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Efficient Method to Identify Islanding Condition for Wind Turbine as Distributed Generation

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ABSTRACT

Distributed generation is increasingly likely to play a major role in electricity supply systems. However, the integration of these units at distribution voltages is a major challenge for utilities. One of the problems of distributed generation working connected to the network is the unwanted islanding phenomenon causing physical or financial losses. Islanding is one important concern for grid connected distributed resources due to personnel and equipment safety. Several methods based on passive and active detection scheme have been proposed. While passive schemes have a large non detection zone (NDZ), concern has been raised on active method due to its degrading power quality effect. Reliably detecting this condition is regarded by many as an ongoing challenge as existing methods are not entirely satisfactory. The main emphasis of the proposed scheme is to reduce the NDZ to as close as possible and to keep the output power quality unchanged. In this paper, a developed algorithm is proposed based on passive methods to detect non-islanding protection for wind turbine which is connected to the network. The proposed algorithm is compared with the widely used rate of change of frequency relays (ROCOF) and total harmonic distortion (THD) and found working effectively in the situations where ROCOF and THD fails. The method is on the basis of the decisions of several parameters. These parameters are voltage changes, frequency changes, and active and reactive power changes. Different scenarios with various loads have been used at different wind conditions and many parameters have been studied in these experiments to propose the algorithm. Simulation results have been obtained using MATLAB/SIMULINK software and the effectiveness of the proposed algorithm is shown for the different performances.

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Islanding Detection, Distributed Generation (DG), Wind Turbine, Voltage Changes, Frequency Changes, Rate of Change of Active and Reactive Power

Introduction

Due to the increasing popularity of energy production facilities such as wind farms and solar cells, distributed generation is becoming more and more widespread. During recent years, utilizing renewable energies have been increased dramatically, especially, because of the problems such as environmental pollution, and limited fossil energy resources. Also, renewable based distributed generations are more advantageous than the conventional power plants made it more interesting and economical [1]. Moreover, renewable energies are of great importance than the other energy resources as they are endless and have no negative effects on the environment. The connection of generation at distribution voltages is seen as one of the most important challenges facing modern electricity supply systems. These units offer the potential to take advantage of local renewable or sustainable energy sources, whilst avoiding the high carbon emissions and losses associated with large fossil fuel thermal stations and long distance transmission respectively. These clean energies have many kinds such as wind energies, fuel cells, photovoltaics, bio-mass and so on [2]. Depending on the type of these energy resources they could deliver either AC or DC power. Some of these distributed generations are connected to the network through power electronic converters or without any interfaces [3], also among the DG resources, wind energy based DGs have great share, also wind turbines are classified into several categories [4].

The use of distributed generation resources has various effects on themselves as well as on the network which one of them is the islanding phenomenon. The islanding occurs when one or more distributed generations separately supply local loads which are not connected to the network. In most cases this phenomenon occurring unwanted that could cause hazard to technicians of electric line maintenance, damage to consumer devices due to the lack of voltage and frequency instabilities, and inconsistency incidence at reconnection to network. This is a particularly undesirable condition and therefore protection is required for its detection and the subsequent tripping of DG. Thus, according to the standard of IEEE 1547, islanding should be identified and disconnected in less than 2 seconds [3-5].

So far several methods to detect islanding mode have been proposed. Although many protection methods have been developed for this task, concern still exists with regard to their performance in terms of the highly interrelated criteria of sensitivity and stability. The two main criteria for comparison of the existing islanding detection methods are: 1) speed of detection or run-on time which is defined as the time interval between the actual islanding instant and the islanding detection instant and 2) non detection zone (NDZ) which is a region (or space) specified by the system parameters, in which islanding detection fails. These methods can be divided into communication (Remote) and local methods. Remote techniques for detection of islands are based on communication between the utility and the DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical. Local methods also including active and passive techniques.[4] Active methods such as impedance measurement method [6], frequency domain analysis [7], changing voltage amplitude and reactive power method [8], the mid-harmonic method [9] work by applying disturbances to the system and evaluating its response. Passive techniques work based on local measurements and data processing. Voltage and frequency relays [10], Rate of change of frequency relay (df/dt) [11], output power variations speed [10], unbalanced voltage and total harmonic distortion (THD) [12] are several passive methods.

The widely used ROCOF relays estimates the ROCOF within a measurement window to detect islanding condition. However, the ROCOF relays may become ineffective if the active power imbalance in the islanded system is less than 15%, resulting in a high risk of false detection. During islanding if the active power imbalance (power mismatch) is high, then frequency drift will have higher amplitude and ROCOF works satisfactorily based on a set threshold. However, when the active power imbalance is below 15%, then ROCOF fails and thus unable to provide effective protection measure to DG interfaced to grid, during islanding. Also it is difficult to provide an absolute threshold for detecting islanding detection using ROCOF as the magnitude of ROCOF vary largely with active power imbalance. If a threshold of 0.5 is set (for example), then it cannot detect islanding with 0%imbalance. Even at a threshold of 0.2 ROCOF is unable to detect islanding at nearly 0% active power imbalance. Thus, ROCOF fails to detect islanding events when active power imbalance falls below 15%.Thus, ROCOF fails in the aforementioned situations [26]. In this research, it is tried to examine different parameters during the various experiments, and according to the obtained results and weaknesses of each passive method an algorithm is presented decreasing the unidentified zone of non-islanding protection. The comparison of radial basis neural network with ROCOF relay with threshold value 0.2 at different DG locations during islanding event with power imbalance of nearly 0% shows that the proposed method works effectively for islanding detection. In the next section, the study system will be analyzed. In section 3, the proposed algorithm in the paper to detect islanding mode will be presented. Test results to diagnose islanding mode will be in section 4, and in last section of this paper the conclusion will be presented.

I. THE STUDY SYSTEM

One line diagram of the study system in this paper is shown in Figure 1. As depicted in this figure, DG has been modeled as a wind turbine connected to the power grid through step-up transformer. The power grid is an ideal source along with resistor and inductance. The system parameters are given in Table 1.

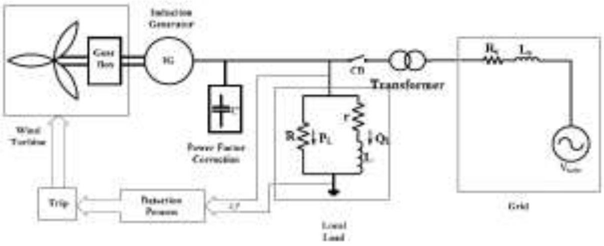

Fig.1 Study power system including local load, power grid and wind turbine to detect the islanding mode

When the circuit breaker (CB) closed as shown in the figure, in this mode DG together with local load is connecting to power grids and produced power by DG is injected to network. But, when the CB opened, in this mode, islanding mode occurs, and DG along with a local load constitute an islanding mode which creates an independent power grid in which just DG supplies loads demand power. In these conditions islanding mode should be detected and power generation entirely disconnected from the power grid and after reconnection it starts to produce power. In order to identify the islanding condition, a measurement system installed at the local load terminals and output of the mentioned measurement ended in a central processor in which measured signals are being processed and in the islanding mode a fast decision made and command for disconnecting system will be exported.

Table.1 Parameters of the study power system, including local load, power grid and wind turbine

Parameters	Value
Turbine Rated Power	660 kVA
Rt	1Ω
Lt	1mH
Rated Voltage of Local Load	660 KVA
Nominal Grid Voltage	0.4kV
Transformer Voltage Ratio	0.4/20kV
Transformer Rated Power	660kVA
Frequency	50Hz

II. THE PROPOSED ALGORITHM

Following the increased number and enlarged size of distributed generating units installed in a modern power system, the protection against islanding has become extremely challenging nowadays. Islanding detection is also important as islanding operation of distributed system is seen a viable option in the future to improve the reliability and quality of the supply. The islanding situation needs to be prevented with distributed generation due to safety reasons and to maintain quality of power supplied to the customers. The main emphasis of the proposed scheme is to reduce the NDZ to as close as possible.

Each method of non-islanding protection has non-detecting areas. And for passive methods, the determination of a threshold is one of the most important problems, because if a small threshold to be considered, switching conditions may be identified as an island mistakenly and if it is assumed large, the islanding mode may be not detected. In this paper, to overcome these problems, different parameters are used for non islanding protection which not only reduce the non detection area, but also the threshold value is chosen so as to avoid protection of mistaken. Since in this method, several parameters are used to detect islanding conditions, therefore the wrongly detection of islanding is decreased more.

In this paper, the vector of equation (1) has been measured and studied for the following experiments.

$$x = [\Delta V, \Delta f, \frac{\partial P}{\partial f}, \frac{\partial Q}{\partial V}, \frac{dP}{dt}, \frac{dQ}{dt}, THD_i, THD_v, \frac{df}{dt}, \frac{d^2 f}{dt^2}]$$

(1)

$$THD_i = \frac{\sqrt{\sum_{n=1}^{N} I_n^2}}{I_1}$$

$$THD_v = \frac{\sqrt{\sum_{n=1}^{N} V_n^2}}{V_1}$$

$$P = |v_a||i_a|\cos(\theta_a) + |v_b||i_b|\cos(\theta_b) + |v_c||i_c|\cos(\theta_c)$$

$$Q = |v_a||i_a|\sin(\theta_a) + |v_b||i_b|\sin(\theta_b) + |v_c||i_c|\sin(\theta_c)$$

(2)

•The islanding mode with a 200kW load and 260kVAr capacitor for various wind speeds (11 14 18 m/s),

•The islanding mode with a 300kW load and 220kVAr capacitor for various wind speeds (11 14 18 m/s),

•The islanding mode with a 100kW load and 180kVAr capacitor for various wind speeds (11 14 18 m/s),

•Switching 100KW and 80KVAr motor for various wind speeds (11 14 18 m/s),

•Switching 50KW and 30KVAr motor for various wind speeds (11 14 18 m/s),

•Switching a 100KW and 80KVAr load for various wind speeds (11 14 18 m/s),

•Switching a 50KW and 80KVAr load for various wind speeds (11 14 18 m/s).

By studying measured parameters in these experiments, the algorithm shown in Fig 2 is proposed to detect non-islanding protection.

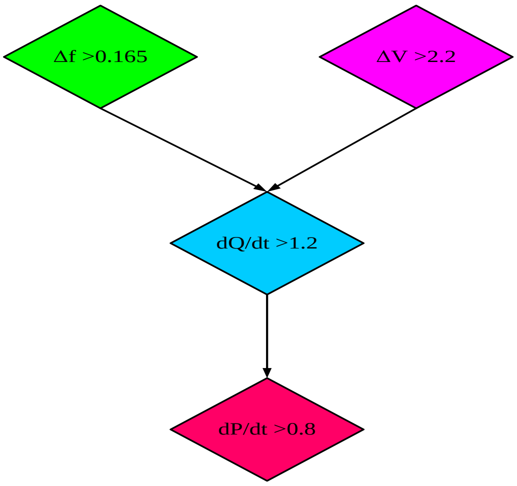

Fig.2 Proposed algorithm to detect the non-islanding mode

III. SIMULATION RESULTS

In this section of the paper, the results of the proposed method to detect the islanding mode have been carried out on different loads and the ability of the proposed algorithm has been depicted for islanding detection.

A. Load Condition 1

In this case, the active power of load and reactive power of capacitor are 150kW and 250kVAr respectively; and wind speed is assumed 11.4 m/s. This load condition is assumed such that power grid not injects active and reactive powers to the load and load power is supplied entirely by the use of DG. At first, CB is closed and system utilized in grid connected mode. At t=5 sec, CB is opened and wind turbine together with local load is separated from power grid and islanding mode occurs. Fig (3-a) shows frequency changes which is exceeding threshold value and Fig (3-b) shows voltage changes. Continuous current and voltage waveforms are illustrated in Fig 4 which there is not significant changes after and before islanding occurrence. Fig 5 shows active and reactive power of the network before and after islanding. It is obvious from the figure that injected power from the network after and before the islanding is roughly zero. Fig 6 depicted the active and reactive power of turbine after and before islanding. From Fig (3-a) it is obvious that at t=5.06 sec. the value of Δf changed and increased over threshold value, here, islanding mode is likely to occur and active and reactive power changes should be examined. According to the Fig (3-c), it is determined that reactive power changes is beyond 100kVAr, then regarding the results, islanding condition is diagnosed. Islanding mode is detected during lesser 0.1 sec and system should be disconnected at t=5.1 sec.

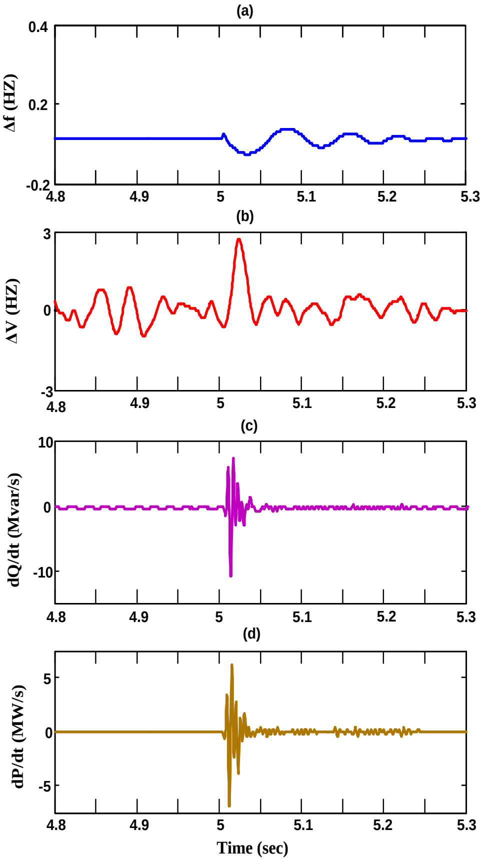

Fig. 3. a) frequency changes of the DG's voltage b) voltage changes of the DG c) reactive power changes of the DG d) active power changes of the DG for load condition 1

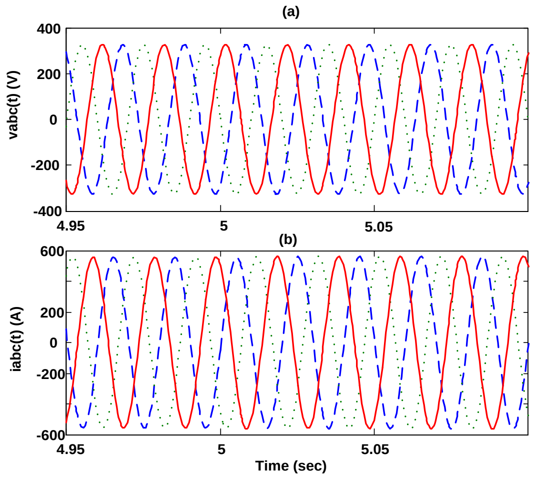

Fig. 4. a) output continuous three-phase voltage of generator b) output continuous three-phase current of DG for load condition 1

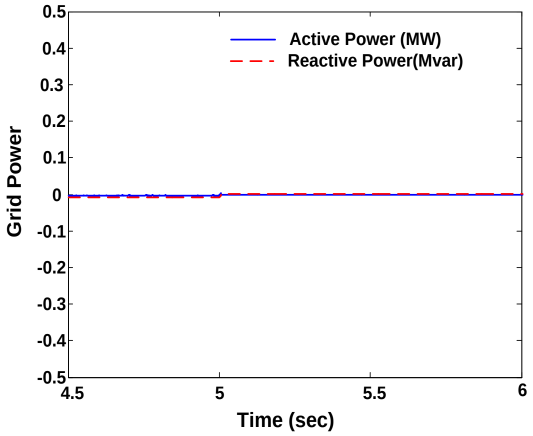

Fig.5 output active and reactive power of the network for load condition 1

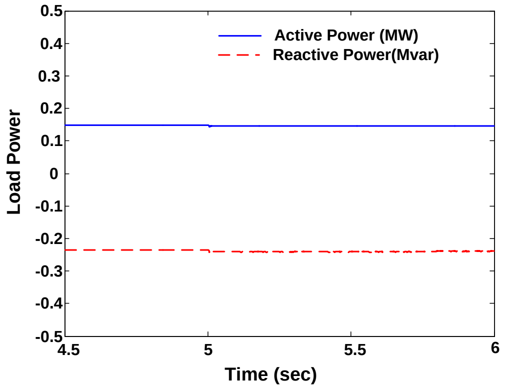

Fig.6 Active and reactive power of load for load condition 1

B. Load Condition 2

For the second test, the active power of local load, reactive power of capacitor and wind speed are considered 200kW, 260kVAr and 16 m/s, respectively.

In this condition, active power of load completely and reactive power partially are supplied from the network. At first, CB is closed and system utilized in grid connected mode. At t=5 sec, CB is opened and wind turbine together with local load is separated from power grid and islanding mode occurs. Fig (7-a) shows frequency changes which is exceeding threshold value and Fig (7-b) shows voltage changes. Continuous current and voltage waveforms are illustrated in Fig 8 which there is not significant changes after and before islanding occurrence. Fig 9 shows active and reactive power of the network before and after islanding. Fig 10 depicted the active and reactive power of turbine after and before islanding. Form Fig. (7-a), it is clear that fluctuations are in the frequency changes, but it is not beyond the acceptable limit, however, according to the Fig (7-b), voltage changes are created after islanding mode and exceeds the acceptable limit, also active and reactive power changes increased sharply and their amount are than higher threshold values, then, considering obtained results islanding condition are diagnosed.

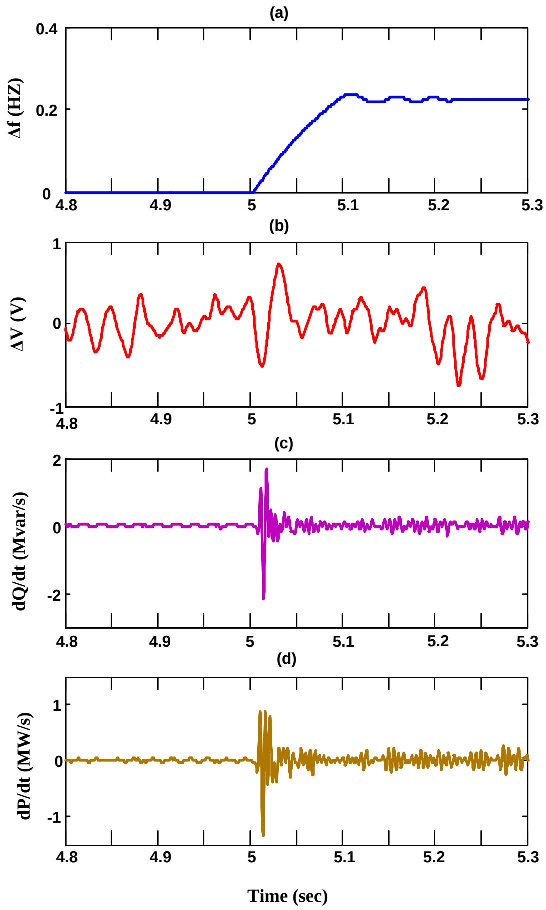

Fig.7 a) frequency changes of the DG's voltage b) voltage changes of the DG c) reactive power changes of the DG d) active power changes of the DG

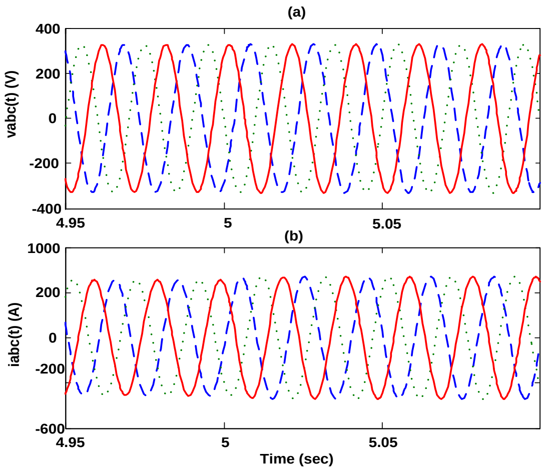

Fig.8 a) output continuous three-phase voltage of generator b) output continuous three-phase current of DG for load condition 2

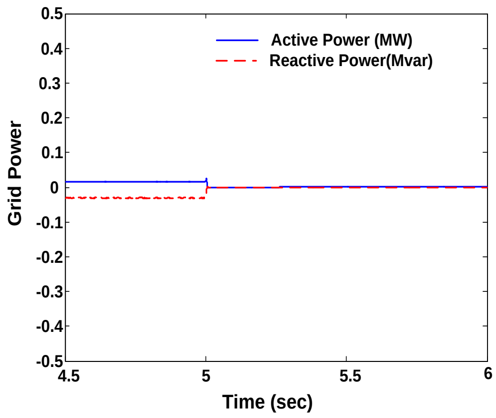

Fig.9 output active and reactive power of the network for load condition 2

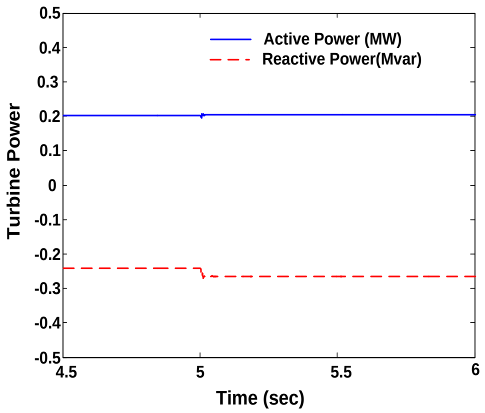

Fig.10 output active and reactive power of DG for load condition 2

C. Capacitor Bank Switching

In this section, the performance of algorithm is studied for capacitor bank switching in grid connected mode to be shown that the proposed algorithm do not mistaken in capacitor bank switching, and effectively diagnose the islanding mode from capacitor bank switching conditions. Initially, the system works in grid connected mode, and local load has P=200kW and Q=260kVAr. At t = 3 sec., a capacitive load with 100kVAr and 50kW is switched and connected to the system. The simulation results are shown in Fig 11. It is clear that the Δf and ΔV do not violate the acceptable boundary and remained in the allowable range, which this verify the robustness of the proposed algorithm. Fig 12 displays the load active and reactive powers.

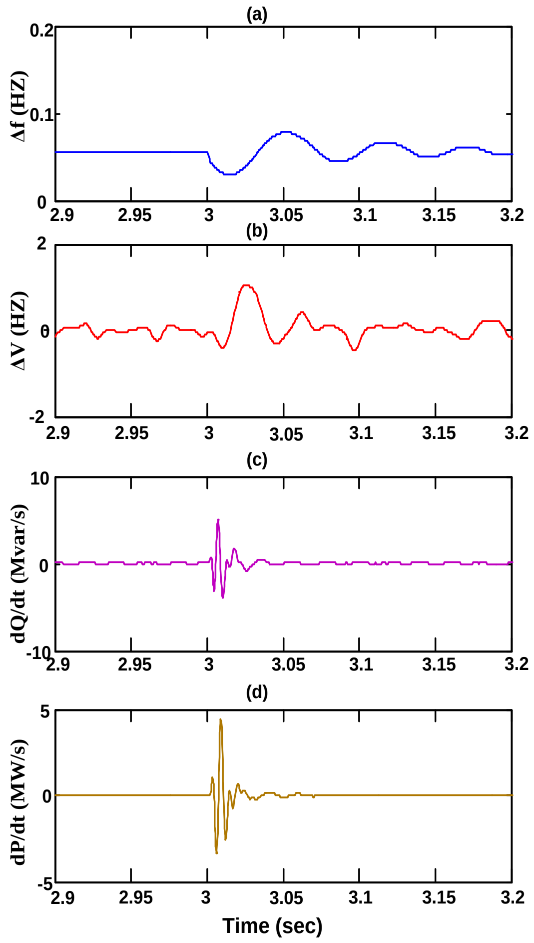

Fig.11 a) frequency changes of the DG’s voltage b) voltage changes of the DG c) reactive power changes of the DG d) active power changes of the DG for capacitor switching

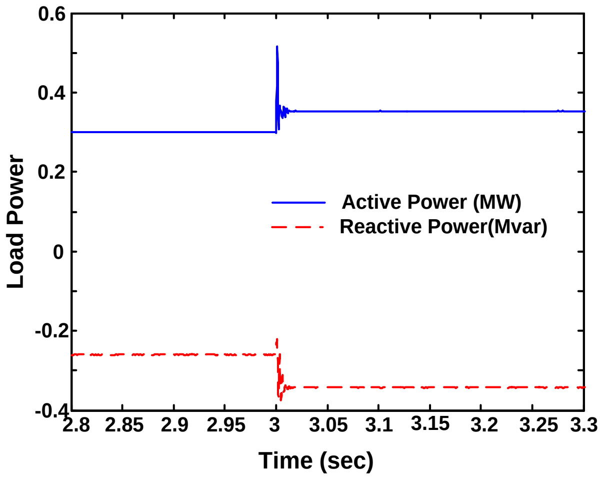

Fig.12 load active and reactive power for capacitor switching

D. Motor Starting

One of the other switching condition in which the algorithm may be mistaken is motor starting in the network. Here, an intense condition is considered to show that the algorithm is able to work defection and readily distinguish islanding mode. To examine this state, a motor with P=100kW and Q=80kVAr is switched at t=3 sec., and connected to the network. Simulation results are shown in Fig 13. From the figure it is clear that the value of frequency does not exceed the allowable value, however, voltage value is exceeded permissible value**.** In the next step, reactive power changes are studied. From Fig (13-c), it is obvious that the change of reactive power do not violate acceptable limit, then the algorithm could easily diagnose and the system will continue to work. Fig 14 illustrates the load active and reactive power waveforms.

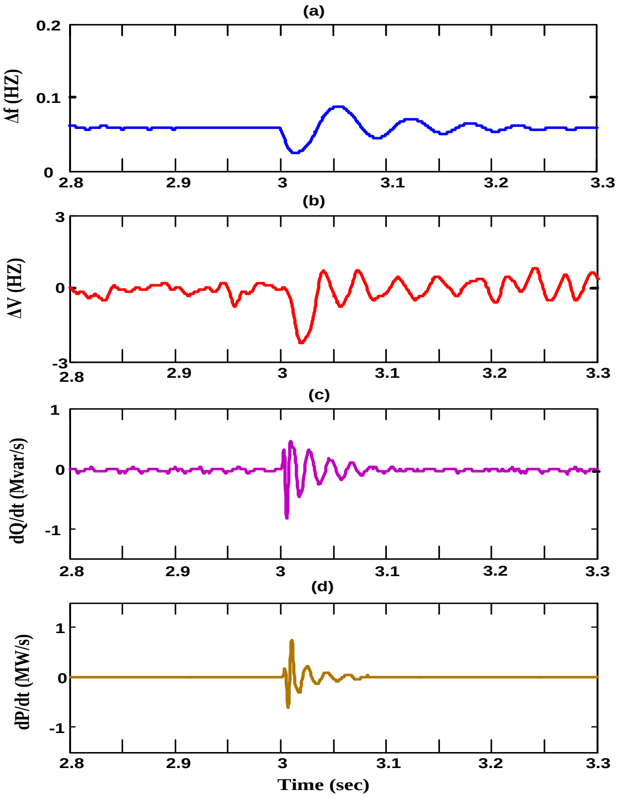

Fig.13 a) frequency changes of the DG’s voltage b) voltage changes of the DG c) reactive power changes of the DG d) active power changes of the DG for motor starting

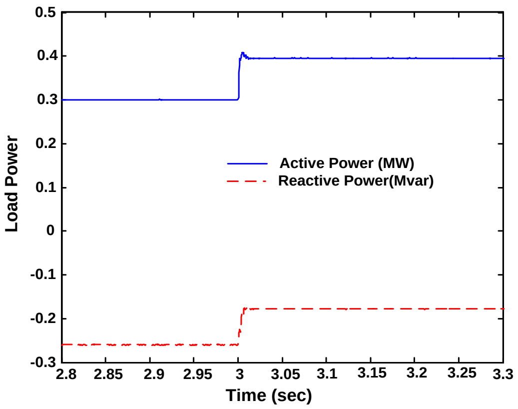

Fig.14 output active and reactive power for motor starting

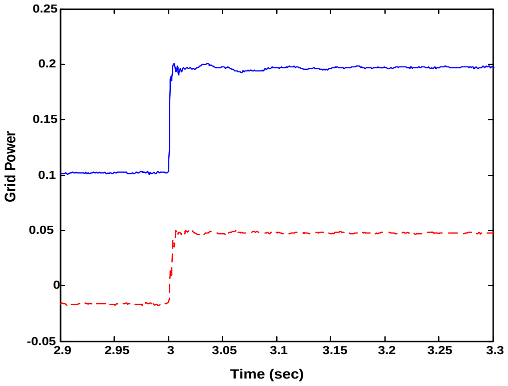

Fig.15 active and reactive power delivered from network to the motor

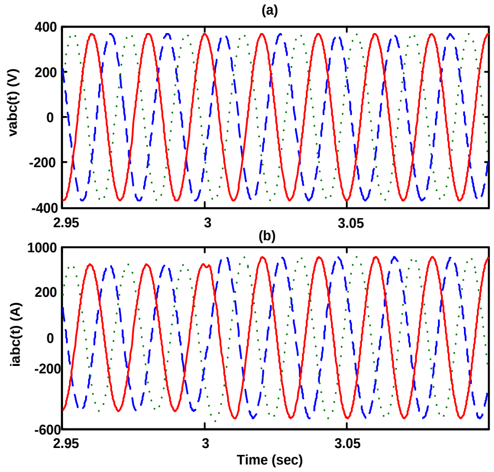

Fig.16 a) output continuous three phase voltage b) output continuous three phase current of DG for motor starting

IV. THE PROPOSED ALGORITHM VS. THE RATE OF CHANGE OF FREQUENCY (ROCOF) ALGORITHM

One of the proposed techniques to diagnose non-islanding protection is the rate of change of frequency (ROCOF) algorithm which in islanding mode the difference between generated and consumed power is stored as kinetic energy in turbine and rotor in turn changes rotor speed affected frequency.

In this paper, to show the efficacy of the proposed method compared to the rate of change of frequency (ROCOF), simulation results will be utilized**.** In [13] and [14], detection of non-islanding protection is expressed using ROCOF. Also, in these conditions, the threshold for the rate of change of frequency relay is considered 200 MHz/sec.

As mentioned above, one of the important conditions of the network on which the algorithm may be mistaken is motor starting in the network. For this, a specific condition of a motor starting is considered to show that unlike the ROCOF technique the proposed algorithm do not mistake and could easily discriminate the islanding mode from the others conditions. For this experiment, a motor with the apparent power S=0.46MVA and power factor of 0.65 lagging is switched at t=2 sec., and connected to the network.

The simulation results are shown in Figs (17) and (18). Initially, the system works in normal condition or load condition expressed in the test 1. At t=2sec induction motor with the mentioned power will be switched. According to the Fig (17) showing the rate of change of frequency, the value of the rate of change of frequency is exceeded the threshold value at t=2 sec., and this shows that the ROCOF technique is acting wrongly.

In Fig (18), the results of the proposed algorithm shown in which after starting motor frequency changes go beyond the threshold value (0.165), then rate of change of active power should be studied which it is clear that threshold value (1.2) does not violated, therefore the proposed algorithm have not wrongly diagnose, and the condition is differentiated good.

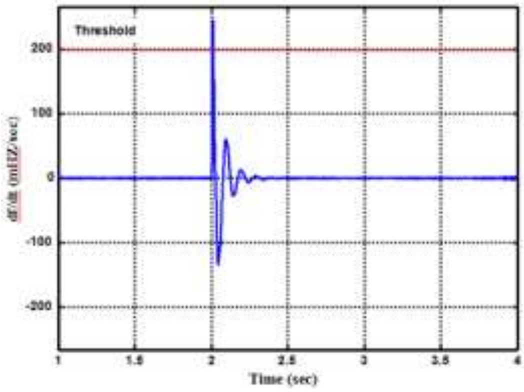

Fig.17 Rate of change of frequency (ROCOF) of the DG generator

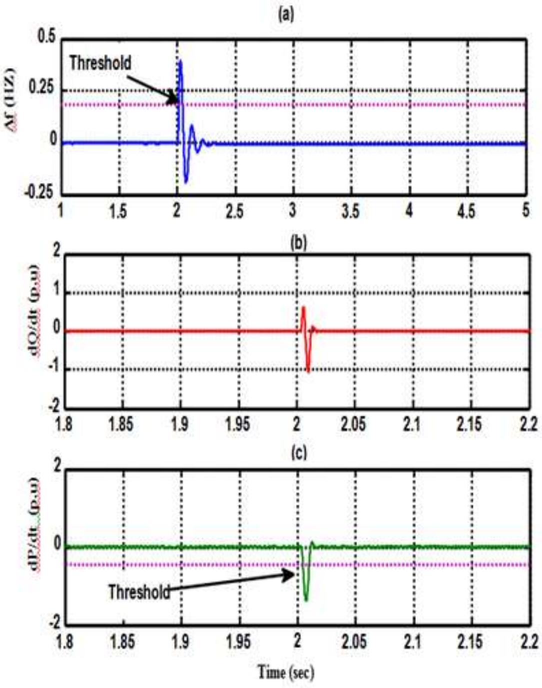

Fig18 a) frequency changes of the DG b) reactive power changes of the DG c) active power changes of the DG

V. THE PROPOSED ALGORITHM VS. THE THD ALGORITHM

Another method described for the detection of non-islanding protection is voltage and current total harmonic distortion (THDi, THDv), for which if the islanding mode is initiated the total harmonic distortion will be changed.

In this part of the paper, the proposed technique efficacy will be shown versus the total harmonic distortion by simulation results. In [15] and [16], cases are considered for which the detection of non-islanding protection is done by total harmonic distortion. According to the performed experiments, threshold values are always selected less than 20%. In this paper, the 20% threshold is considered for total harmonic distortion.

One of the major modes for which the passive algorithms may perform wrongly is the presence of non-linear load in the network. To study this condition, in this part of the paper, a non-linear load is switched into the network and it will be evaluated and checked if the total harmonic distortion makes decision wrongly. Also, the proposed algorithm is evaluated for this condition to show that the condition of the islanding by the proposed algorithm is well recognized**.** For this test, a DC load switching circuit, all controlled by an IGBT, is switched at t=2 sec. and connected to the network**.** The total harmonic distortion of current is shown in Fig. 19, it is clear that during and even after islanding initiation, THD has reached 25% indicating that the THD algorithm distorted for this load condition.

Obtained results of the proposed algorithm are shown in Figs (20) and (21), Fig (20-a) indicates that the frequency changes exceeds threshold limit (0.165) after load switching, also, it is clear from Fig (21-a) that voltage changes go beyond the threshold, thus, the rate of change of reactive power must be checked which Fig (21-b) specifies that it does not violate the threshold value (1.2), also, the active power changes in Fig (20-b) shows that the threshold value has not, therefore, the proposed algorithm does not misapply and could easily distinguishes the situations.

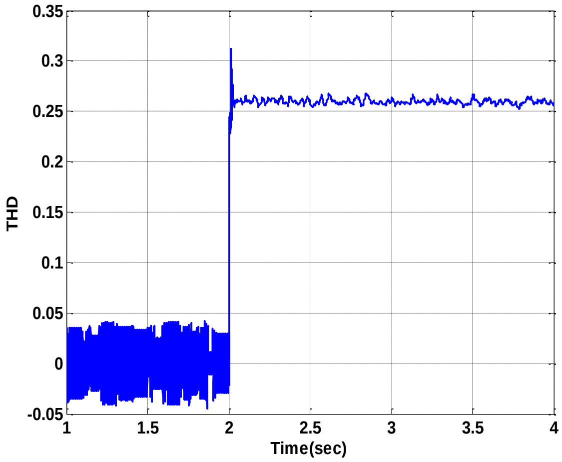

Fig.19 Total harmonic distortion of current for non linear load

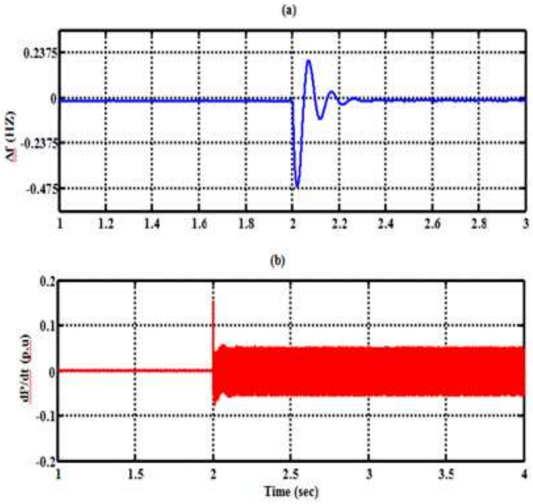

Fig. 20. a) frequency changes of the DG b) active power changes of the DG for non-linear load

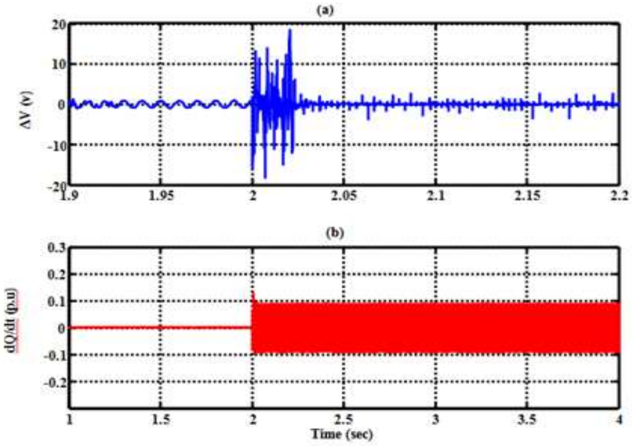

Fig. 21. a) Voltage changes of the DG b) reactive power changes of the DG for non-linear load

VI. Conclusions

Following the increased number and enlarged size of distributed generating units installed in a modern power system, the protection against islanding has become extremely challenging nowadays. In this paper, a novel combined technique was proposed to diagnose the islanding mode for wind turbines. This technique is of passive methods and makes decisions based on local measurements. Obtained results emphasize on good performance of the method since other method may misunderstand the situations, however, this method could efficiently recognize the situations from each other and disconnect the system. Of course, this method obviates the wrong doing of the other methods because it utilizes all the method together to extract a correct decision. Also, simulation results and their comparisons with the other methods substantiated this claim. Study system was simulated for different conditions and it was inferred that unlike the other methods the proposed method could easily detect the islanding mode from the other modes.

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