly used emergency control action during mismatch of power in the island. Since the control action cannot be based on under-voltage, under-frequency load-shedding method is the commonly used method [19–22]. Most of the existing schemes need to be reinvestigated in the presence of DG units as load shedding depends on economic reasons along with technical reasons. In some cases higher amount of load shedding than required has been done since the load shedding has been performed on discrete basis in distribution systems to regain the stability.

The proposed modified islanding detection technique (MIDT) is based on utilizing the advantages of the existing passive methods of islanding detection with appropriate threshold values being identified for early and effective detection of the islanding event. In the proposed MIDT, in addition to the existing parameters used in the passive islanding detection techniques (IDTs), a new parameter is utilized for effective identification of the islanding event. The proposed parameter is based on the voltage sensitivity to the active power (voltage-active power sensitivity parameter (Δ_{VP})). A rank-based load-shedding scheme is proposed in the island to alleviate the power mismatch and to identify the island. The effectiveness of the proposed load-shedding scheme has been determined by a quantitative reliability analysis from the available failure data and reliability indices of the system.

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2. Proposed modified islanding detection technique (MIDT)

The complete blackout of the system may occur due to faults upstream or failure of the grid. The major requirement of installation of DG units in the distribution system is the ability to operate the system on islanded mode and also reducing the amount of load shedding needed under contingencies to achieve stable operation of the system. However, active or reactive power imbalance leading to frequency, angle, or voltage instability may take place in the unintentional islands or improper partition of the system. This further leads to instability in the interconnected network due to unwanted tripping of interconnected tie-lines. Hence, the unintentional islanding event has to be detected early and accurately to assist the system operator for ensuring appropriate control actions being initiated and avoid a blackout of the islanded region of the system.

The passive techniques have inherent disadvantage of large NDZ and requires accurate setting of threshold values of different parameters. Unwanted tripping occurs for low threshold values and higher threshold values may result in failure of detection of islanding event. The less cost of implementation of passive islanding detection techniques (IDTs) along with early detection of islanding makes it a most preferred method for IDT. Since the DG can supply only a small amount of load, the islanding has to be detected early and accurately. If undetected, the instability in the islanded part could cascade into the stable part of the system resulting in complete failure of the system. In the presence of DG units, the accurate identification of islanding becomes difficult due to complexity in monitoring the system parameters. Hence, the existing methods need to be reinvestigated for early and accurate detection of the islanding event. For accurate and early detection of islanding, the existing passive IDTs are modified by utilizing more robust parameters along with the existing parameters used in the passive IDTs. The existing parameters are used as alarm signals for the impending islanding event and the system enters into the alert state. The following parameters are utilized in the existing passive detection techniques:

The deviation in voltage at each bus is measured for every time instant as:

$$\text{Variation of voltage} = dV(\text{Volts}) \tag{1}$$

To avoid any errors in measurement, the voltage parameter is computed by averaging over five continuous cycles and is expressed in (V/s).

$$\text{Voltage parameter}(\delta_{vt}) = \left|\frac{dV}{dt}\right| < \sigma \text{ for 5 cycles} \tag{2}$$

σ is the predefined threshold value for the parameter and is taken as 160 V/s [17]. The frequency at each bus is measured and the deviation in frequency is calculated for every time instant as:

$$\text{Variation off requency} = df(\text{Hertz}) \tag{3}$$

The rate of change of frequency (ROCOF) is computed at every bus for each cycle and is expressed as frequency parameter in (hertz/seconds)

$$\text{Frequency parameter } (\delta_{ft}) = \left|\frac{df}{dt}\right| < \in \tag{4}$$

The ROCOF is used for fast islanding detection as the rate of change of frequency is a sensitive measurement. The ROCOF is calculated over few cycles and is set between 0.1 and 1.2 Hz/s for a 60 Hz system. The ROCOF relays may become ineffective if the power imbalance in the islanded system is <15% and is set as 2.18 Hz/s for 60 Hz system [14].

The variation of net active power is monitored at each bus for every cycle. The variation will be less in DG buses since the power available from DG units is fixed. The buses farther away from the DG bus will have more variations in active power for load variations

$$\text{Variation of active power} = dP(\text{MW}) \tag{5}$$

The ROCOP is calculated at each bus for every time instant in (megawatt/seconds)

$$\text{Rate of change of active power } (\delta_{Pt}) = \left|\frac{dP}{dt}\right| < \Upsilon \tag{6}$$

Υ is the predefined threshold limit and is fixed as 0.64 MW/s [14]. In this work, the parameters computed by Eqs. (3)–(5) are monitored and checked for threshold violation and the operator is alerted for an impending islanding event. Two additional proposed parameters are also monitored and computed for violations in the alert state. The voltage-active power sensitivity parameter (Δ_{VP}) is calculated by dividing Eq. (2) by Eq. (6) and the variation of voltage to real power parameter at a bus and is calculated in (volts/megawatt)

$$\text{Votlage active power sensitivity } (\mathit{\Delta}_{v\mathrm{p}}) = \left|\frac{dV}{dP}\right| < \mu \tag{7}$$

μ is the threshold value of the proposed voltage-active power sensitivity parameter and set at 10%. During simulations, it was observed that for "μ" values less than 10%, false triggering of islanding event set in and for greater threshold values some islanding events were not detected. If either the voltage parameter (δ_{vt}) or frequency parameter (δ_{ft}) or ROCOP (δ_{Pt}) violates the predefined threshold limit, a case of islanding is suspected and the system operator is alerted for an impending islanding event. Mathematically it can be expressed as*****:

$$\text{Islanding suspicion} = \left|\frac{dV}{dt}\right| > \sigma(or)\left|\frac{df}{dt}\right| > \in (or)\left|\frac{dP}{dt}\right| > \Upsilon \tag{8}$$

Subsequently, if the voltage-active power sensitivity parameter (Δ_{vp}) also violates the threshold limit at any bus when the system is in alert state, it is classified as an islanding event and the bus at which these proposed parameters initially violate the limit is identified for islanding.

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Mathematically it can be expressed as

$$\text{Islanding detection} = \text{Islanding suspicion and } \left|\frac{dV}{dP}\right| > \mu \tag{9}$$

A flowchart of the proposed MIDT is shown in **Figure 1**.

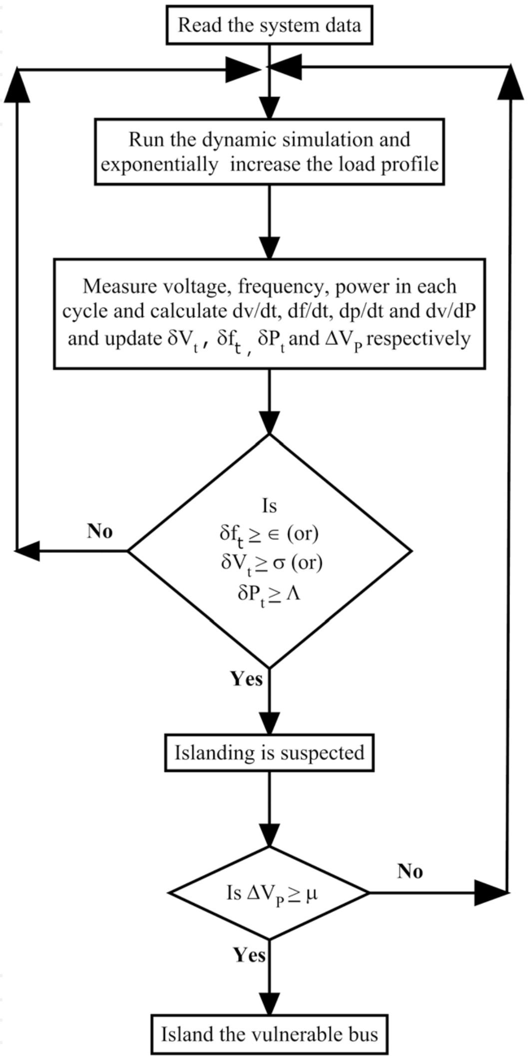

Figure 1. Flowchart for the proposed MIDT.

3. Rank-based load-shedding scheme with quantitative reliability analysis

The power mismatch in the islands makes the operation of islands a challenging task. The load shedding is an extensively used countermeasure for the stable operation of the island under such conditions. The quantitative reliability analysis gives a comprehensive idea to evaluate the merits of investing in various reinforcements for the system planner. Since it is based on the number of customers being affected, standard reliability indices help in measuring the effect of the load. A measure of number of customers affected by load shedding can also be obtained by the computed reliability indices. A rank-based load-shedding scheme is proposed for maintaining the power balance in the detected island when the power demand exceeds the power output of the DG sources in the island. The ROCOF and rate-of-change of voltage is utilized for ranking of the loads to ensure that the most vulnerable bus with overload for tripping is ranked higher. This ranking ensures that the DG bus does not participate in the load shedding as the frequency variation is not significant. The load shedding process continues till the frequency and voltages are brought back within threshold limits in the island. The total amount of load shed from each bus can be calculated as:

$$\text{Load shed} = DPC_{\mathrm{i}} \times P_{\mathrm{load,i}} \tag{10}$$

where $P_{\mathrm{load,i}}$ is the load at bus "i," DPC is the definitive participation coefficient for a particular bus and is calculated as:

$$\mathrm{DPC} = K_{\mathrm{i}} \times \zeta_{\mathrm{f}} \times \zeta_{\mathrm{v}} \tag{11}$$

where ζ_{f} and ζ_{v} are the coefficient of frequency and voltage components, respectively, of the buses and are calculated as follows:

$$\zeta_{\mathrm{f}} = \frac{f_{\mathrm{i,t}}}{f_{\mathrm{init,0}}} \tag{12}$$

$$\zeta_{\mathrm{v}} = \frac{V_{\mathrm{i,t}}}{V_{\mathrm{init,0}}} \tag{13}$$

where $f_{\mathrm{init,0}}$ is the frequency of the islanding bus when the islanding is detected $f_{\mathrm{i,t}}$ is the frequency at bus "i" when the proposed rank-based load-shedding process is initiated, $V_{\mathrm{i,t}}$ is the voltage at bus "i" when the proposed rank-based load-shedding process is initiated, and $V_{\mathrm{init,0}}$ is the voltage of the islanding bus when the islanding is detected. The value of K_{i} for the buses is given as:

$$K_{\mathrm{i}} = \begin{cases} 0, \text{ if DG is available} \\ 1, \text{ if DG is not available} \end{cases} \tag{14}$$

By the proposed method of load shedding, the amount of load being shed will be less than the total power demand in the island since loads of the most vulnerable buses are shed

$$\sum_{i=1}^{c} P_{\mathrm{Load\ shed,i}} < P_{\mathrm{L,island}} \tag{15}$$

considering "c" is the total number of buses in the island, $P_{\mathrm{Loadshed,i}}$ is the amount of load needed to be shed in the island to regain the stability, and $P_{\mathrm{L,island}}$ is the total demand in the island. As load shedding in the distribution system is performed in discrete values, the value of

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K_i is considered as either 0 or 1. At each step of the load-shedding process, the frequency, voltage of the islanded bus, and the power flow limits of the identified island are monitored during each step of the load-shedding process and mathematically expressed as:

$$f_{\min} \leq f_i \leq f_{\max} \tag{16}$$

$$V_{\min} \leq V_i \leq V_{\max} \tag{17}$$

$$P_{\min} \leq P_i \leq P_{\max} \tag{18}$$

The values of $f_{\min}$ and $f_{\max}$ are taken to be 57.5 and 60.5 Hz. The values of $V_{\min}$ and $V_{\max}$ are considered as 0.95 and 1.05 pu. The quantitative reliability of the islanded system is computed before and after the load shedding to measure the effectiveness of the proposed load-shedding scheme. The reliability analysis is performed through standard reliability indices and from the failure rate and repair time of the lines in the system. From the customer failure statistics [23], the standard quantitative reliability indices system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), energy not supplied (ENS), and average ENS (AENS) are computed. A flowchart of the proposed rank-based load-shedding scheme is shown in **Figure 2**.

SAIDI is system average interruption duration index and expressed in terms of hours per customer

$$\mathrm{SAIDI} = \frac{\sum \text{of Customer interuption durations}}{\text{Total number of customers}} = \frac{\sum U_i N_i}{\sum N_i} \tag{19}$$

where U_i is the annual outage time and N_i is the number of customers of load at point i.

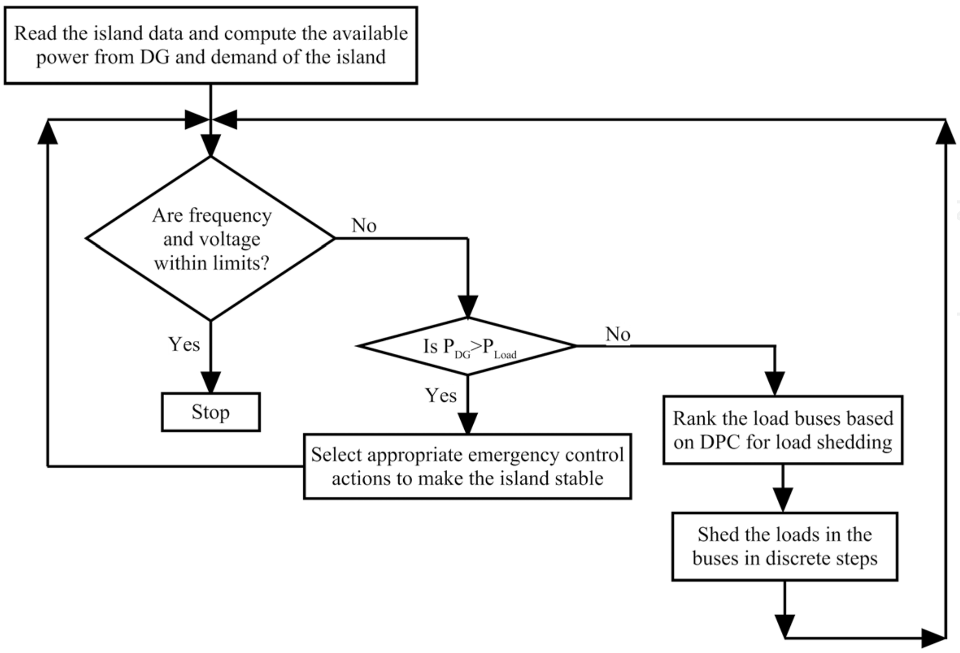

Figure 2. Flowchart of the proposed rank-based load-shedding scheme.

SAIFI is system average interruption frequency index and expressed as interruptions per customer

$$\text{SAIFI} = \frac{\sum \text{of Customer interuption durations}}{\text{Total number of customers}} = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{20}$$

where λ_i is the failure rate and N_i is the number of customers of load at point i.

CAIDI is customer average interruption duration index and expressed as hours per customer interruption

$$\text{AIDI} = \frac{\sum \text{of Customer interuption durations}}{\text{Total number of customer Interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \tag{21}$$

ENS is energy not supplied index and is measured as kilowatt hour

$$\text{ENS} = \text{Energy not supplied} = \sum L_{a(i)} U_i \tag{22}$$

$L_{a(i)}$ is the average load connected to load at point i

AENS is the average ENS index and is expressed in kilowatt hour per customer

$$\text{AENS} = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}} = \frac{L_{a(i)} U_i}{N_i} \tag{23}$$

4. Results and discussion

All simulations have been performed in MATLAB R2010a [24] and PSAT [25] Intel Core i5, 2.5 GHz, 4 GB random access memory machine. The proposed methods were tested for different loading conditions (base load and 140% of base load) on standard 11 kV IEEE 118 Bus Test system [5]. The DG units have been installed in the system by QOTLBO as mentioned in Ref. [5] and the loads are increased exponentially from the base load. The proposed MIDT is compared with existing passive IDT using the rate-of-change of voltage as given in Eq. (2) [3], ROCOF as given in Eq. (4) [15], and ROCOP as given in Eq. (6) [15]. In the proposed method, the rate-of-change of voltage with active power known as voltage-active power sensitivity is calculated along with voltage, frequency, and active power variations at each bus for every instant of time. The results of base case and extreme loading condition (i.e., 140% of base case) are considered for discussion in this work. The results obtained are shown in **Table 1**.

From this table, it can be seen that the proposed MIDT is effective in identifying the islanding event early and accurately. The frequency parameter initially triggers the MIDT. In the existing passive methods, since only one parameter is used for the identification of islanding events, the bus nearer to the grid is the vulnerable bus for islanding erroneously. In the passive method-II, at least three averaged values are needed for the identification of the islanding event as it uses averaging of voltage measurements for islanding detection, thus making a delayed identification

Loading level	Islanding detection											
	Passive method–I			Passive method–II			Passive method–III			Proposed method		
	Time of detection	Islanded bus	No. of buses in island	Time of detection	Islanded bus	No. of buses in island	Time of detection	Islanded bus	No. of buses in island	Time of detection	Islanded bus	No. of buses in island
Base load	1.052	4	38	1.083	23	Wrong trigger	1.0187	29	37	1.0187	31	18
140% of Base load	1.052	4	38	1.083	24	Wrong trigger	1.0187	29	37	1.0187	31	18

Table 1. Islanding analysis of 118 bus system with DG units.

of the islanding event. The proposed MIDT works satisfactorily when the minimum base load in the system is increased to 140% of the base load. The islanding event is simulated by increasing loads from t = 1 s and the islanding event is identified at time t = 1.05 s. As the effect of DG penetration cannot be effective on buses away from the DG buses, the islanded bus moves away from the grid as the minimum load in the system is increased. The MIDT as the variations of voltage to active power is considered for each bus overcoming the problem of NDZ prominent in the frequency parameter. The islanded bus is identified accurately by the proposed MIDT and is not triggered due to switching of capacitors or switching events. This occurs as the variations of all the parameters are considered in every bus. Moreover, as the cross-coupling of parameters, namely, the voltage-active power sensitivity parameter does not vary much during nonislanding events. The identification of islanding event is effective as the cross-coupling of parameters exhibit large variations only under actual islanding conditions. A comparison of the formation of the island by different methods is shown in **Figure 3**.

In the identified islands the proposed rank-based load shedding is initiated. The load shedding is initiated at t = 1.084 s, i.e., after two cycles (in 60 Hz) system after the islanding is detected. The effect of the DPC parameter on the load shedding is measured when load shedding is performed without the DPC parameter. The load shedding is performed by shedding the loads from the buses farther away from the DG bus when the DPC parameter is not considered leading to more amount of load shedding to regain the voltage and frequency stability. The results of the proposed load-shedding scheme in the islands are shown in **Table 2**.

The effect of the load-shedding scheme is measured by quantitative reliability analysis, based on the failure data of the line and the repair time of the lines. The results of the reliability analysis are shown in **Table 3**. It can be seen from the indices that the number of customers affected by the proposed load-shedding scheme is less by considering the DPC parameter for load shedding.

The variations of frequency and voltage at the islanded bus, before and after the proposed load shedding, are shown in **Figures 4** and **5**.

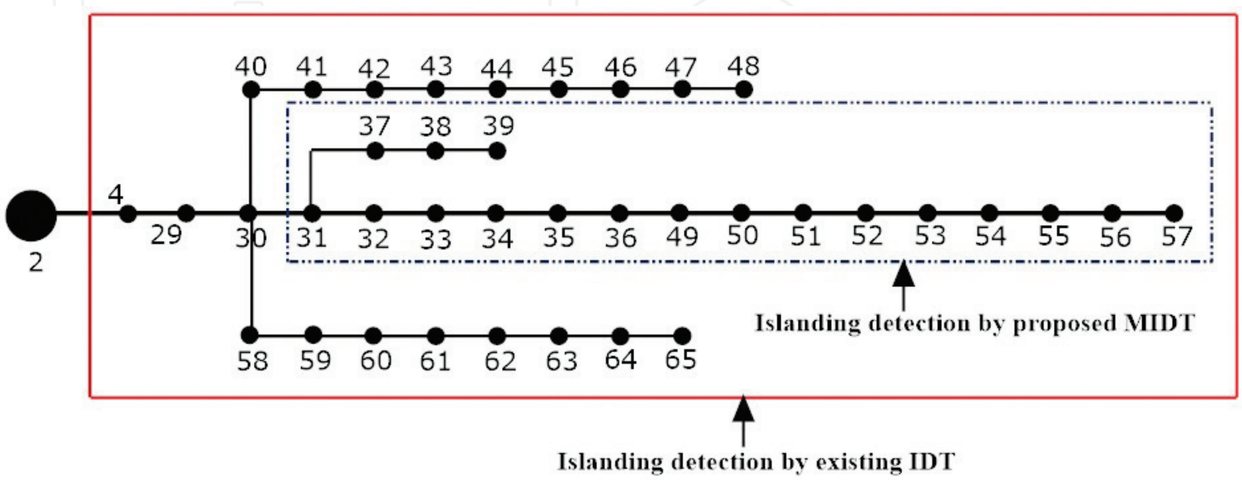

Figure 3. Identification of islands by proposed MIDT and existing IDT.

Load shedding technique	Islanded bus	Number of buses in the island	Power available, MW	Load, MW	Actual load shed, MW	Amount of load shed, %
With DPC	31	18	4.8302	7.612		
Without DPC	31	18	4.8302	7.612		

Table 2. Load shedding in island at base load.

Cases	Before load shedding					After load shedding				
	SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
With DPC	0.3463	0.4090	0.8466	1.38	0.0511	0.3403	0.3993	0.7983	0.72	0.036
Without DPC	0.3463	0.4090	0.8466	1.38	0.0511	0.3419	0.4035	0.8428	0.9	0.05

Table 3. Reliability analysis of the island.

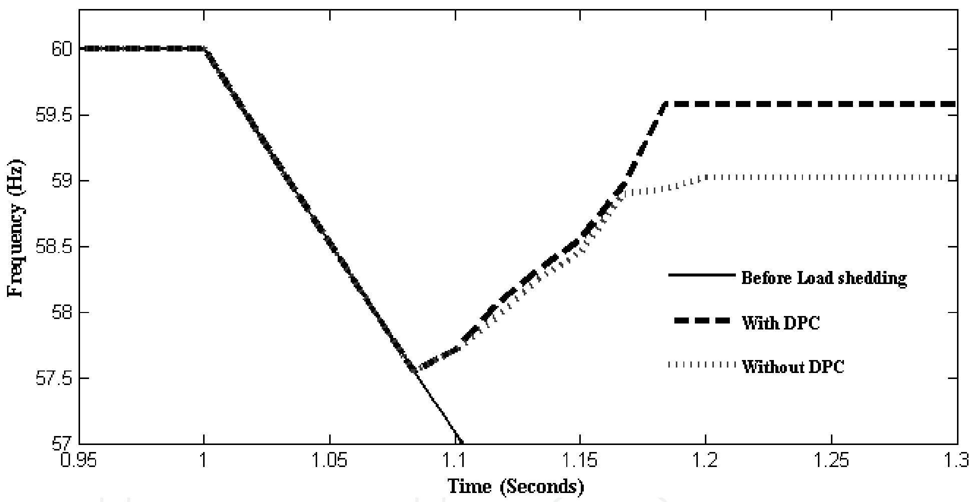

Figure 4. Comparison of frequency at islanded bus before and after load shedding.

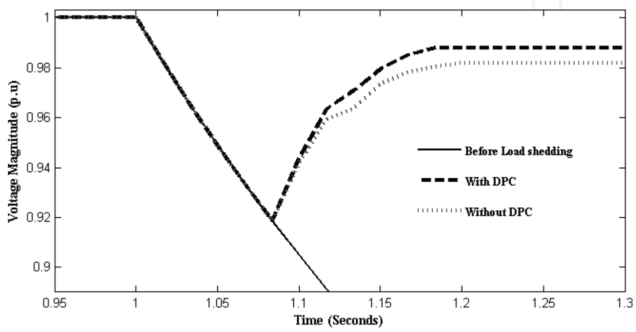

Figure 5. Comparison of voltage at islanded bus before and after load shedding.

As seen from the figures, the regain of frequency and voltage in the islanded bus is faster and effective by the proposed rank-based load-shedding method which considers the DPC parameter as the most vulnerable loads are shed from the islanded part of the system.

5. Conclusion

For identifying the islanding event in the presence of DG units, an additional voltage-active power sensitivity parameter which measures the variation of voltage with active power at a bus is proposed along with the existing parameters utilized in the passive IDTs. The additional voltage-active power parameter ensures against the false triggering of islanding event and also identifies the vulnerable bus accurately. Due to cross-coupling of voltage-real power and frequency-reactive power, the proposed parameter is more sensitive to sudden large load variations or disturbances and does not trigger the islanding event due to sudden switching of loads or capacitor switching events.

The proposed rank-based load shedding identifies the vulnerable buses for load shedding by using a dynamic DPC parameter. The amount of load shed by the proposed method is lesser compared to the conventional load shedding strategy for regaining the frequency and voltage stability in the island. The availability of DG unit, frequency, and voltage variations in a bus is taken into account in the proposed DPC parameter for identifying a bus for load shedding. The effectiveness of the proposed load shedding is analyzed by a quantitative reliability analysis in the islands before and after the load shedding. The reliability indices are improved as the number of customers affected by the load shedding is less. This is because only the vulnerable loads are shed when DPC parameter is considered. The proposed DPC parameter is effective in improving the reliability of the island as the reliability indices also depend on the number of customers being affected. Further investigations are needed for proper control actions when the DG power available is more than the demand in the island.

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