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An Isolation Detection Technique for Distributed Generators Based on Inverter for Power Quality Improvement

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Abstract: *In the present paper, an isolation method of detection for the inverter-based system of Distributed generators is proposed and based on perturbing output of reactive power. In the proposed method two sets of the disturbances are designed and have different magnitudes and time durations. In the primary set of reactive power disturbance, amplitudes are periodic and small to break reactive power balancing during isolation process. The secondary set of reactive power disturbance is required for deviation of the frequency beyond its threshold limits. The characteristics of the frequency variations with primary set after isolation are considered and three criterion are designed for switching the disturbances from primary set to secondary set of RPD. All the DGs which are located at different positions have same variation in frequency characteristics and primary set of RPD can be added to different DGs without any further communication at the same instant. Here, synchronization of the secondary set of disturbances can be guaranteed for a system with the multiple DGs. The proposed method is applied to DGs which operate at UPF or for supplying of reactive power to the local loads and the method is validated with cases mentioned in the Matlab/Simulink environment.*

Keywords*: Distributed generation, Reactive Power Disturbance (RPD) , isolation detection, synchronization*

I. Introduction

Renewable energy such as photovoltaic, fuel cell, wind power and microturbine etc. are used by the inverter-baseddistributed generator(DG) to supply power for the network and local load [1],[2] which is being extensively applied to protect environment and make the power industry development renewable. For ensuring the safe operation of both the network and DG, the islanding detection function and the DG are to be equipped according to IEEE Std. 929-2000 and IEEE Std. 1547-2003 [2].

For supplying of power to the network and local loads , renewable energy sources like fuel cell, wind, photovoltaic cells, micro-turbine are inverter based distributed generation(DG).

The condition in which a portion of the utility system containing both the DG and load continuous operating while this portion is electrically separated from the main utility is said to be islanding. Accidental islanding can result in power quality problems, serious equipment damage, and even safety hazards to utility operation personnel [3]. Hence, the DG needs to detect islanding effectively in this case and disconnect itself from the network immediately to prevent the damages specified earlier.

A maximum delay of 2 s is required for the detection of an islanding and generic system for islanding detection study is recommended, where the distributed network, the RLC load and the DG are connected at the point of common coupling(PCC) according to the standards of IEEE Std. 929-2000 and IEEE Std. 1547-2003.
Islanding detection methods are categorized into three types: 1) Communication-based methods; 2) active methods and 3) passive methods. In theory, the communication-based methods does not harm the power quality of the power system and does not have any non-detection zones (NDZ).

Further, the effectiveness cannot be guaranteed with the risk of communication breakdown [4]. Hence, passive and active methods are well developed. So, to reduce or eliminate the NDZ, active methods depends on accidentally injecting disturbances, negative sequence components or harmonics into some DG parameters to identify whether islanding has occurred [4]. [5].

Passive methods obtain the condition of islanding by the measurement of system parameters like voltage at the PCC, PCC frequency and also phase jumps [5]. They are easy for the implementation but it may fail to detect islanding when DGs output power is almost equivalent to power consumption of the local load [6].

The slip-mode frequency shift [16], active frequency drift [8] and Sandia frequency shift [9] methods are the three classical active methods which creates a continuous trend to change the frequency during islanding. The active methods sacrifice power quality and reliability of the power system duringnormal operation though they suffer smaller NDZs. Furthermore, some active methods have difficulty in the maintenance of synchronization of the intentional disturbances. Hence, they may not work owing to the averaging effect when it is applied in multiple-DG operation [10]

Newly, schemes based on reactive power control to detect islanding are attractive and many methods are proposed [11]-[16]. To detect islanding, the basic mechanism of the methods is to create the reactive power mismatch that drives the frequency of the PCC voltage to change at the time of islanding. This is achieved only by redesigning reactive power reference for the DG or injecting reactive power/current disturbance that can be easily implemented. The idea here is inspired by the studies in [12] and [13].An islanding detection method based on intermittent bilateral reactive power variation (RPV) was proposed in [12].

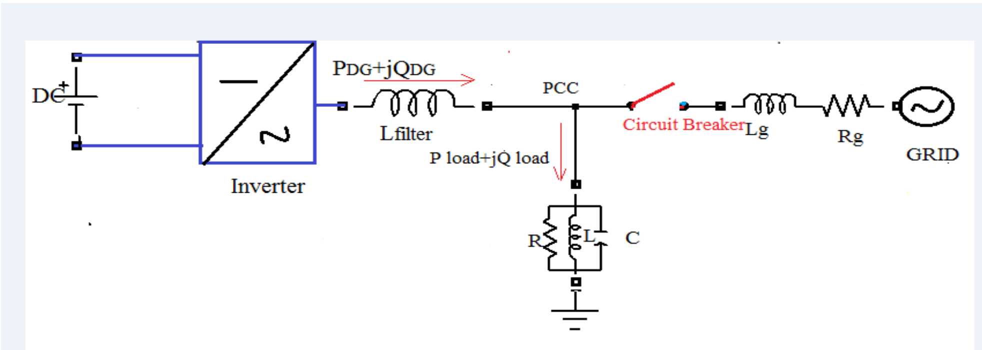
Anyhow, both the methods suffered a serious problem i.e., the synchronization of the RPVs could not be guaranteed when the methods were applied to multiple DGs. Hence, the effectiveness of the methods was reduced and might fail to detect islanding for the system with multiple DGs. Nevertheless, the DG was also explored to generate both active and reactive power together for power factor improvement [16],as well as the voltage regulation [15], [17]. The methods that were proposed in [12] and [13] were applicable only for the DG operating at unity power factor'.

In this paper, the relationship between the reactive power disturbance and the frequency variation during islanding for the DG generating both the active and reactive power is analysed. This is different from that for the DG operating at unity power factor. Furthermore, this paper presents an innovative islanding detection method, that is based on annoying reactive power output as well.

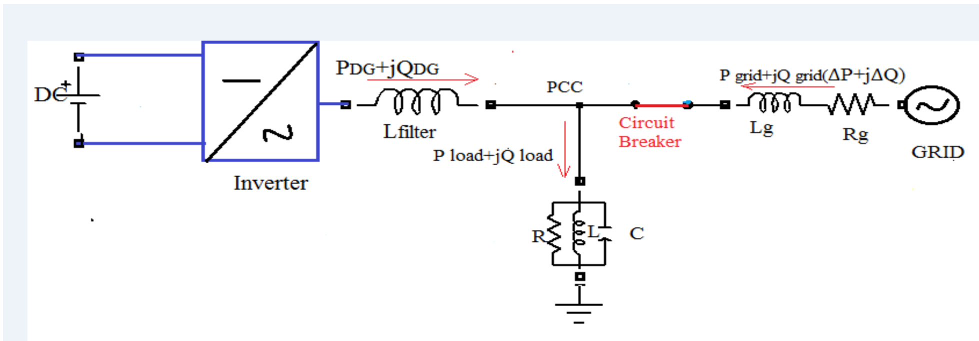
Here, two sets of Reactive Power Disturbances (RPD) are designed and have different duration time and amplitudes. They are Primary set of RPD is always periodic and has small amplitudes and the Secondary set of RPD has the magnitude which is sufficient for forcing frequency and also to deviate outside the threshold limit during the process of islanding. With all possible variations of frequency characteristics with primary set of RPD after islanding, three conditions are designed for switching of disturbance from primary set to secondary set of RPD.

As the DGs located at different positions have the same frequency variation characteristics, the SSORPDs on different DGs can be activated at the same time without the need for communication.

Hence, the proposed method has following three differentiating features: 1) It can either be applied to the DG operating at unity power factor or supplying reactive power as well for its local load; 2) The perturbation of reactive power further reduced during normal operation; 3) The synchronization of disturbances can be guaranteed for the system with multiple DGs and the method can detect islanding with NDZ property.



(a)



(b)

Fig. 1. Islanding detection operation for (a) Isolated operation mode (b) Grid connected mode

II. Basic Relationship Analysis And Reactive Power Variation Methods

A. Modelling of the System and basic Analysis

The recommended test system of IEEE standard for detection of Islanding is shown in Fig.1. It consists of a Grid with source behind impedance, an inverter based Distributed Generation, parallel RLC load. The inverter based DG such as wind power, photovoltaic generation is always designed with MPPT controllers. During the process of identification of islanding, process time is very short, output power is considered constant during the process. So, a constant DC source is used and DG is considered as constant source of power. The operation method of DG depends on closing and opening of circuit breaker.

In Fig. 2 DG interface control of block diagram is represented. DG controls the active and reactive power output using instantaneous power theory and park's transformation independently. In the Fig. 2 since DG is connected to utility grid, below equations describe power flow of active and reactive power consumption of load.

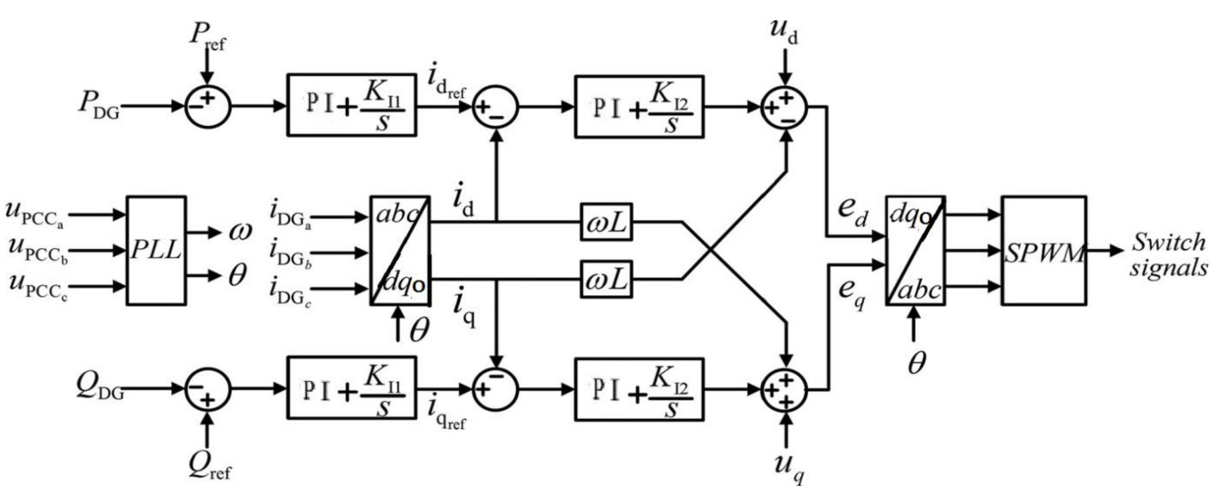


Fig. 2 For constant power operation DG interface control

$$P_{Load} = P_{DG} + P_{Grid} = 3\frac{V_{PCC}^2}{R} \qquad (1)$$

$$Q_{Load} = Q_{DG} + Q_{Grid} = 3V_{PCC}^2\left(\frac{1}{2\pi fL} - 2\pi fC\right) \qquad (2)$$

Resonant frequency fo and quality factor Qf are expressed as

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (3)$$

$$Q_f = R\sqrt{\frac{C}{L}} = 2\pi f_0 RC \qquad (4)$$

As per the IEEE STD, 929, $Q_f$as referred from the equations (1) to (4) is

$$Q_{Load} = Q_{DG} = P_{Load.i}Q_f\left(\frac{f_0}{f_i} - \frac{f_i}{f_0}\right) \qquad (5)$$

If there is active power mismatch it can be inferred from Fig. 1(a) , ΔP is not equal to zero. DG operates at power factor of unity PCC voltage may rise or fall and the magnitude of deviation in voltage is based on value of ΔP. If the reference value of active power in DG is set to a constant value the ΔP is expressed as

$$\Delta P = P_{DG}\left(\frac{1}{(1+\Delta V)^2} - 1\right) \qquad (6)$$

And ΔV represents voltage deviation and it is obtained by

$$\Delta V = \frac{V_{PCC.i} - V_{PCC}}{V_{PCC}} \qquad (7)$$

Also , it can be inferred from equation (5) , if there is any reactive power mismatch it causes frequency variation once process of islanding occurs. So, frequency variation can also be used for the detection of islanding which is based on UPF/OFP method. During the process of islanding power consumed by load is same as generated by DG. According to (8), the required reactive power disturbance to force the frequency to deviate from fi to its target value (Qdis) can be expressed as shown below

$$Q_{dis} = P_{DG}Q_f\left(\frac{f_0}{f_i + \Delta f} - \frac{f_i + \Delta f}{f_0}\right) \qquad (8)$$

where Δf is the frequency y deviation and it can be expressed as

$$\Delta f = f_{i.tar} - f_i \qquad (9)$$

fi.taris the target frequency and it is set to any value which is beyond the normal range of the frequency.So, the relationship between *Q*dis and Δ*f*are to be modified when the DG supplies both active and reactive power for the local load. The frequency will not change after islanding when there are no power mismatches.

B. Methods of Islanding detection in [12],[13]which are based on Reactive Power Variation

The islanding methods of detection which are based on the disturbance of reactive power are better choice when compared to the method based on active power disturbance . The islanding detection methods for the DG operating at unity power factor based on periodical bilateral and unilateral reactive power variations are presented in [12], [13].

The DG's reactive power reference (Qref) switched among three different values in each of the variation period in [12] can be expressed as follows$Q$ref

Qdis,0 $\leq t < T+Q$

$= -Q$dis, $T+Q \leq t < T+Q+T-Q$ (10)

0, $T+Q+T-Q \leq t < T$dis

The rated value of Qref is zero for the DG operating at unity power factor. The RPV methods which are mentioned previously, the bilateral and unilateral reactive power disturbance on the DGs reactive power reference intermittently added to force the frequency to deviate during islanding. The islanding can be detected effectively, by applying these methods to single DG.

Despite of all, when applied to multiple DGs, the variations that are synchronized could not be guaranteed in both the methods. Due to the averaging effect, detection of islanding for the system with multiple DGs might be failed to detect.

Fig. 3 illustrates the separate and total reactive power variations for the system with two DGs, as per the method in [13], where the reactive power disturbance on the DG2 diminished behind than DG1and f0 is 50 Hz. Hence, at the time when islanding occurs, the variation on DG1 forces the frequency to increase earlier and the frequency was larger than 50 Hz when the variation started on DG2. Consequently, the variation magnitude on DG2 was less than 5% PDG2.

Considering that the active power references are same for both the DGs (PDG1 = PDG2), after islanding, the maximum value of the total reactive power variation was smaller by 10%PDG1 whose duration time is less than T1. Hence, to force the frequency to depart outside its limits, the reactive power variation was not sufficient and the method failed in detecting islanding. The analysis for multiple - DGs is similar for the performance of the method in [12].

Fig. 3. A system with two DGs with separate and total reactive power Disturbance as in [13] method.

Both the methods mentioned earlier were prepared for the DG operating at unity power factor. As figured in section II-A, the value of Q_{dis} will be unpredictable, if the DG is generating reactive power as well to improve the load's power factor and voltage quality. In addition, the reactive power disturbances on multiple DGs can be still asynchronous. Hence, these methods may no longer be applicable for the DG of this kind.

III. Proposed Islanding Detection Method Which Is Based on Reactive Power disturbances (RPD)

For the improvement of the performance of detection of islanding
methods which are based on the reactive power disturbance, the following three problems need to be solved: 1) the method needs to be applicable to the DG operating at unity power factor and that generating reactive power as well; 2) it is better to reduce the disturbance on the DG as much as possible during normal operation and it also need to be sufficient to drive the frequency outside its threshold limits after islanding; and 3) need to guarantee the synchronization of the disturbance on different DGs. As studied in Section II, the relationship between f0,fi, and Qdis are different for these two kinds of DGs. Taking into account the different relationship characteristics, the proposed method can detect islanding effectively for both the kinds of DGs.

As mentioned earlier, to solve the second problem, two sets of reactive power disturbances with different amplitudes and duration time are designed in the proposed method. The Primary Set of RPD (PSRPD) is periodic with small amplitudes, whereas the magnitude of Secondary Set of RPD (SSRPD) is sufficient to force the frequency to deviate from its threshold limits during islanding. Further considering all the possible frequency variation characteristics with the Primary set of SRPD after isolation, to switch the disturbance from the Primary to Secondary set of RPD, three criterions are designed. As the DGs located at different positions can detect the same frequency variation characteristics, theSecondary set of RPDs on different DGs can be activated synchronously without the need for communication. The proposed method is introduced in detail in the following parts.

A. Primary set of RPD and The Three Different Criterion for Switching Disturbance From the Primary to the Secondary set of RPD

During isolation, the reactive power disturbance can itself break the reactive power balance, thus NDZ can be eliminated possibly. Further, the design of the PSRPD also has to act in accordance with the following two principles: 1) During normal operations, the disturbances must be reduced as much as possible and 2)Need to form criterion after starting the SSRPD after islanding. In order to meet the earlier mentioned requirements,the PSRPD is designed to contain two parts whose amplitudes are *Q*dis1 and 2*Q*dis1,respectively, and it is added on the DGs rated reactive power reference periodically.

The value of *Q*dis1 is equal to either of *Q*dis11 or *Q*dis12, that depends on the frequency at the beginning of the Primary set of RPD also Δ*f*set is a preset positive value and *f* is the instant frequency at the beginning of the Primary set of RPD. Furthermore, the duration time of the first part is the same as that of the second part.

The premise of the first criterion is the synchronization of the Primary set of RPDs for the system with multiple DGs. On the other hand, this premise cannot be guaranteed and the total disturbance might not be adequate to force the frequency to be larger than 50.3 Hz or smaller than 49.7 Hz at the time of islanding. Furthermore, when the DG generates both active and reactive power simultaneously, *f*0 cannot be obtained in advance as well and it may not be equal to 50 Hz. Hence, the first criterion might not be satisfied during islanding. Hence more criterions are needed. Two possible cases that the PSRPD are asynchronous: 1) the overlap region exists among the PSRPD on several DGs and 2) the PSRPD on one DG does not overlap with the other DGs. By considering the frequency variation characteristics that corresponds to the previously mentioned two conditions during islanding, another two criterions are designed.

Hence, the second criterion is designed based on this characteristic. So, to obtain a precise measurement of the frequency variation, the sum of absolute frequency variation (SOAFV) ΔF total is used and its value is calculated by *T*win is the measurement window size,*T*sam is the sampling time, *N* is the total sampling number in a measurement window, and *fn* is the *n*th *sampling value of the instantaneous frequency.* The second criterion is the time difference between two adjacent maximum values of ΔFtotwhich is equal to Tdis .

Table – I

Criterions For Switching The Disturbance From The Primary Set Of RPD To The Secondary Set Of RPD

Criterion	Content	Corresponding Condition
First	1) f > 50.3 Hz or f < 49.7 Hz; 2) its duration time is no less than T_{dur}	1) The primary set of RPDs are synchronous or the non-synchronization is not serious.
Second	1) The SOAFV is periodic; 2) its cycle time is equal to Tdis .	1) The primary set of RPDs are asynchronous; 2) some primary set of RPDs overlap with each other.
Third	1) The SOAFV satisfies equation (11) 2) the frequency variation is not zero.	1) The primary set of RPDs are asynchronous; 2) a certain primary set of RPD does not overlap with the others.

Previously mentioned three criterions for switching the disturbance from the primary set of RPD to the Secondary set of RPD are shown in Table I. The second and the third criterions are complement to each other, that can reduce the starting time of Secondary set . Furthermore, the two criterions reflect the frequency variation characteristics corresponding to the primary set RPD at the time of islanding. Hence, when either of these criterions is satisfied, the operation mode can be primarily judged as the suspected islanding.

B. Secondary set of RPD and Two Criterions for Determination of islanding

As the DGs located at different positions have the same frequency variation characteristics, the Secondary set of RPDs on different DGs can be activated at the same time without the need of communication. The designed Secondary set of RPD has the ability to force the frequency to deviate outside its threshold limits and determine islanding finally. Hence, when compared with the Primary set,the Secondary set has larger amplitude. Furthermore, its value for the DG operating at unity power factor is different from that of the DG which generates both active and reactive power simultaneously.

Also $f0$ is unknown in advance when the DG generating both active and reactive power simultaneously and it cannot be calculated after islanding. Hence, the Secondary set of RPD for the DG of this kind has two parts, that has the same duration time $T1$ but different amplitudes. The amplitude of the first part can be expressed as shown below: equation (10) as given at the bottom of the page. So, disturbance forces the frequency to deviate outside its threshold for the load whose resonant frequency equals 50 Hz. The magnitude of the second part is set to $3Q$dis2, that forces the frequency to exceed its thresholds for the load whose resonant frequency equals 300 Hz as evaluated in section II. Hence, the SSORPD is sufficient to detect islanding when $f0$ is within the range of 50 and 300 Hz. When $f0$ is out of this range, an additional criterion is needed to determine islanding. Due to different disturbance amplitudes, the steady frequency variation corresponding to the second part is three times more than that corresponding to first part during islanding. Hence, the additional criterion can be obtained as follows:

$$\left.\begin{array}{l} \Delta F\text{tot.22} = 3\Delta F\text{tot.11} \\ |\Delta f11| > 0 \\ |\Delta f22| > 0 \end{array}\right\} \qquad (11)$$

It is to be noted that the value of Twin for ΔFtot.22 and ΔFtot.11 should be no more than that of ($T1 - T$tra). Finally, two criterions for determination of islanding are given in Table II. The first criterion is enough for the DG operating at unity power factor. Anyhow, both the criterions have to be configured to complement each other for the DG generating both active and reactive power synchronously. If either of the criterion is satisfied then islanding is confirmed.

TABLE - II

Criterions for determination of Islanding

Criterion	Content	Suitable Application
First	1) f >50.5 Hz or f <49.3 Hz 2) its duration time is no less than Tdur .	1) DG operates at UPF; 2) The DG generates both active and reactive power .
Second	1) The SOAFV satisfies equation (11) 2) The frequency variation is not zero.	The DG generating both active and reactive power.

C. Time Variable Design

The time variables that are used in the proposed method are given in Table III and this part introduces the design of their values. The frequency which is based on the input of three single-phase voltages at the PCC can be obtained from the PLL. In [12], the authors analyzed the transient characteristics of the PLL in detail when the mode of operation transferred from grid-connected to islanding.

TABLE - III
Expansion of Time variables

$T1$- The duration time of each part in both the FSORPD and the SSORPD.

*T*dis- The period time of the FSORPD.
*T*win - The measurement window size for SOAFV calculation.
*T*tra -The transient time of frequency deviation from a steady value to another steady state one.
*T*dur - The duration time of the abnormal frequency state.

The severe condition for detecting islanding is that there is no active and reactive power mismatches between the generation of DG and also the load's consumption. The frequency is still 50 Hz after islanding, when the reactive power disturbance is not added. Correspondingly, the maximum detection time of the proposed method appears in this condition as well. According to the first and the third criterions, the time needed to start the SSORPD after islanding is not more than *T*dis which is because both criterions are designed based in the frequency variation characteristics corresponding to the synchronous FSORPDs on different DGs or the FSORPD on a certain DG. However, based on the second criterion ,the time needed for disturbance switching is at least equal to *t*dis. By assuming that the active power references of two DGs are same (PDG1 = PDG2) and the FSORPD on the DG2 lags behind the DG1 by 1.5*T*1. As per the standards of IEEE 929 and IEEE Standard 1547 , detection of islanding is to be detected in 2 Seconds.

D. Implementation process for the Proposed Method

The implementation procedure for islanding detection method is easy. Flowchart for the proposed method is shown in Fig. 4 and Reactive power distribution addition circuit is shown in Fig. 5. Initially, two sets of reactive power disturbances, the three criterions for disturbance switching and two criterions for islanding determination have to be configured. The relative parameters are set in advance. In general, the rated reactive power reference of the DG is added on the primary set of RPD. If anyone criterion among the three criterions for the disturbance switching is satisfied, the Secondary set will take the place of the primary set of RPD. If any of the two criterions for islanding detection is met, islanding will be determined. On the other hand, the Secondary set will be replaced by the primary set after its duration time. Constant RLC load is recommended in the generic system to examine the islanding detection methods' performance and is considered as the hardest detectable condition for detection of islanding. Hence, the proposed method and the passive methods of islanding can form the redundancy configuration which can realize islanding detection effectively and reliably for the system with different kinds of loads.

IV. Implementation of The Proposed Method of Islanding Detection

In the present section, for the disturbances created simulations are performed in matlab/simulation which are shown in the Fig.1. The parameters of the DG and grid are shown in the Table IV. PI parameters are Kp1/Ki1 and Kp2/ Ki2 for the outer power controlling loop and inner current controlling loop respectively. In the present case only two DGs are pondered and only reactive power ratings are different and active power of both the DGs are set to 200 KW.

The functioning of the isolation detection method is simulated with RLC load conditions. In primary set of RPD T1 and Tdis are taken as 100 and 600 ms and Tdur in criterions are set as 10 ms. When the islanding is initiated at an instant of t = 0.3 sec and frequency is 50 Hz before the islanding process. Once islanding is initiated, it is detected by secondary set of RPD and after its duration time is over, the Primary set of RPD has no impact on simulation and also the DG.

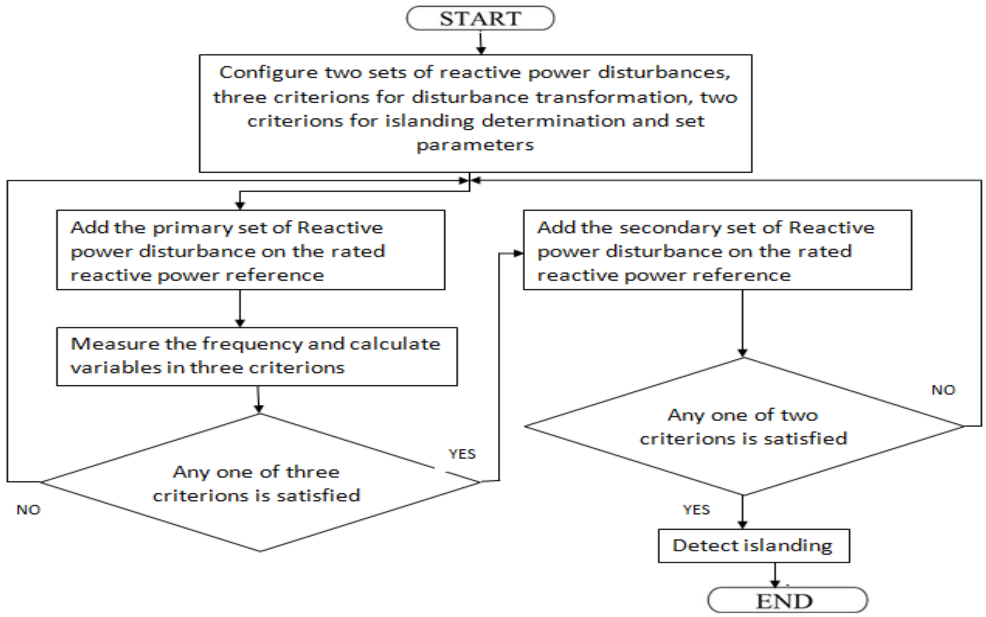


Fig.4 Proposed islanding detection methods flowchart

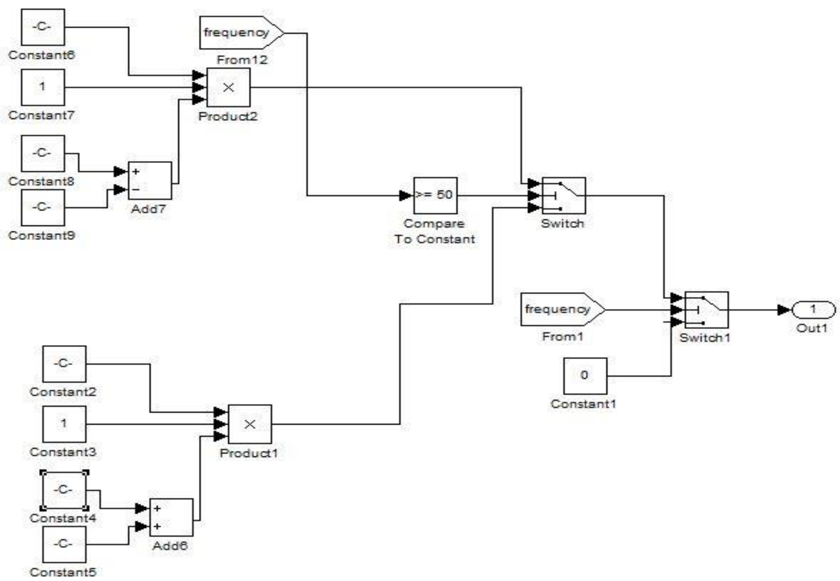


Fig. 5 Reactive Power Disturbance Addition Circuit

A. Implementation of DG operation for the proposed method at UPF

If the DG operates at the UPF, its reference rated reactive power will be '0' Vars. By changing the values of loads L and C different values of $f_o$are created. In the given Table V, 5 sets of parameters of R,C,Lare designed reactive power equal to value of 2.5. Once DG operates at UPF, there is no impact of active power mismatching during islanding and no impact on frequency variation also.

In all the five cases of the test values of R's are set to 0.8 Ω for matching of DGs active power output. If islanding is not considered, a new cycle of primary set of RPD are designed to add to the reactive powers reference at t = 0.5 sec in every case. There will not be any disturbance of the reactive power when the system operates normally before 0.5 sec. During the process of islanding the frequency at the PCC and also DGs reactive power output are shown in Fig. 6(a to e) in every case of part A. In all the five cases, frequency deviated beyond the threshold limits in all the five cases and also detected with different detection times which is shown in Fig. 6 in all the cases.

Table IV Parameters of the proposed system

	Parameters	Values
Grid	Voltage	400V
	Frequency	50Hz
	Grid Resistance	0.1Ω
	Grid Inductance	1.5915mH
DG Inverter Controller	K_{p1}/K_{i1}	0.025/2
	K_{p2}/Ki2	1.5/0.01
	P_{ref}	200kW

Table V Load Parametersettingfor differenttestcasesinthepart-A

Case	R(Ω)	L(mH)	C(μF)	F_0(Hz)
1	0.8	1.0186	9947.2	50
2	0.8	1.0145	9907.6	50.2
3	0.8	1.0105	9868.2	50.4
4	0.8	1.0227	9987.1	49.8
5	0.8	1.0268	10027.4	49.6

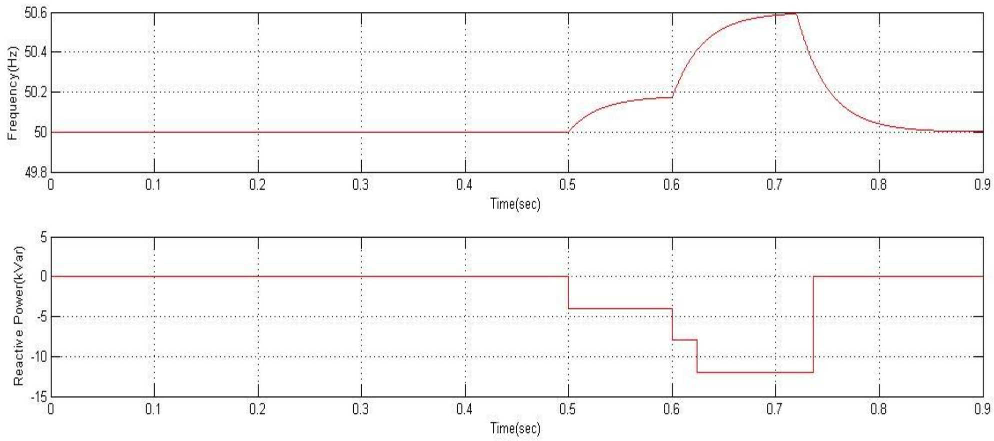


Fig. 6(a) for Case 1

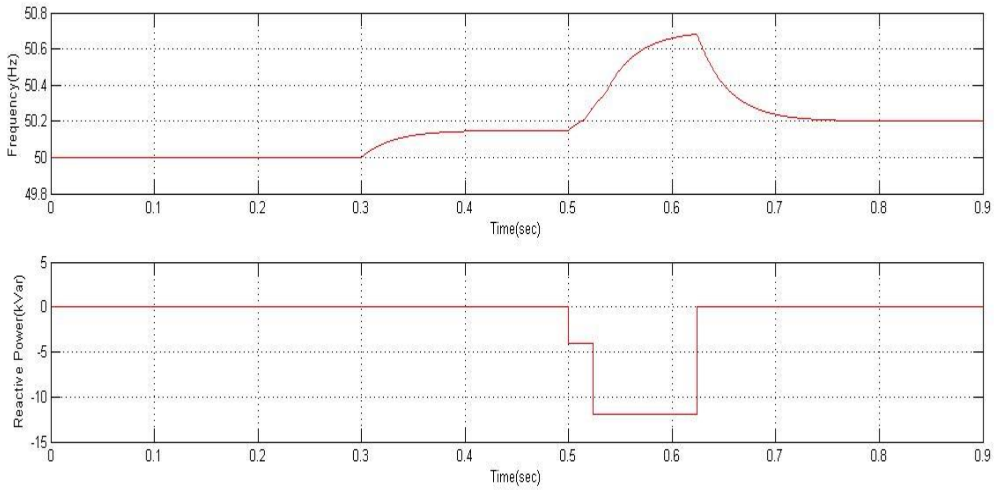


Fig. 6(b) for Case 2

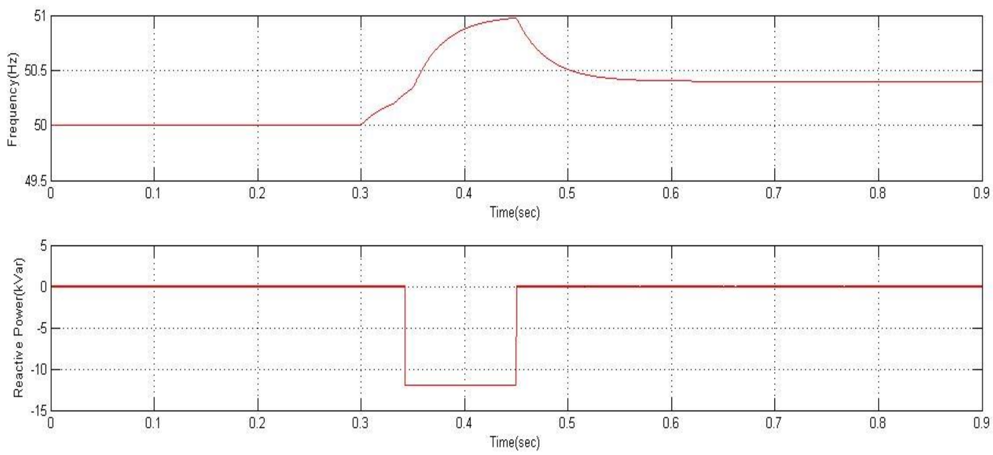


Fig. 6(c) for Case 3

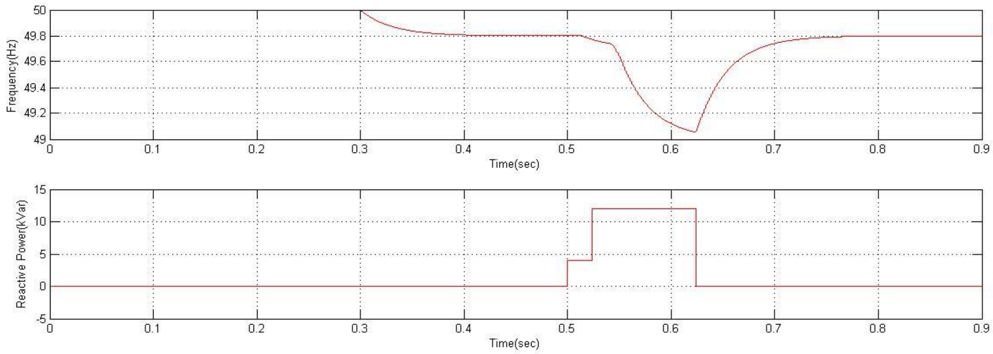


Fig. 6(d) for Case 4

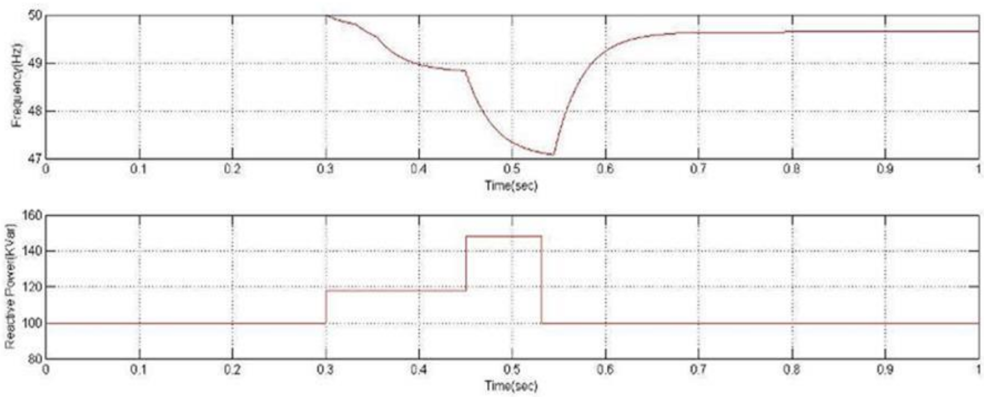


Fig. 6(e) for Case 5

Fig. 6 (a to e) Illustrates simulation result of the PCC frequency (fo) upper one and DG's reactive power output lower graph during islanding for each load case when DG operates at UPF.

In the conditions of case 1, frequency increases above the 50.3 Hz at 0.614 s because of second part of primary set of RPD and it stays above 50.3 Hz in 10 ms . So, the first criterion of disturbance switching satisfies at 0.624 s and replaces the primary set by secondary set of RPD. Here islanding is detected eventually at 0.656 s and frequency is greater than the upper threshold of 50.5 Hz. When compared with the case 1, frequencies get deviate in all the other four cases after islanding takes place. Since values of fo are not 50 Hz and can be viewed from 0.88 s and also no reactive power disturbance at this instant. In the cases of 2 and 4 also the fo is in threshold range for disturbance switching in first criterion. Nevertheless , first part of primary set of RPD is sufficient to meet the first criterion . Also, the disturbance switching from primary set to secondary set is recognized and detection time is very small than in the case 1. In the other two cases of 3 and 5 , value of fo is beyond the threshold for both the cases in criterion 1 for the disturbance switching. In the last two cases second set of RPD is activated fast and detection of islanding is obtained in minimum time.

Table VI Detection time for five load cases

case	f_0 (Hz)	Start up time of the SSORPD(ms)	Detection time (ms)	Detection results
1	50	324	356	Detected
2	50.2	226	245	Detected

3	50.4	42	60	Detected
4	49.8	224	260	Detected
5	49.6	42	70	Detected

The results of the five cases mentioned i.e., start uptime , detection results are described in the Table VI. It can be inferred that proposed method detects islanding for all the loads which has variation in values of the frequency f_o. After the detection of islanding at f_o= 50 Hz and also condition of no reactive power mismatch existed, it proved detection time is longest and still much less than 2 sec which is specified in IEEE standard of 1547. Even though the frequency is closer to the threshold limits before primary set of RPD starts, detection time is still shorter.

For unbalanced loads also the performance of proposed method is analysed. The load imbalance is also simulated by changing the resistance of one of the phase of the load as mentioned in [14], [25]. Based on condition in Table-V , the three conditions considered are

a) Case (A) **-** resistance of phase A is set to 97% of its rated value
b) Case (B) **-** resistance of phase C is set to 103% of its rated value
c) Case ©) **-** resistance of phase A and phase C are to 97% and 103% of their rated values respectively.

In the present case DGs are adopting constant power control strategy , output reactive power of the DGs and PCC frequency during islanding in the above mentioned cases are analysed in the Fig. 7.

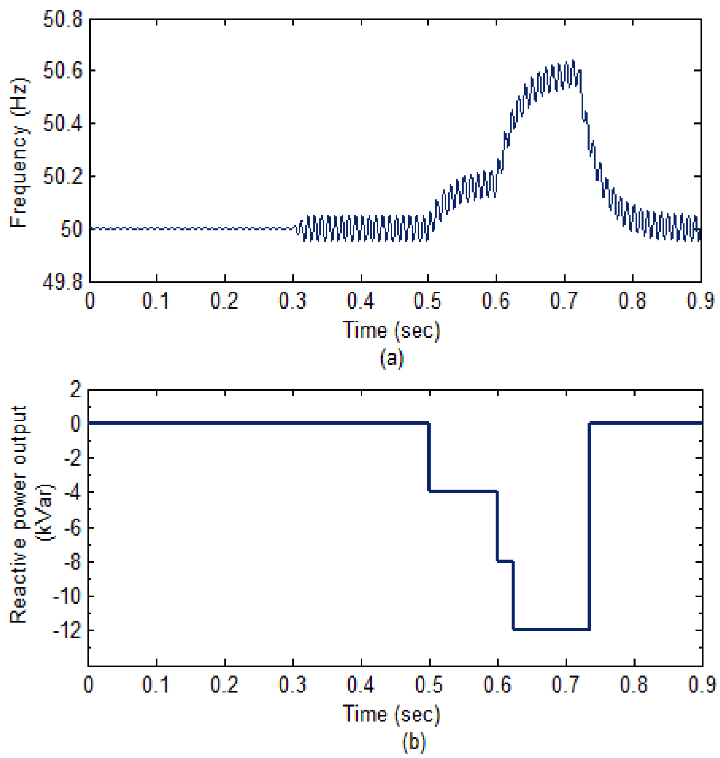


Fig. 7 (a),(b) Illustrates simulation result of the unbalanced loads
(a) PCC frequency (b) Reactive power output of the DG's.

As shown in the Fig. 7(a) all the frequencies in all the three cases mentioned deviates outside the upper threshold of greater than 10ms and duration of the condition is greater than 10ms. So, the method which is proposed is capable of detecting islanding more effectively in the conditions of load imbalance also. It can also be inferred from the Fig. 7(a) that PCC frequency is greater for most of the unbalanced loads. For the detection of islanding more reliably , magnitudes of the Second Set of Reactive power Disruptions can be set to bit larger values for serious unbalanced loads.

B. Performance of proposed method for DG which generates simultaneously Active and Reactive power

As mentioned in [15] , when DG generates active and reactive powers at a time , if there is no reactive power mismatch during the normal operation , active power mismatch may cause reactive power during the islanding and drives frequency to deviate and makes the process of islanding detect faster and easier. Also the mismatch of active power can be obtained by the change in value of load resistance. The reference reactive power rated value is set as 100 kVar without the consideration of the disturbance. The variation in the reactive power mismatch can be obtained by changing the values of load inductance and load capacitance. From the table VII , five sets of parameters of R,L and C are assigned and also represents ΔPnor and ΔQnor which shows active and reactive power mismatch between load and the DG during normal operation correspondingly. The values of Q*f*is 2.5 in case of 1,4,5 and cases 2 & 3 are designed based on the value of case 1 and they had different values of ΔP_{nor} .

Table VII Load Parameters setting for the different test cases in part B

Case	R(Ω)	L(mH)	C(μF)	f_0(Hz)	ΔP_{nor}/kw	ΔQ_{nor}/kVar
1	0.8	0.9218	9002.1	55.3	0	0
2	0.7619	0.9218	9002.1	55.3	10	0
3	0.8421	0.9218	9002.1	55.3	-10	0
4	0.8	0.9145	8930.7	55.7	0	8
5	0.8	0.9292	9074.1	54.8	0	-8

The DG reactive power and PCC frequency during the islanding in part B is shown in the Fig. 8(a to e). The divergence of active power remains the same when islanding occurs and magnitude of reactive power mismatches in case of 2 and 3 after islanding, since active power mismatches are not equals zero and PCC voltage changes in both the cases. When compared with the frequency of case 1, it can be inferred from the Fig. 8(a) , frequency decreases in the case 2 or increases in the case 3 if islanding occurs. So , second set of RPD in 2 & 3 cases are initiated prior to case 1 which infers islanding can be detected in a short time in the case of 2 and 3. The detection time of islanding for the three cases are 357 , 241 and 239 ms respectively.

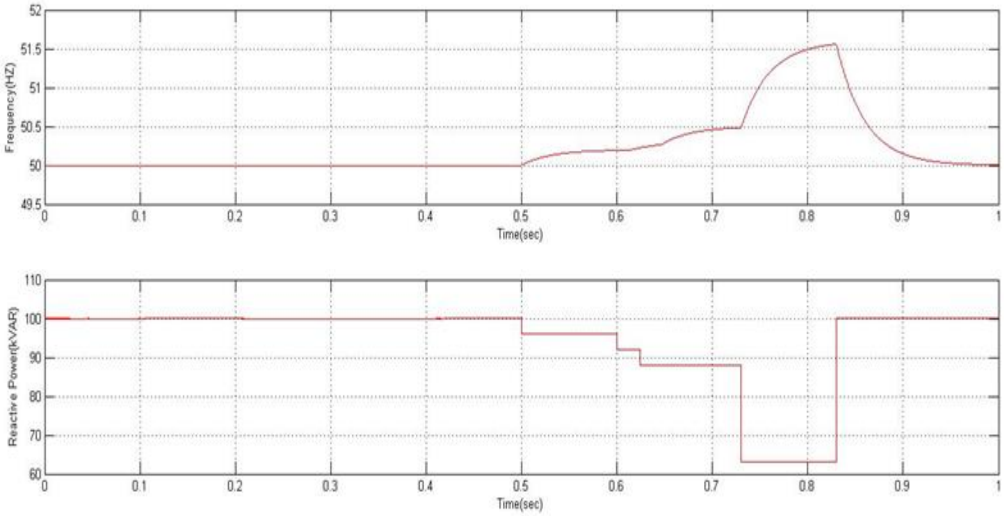


Fig. 8 (a) for case 1:

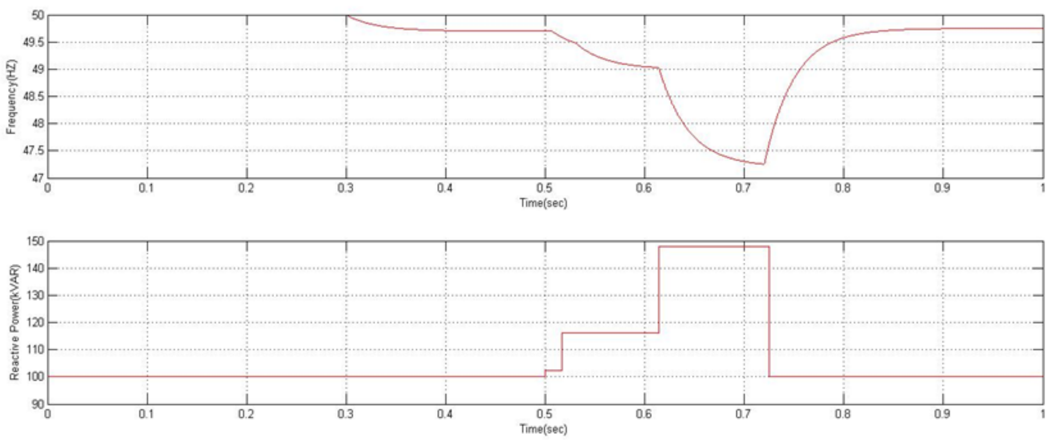


Fig. 8 (b) for case2

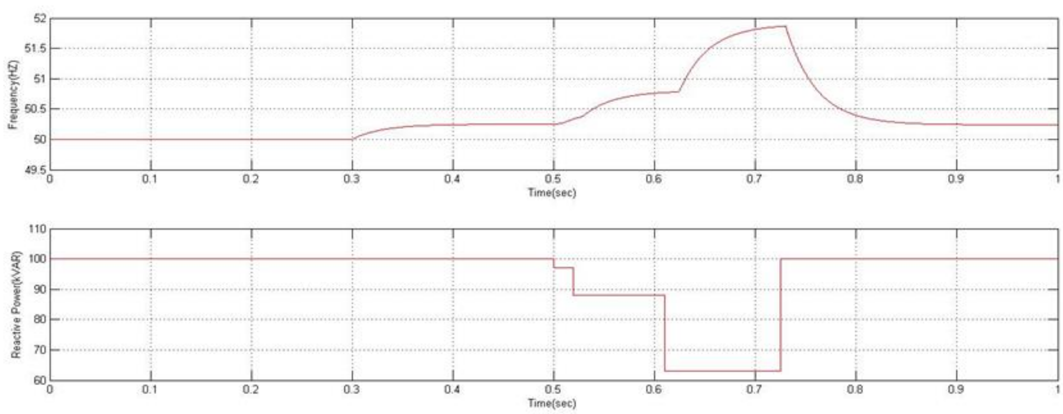


Fig. 8 (c) for case 3

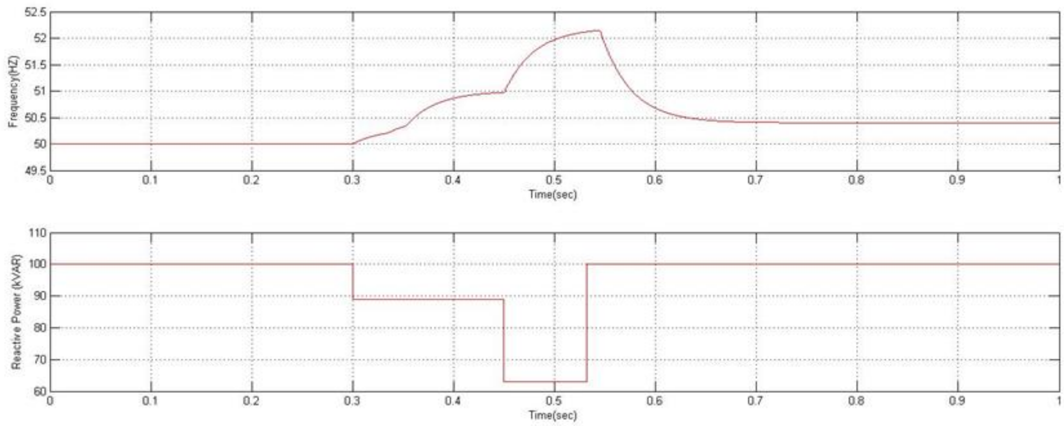


Fig. 8 (d) for case4:

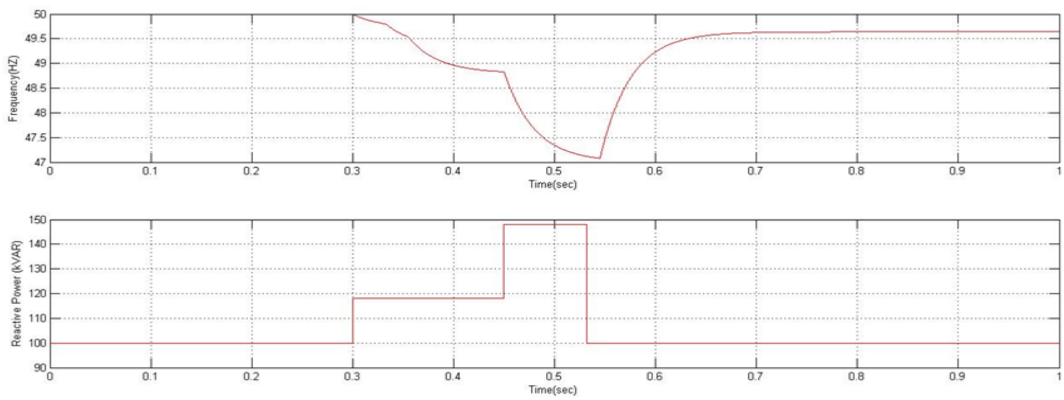


Fig. 8 (e) for case 5:

Fig. 8 (a ,b, c, d, e) illustrates the PCC frequency (upper graph) and the DG's reactive power output during islanding for each load case (lower graph) when DG generating both Active and Reactive power.

Even though generated power from the DG equals the power consumed by load in the case of 4 & 5 , here reactive power disparities makes the frequency deviation after the islanding. In all the cases the frequencies are in the steady state is shown in the Fig. 14(a) at t = 0.96 sec. At this instant, in the case of 4 & 5 frequencies are beyond the limit of threshold for the first criterion for starting of second set of RPD while not in the case of 1,2 3.

In the case of 4 & 5 secondary set of RPD starts shortly once islanding occurs and those in the other three cases are not activated till the primary set of RPDs are added to the reactive power rated references. Also the detection time of islanding in case of 4 & 5 are 63 and 65 ms and are shorter than in other three cases. In all the five cases value of fo is little more than 50 Hz. Here reactive power disturbances required for forcing the frequencies to overcome the threshold limit is approximately same as of the load whose resonant frequency is 50 Hz. In all the 5 cases process of islanding is detected during first part of secondary set of RPD.

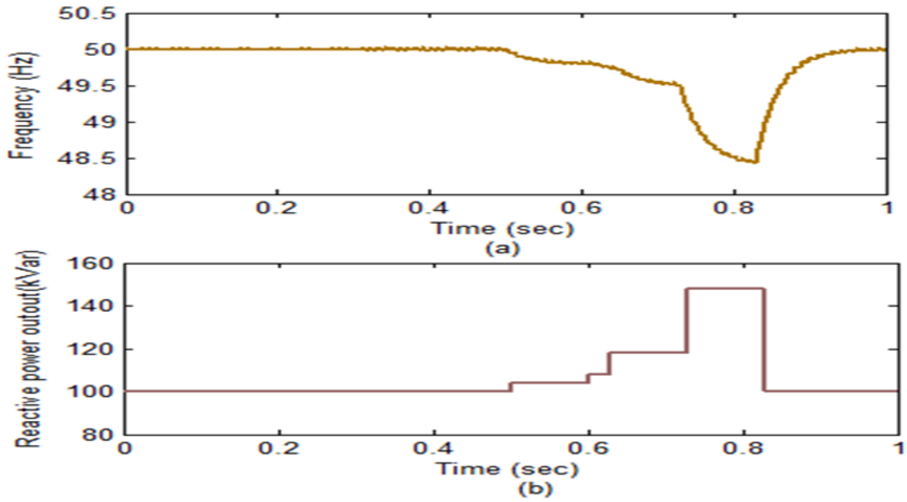


Fig. 9 (a), (b) Illustrates simulation result of the unbalanced loads
(a) PCC frequency (b) Reactive power output of the DG's

For unbalanced loads also the proposed method's performance is observed and based on case I in the table VII , all the three same conditions are in part A by a change in load resistance are simulated. The simulation results are shown in Fig. 9. It can be inferred from the above Fig. 9 (a) that frequency deviates beyond the threshold limits and duration time is longer than 10ms. So, the DGs which generates active and reactive power, the proposed method helps in detection of islanding even for three single phase unbalanced loads.

V. Conclusion

The inverter based DGs can operate at UPF or generates both active power and reactive power simultaneously under the condition of constant power control. The present paper analyses the relation between disturbances in reactive power and variation in frequency during the process of isolation. In the paper an innovative isolation detection method for DGs of both the cases based on distressing the DGs output reactive power, variation in the frequency and the method is easy for implementation. In this method proposed,
Two sets of RPD are added to DG, primary set of RPD is periodic and it creates disturbance in reactive power balance between DG and load after islanding and activates secondary set of RPD. All the DGs located at different locations detects the frequency variation and synchronizes the secondary set of RPD without any special communication means. So, proposed method detects the islanding with multiple DGs also Reliably and effectively and simultaneously improves the quality of power.

When the primary set of RPD are added to different DGs, they may be asynchronous. By considering the different possible variation in frequency characteristics with the Primary set of RPD after islanding and three more criterion are designed for switching the disturbances from primary set to the Secondary set on DG. So, without any necessity of communication the DGs which are placed at different locations can recognise the same variation in frequency characteristics no matter of operating mode and it guarantees the synchronization of secondary set of RPD on various DGs.

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