Hybrid Anti-Islanding Algorithm for Utility Interconnection of Distributed Generation

Maher G. M. Abdolrasol
maher_photo@yahoo.com
Dept. of Electrical Engineering
University of Malaya
Lembah Pantai, 50603 Kuala Lumpur.

Saad Mekhilef
Dept. of Electrical Engineering
University of Malaya
Lembah Pantai, 50603 Kuala Lumpur.

Abstract- **In this paper hybrid anti-islanding algorithm for utility interconnection of distributed generation is proposed. This algorithm is based on two detection schemes; namely active and passive. Active detection algorithm generates disturbances at the output by Positive feedback and Continuous feedback signal injection which is based on DQ implementation. On the other hand passive detection algorithm detects islanding by measuring voltage, frequency, active and reactive power. Using total harmonic distortion (THD) as an additional parameter is proposed in this paper. Passive detection algorithm uses several types of loads such as resistive, capacitive and inductive connected in parallel and compares the performance of the algorithm in each case.**

I. Introduction

In contemporary world interconnection of distributed generations (DG) which operate in parallel with electrical power networks, is currently changing the paradigm we are used to live with. Distributed generation is gaining worldwide interest because of environmental issues and rising in energy prices and power plant construction costs. Distributed generations are relatively small and many of them make use of renewable energy such as fuel cells, gas turbines, micro-hydro, wind turbines and photovoltaic. The operation of distributed generation will enhance the power quality in power system and this interconnection especially with reverse power flow may lead to some problems like voltage and frequency deviation, harmonics, reliability of the power system and islanding phenomenon. Islanding is one of the most technical concerns associated with the proliferation of distributed generation connected to utility networks. Islanding can be defined as a condition in which a portion of the utility system contains both load and distributed generation remains energized while being isolated from the remainder of the utility system [1]. Islanding detection is a mandatory feature for grid-connected inverters as specified in international standards and guidelines. Inverters usually operate with current control and unity power factor and employ passive monitoring for islanding detection methods based on locally measured parameters. Under islanding conditions, the magnitude and frequency of the voltage at the point of common coupling (PCC) tend to drift from the rated grid values as a function of the power imbalance (ΔP and ΔQ). As it is known that distribution system does not have any active power generating source and does not receive power in case of a fault in transmission line. However, with Distributed Generation this presumption is no longer valid. In current practice DG is required to disconnect the utilities from the grid in case of islanding. IEEE 929-1988 standard [2] requires the disconnection of DG once it is islanded and IEEE 1547-2003 standard [3] stipulates a maximum delay of 2 seconds for detection of an unintentional island and for DG to interrupt the power supply to the distribution system.

The main issues about islanding are [4]:

1). Safety issues since a portion of the system remains energized while it is not expected to be;
2). Islanded system may be inadequately grounded by the DG interconnection;
3). Instantaneous reclosing could cause out of phase in the system;
4). Loss of control over voltage and frequency in the system;
5). Excessive transient stresses upon reconnection to the grid;
6). Uncoordinated protection;

The strategy of islanding detection is to monitor the DG output parameters for the system and based on the measurements decide whether an islanding situation has occurred from monitoring of these parameters. Islanding detection techniques can be divided into remote and local techniques [8]. Local techniques can further be divided into;

1) Passive methods [5][6][7].
The idea of passive method is to measure system parameters such as variations in voltage, frequency, harmonic distortion etc. based upon the thresholds set for these parameters if these parameters has exceeds more that it is normal rate Islanding can be detected. This method fast to detect the islanding. But it has large non detection zone and it need special care to set the thresholds for it is parameters. Passive method can classified into:

- *Rate of change of output power*
- *Rate of change of frequency*
- *Rate of change of frequency over power*
- *Change of impedance*
- *Voltage unbalance*
- *Harmonic distortion*

2) Active methods [4][8][9].
Active method tries to overcome the shortcomings of passive methods by introducing perturbations in the inverter output. Active method can detect the islanding even under the perfect match of generation and load, which is not possible in case of the passive detection schemes but it caused

degradation of power quality. active method can be classified into:

- *Reactive power export error detection*
- *Impedance measurement method*
- *Phase (or frequency) shift methods*
- *Active Frequency Drift*
- *Active Frequency Drift with Positive Feedback Method*
- *Adaptive Logic Phase Shift*
- *Current injection with positive feedback*

3) Hybrid methods [10][11].
Hybrid method based on implementing of two assortment of active and passive method. The active technique is implemented only when the islanding is suspected by the passive technique. It can be classified into:

- *Technique based on voltage and reactive power shift*
- *Technique based on positive feedback and voltage imbalance*

In general, once the main grid source supply is lost the DG has to take charge of the remaining network and the connected loads. Therefore, the loading condition of the DG is suddenly changed after islanding. Since the distribution networks generally include single-phase loads, it will be highly possible that the islanding changes the load balance of DG. Additionally, different loading conditions might result in different harmonic currents in the network since the amount and configuration of the load are changed. Therefore, this paper proposes hybrid detection techniques which use active and passive detection techniques. Active detection scheme disturbs the system and causes it to go out of it is boundaries by using Positive feedback and Continuous feedback signal injection based on DQ implementation. Passive detection scheme, on the other hand, monitors parameters for detecting the islanding operations of DG: voltage unbalance, frequency, active and reactive power along with total harmonic distortion (THD). The proposed method utilizes not only two new monitoring parameters but also incorporates voltage magnitude in the conventional islanding detection techniques. The method monitors the changes in four parameters and diagnoses the operating conditions of DG by using different loading conditions, which are the combination of resistance, inductive and capacitive loads connected in parallel.

Following the organization of the paper; first methodology and system configuration are presented. Theory of operation and some key design considerations such as details about the islanding phenomenon as well as the configuration of the Active and passive schemes implementation are also explained. Second MATLAB simulation results which verify the proper operation and show the responses for different loading conditions are given. An analysis is performed on these results. Finally, the conclusion sums up the work and the findings presented in this paper.

II. Methodology and System Configuration

A single-line diagram of the proposed system configuration is depicted in Figure 1; we assume that the three-phase DG system consists of a dc source, an inverter, a filter, a transformer, and a controller. This kind of dc-ac inverting DG structure is easily found and commonly used in photovoltaic systems, fuel cell systems, micro-turbines, and modern wind power systems connected in parallel to the grid and feeding RLC load at the same time. The controller plays a key role in operating, managing, and protecting the DG system. In this model, the controller uses unintentional islanding technique which means that once the islanding occurs the DG disconnects itself from the rest of the system to prevent itself and the load. By opening switch S1 the system will become islanded as shown in Figure 2 After interrupting of S1 there will be variations in system voltage, frequency, active and reactive power and THD.

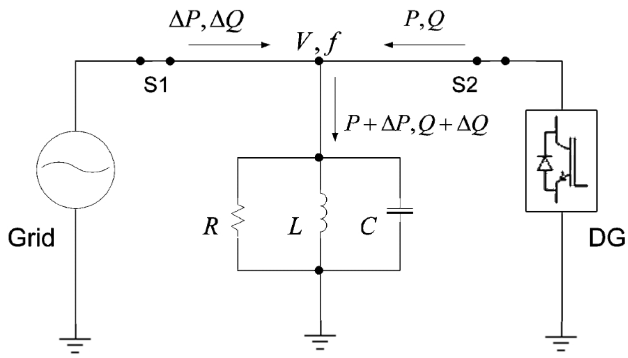

Figure 1. Single line diagram for inverter grid connection.

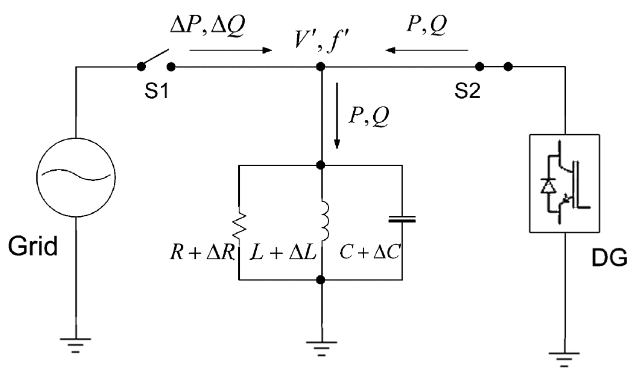

Figure 2. Single line diagram for islanding system.

The controller contains both active and passive detection schemes. Active detection scheme method injects current through the system and causes a disturbance and continuous feedback signal during islanding. Whereas the passive detection scheme decides whether the system is islanded or not. Figure 3 shows the complete controller for Anti Islanding scheme using MATLAB-Simulink.

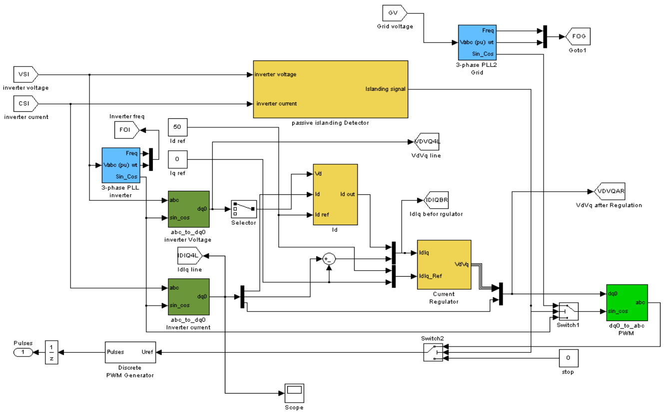

Figure 3. Full controllers for Anti Islanding

1). Active scheme design implementation

The philosophy of the voltage feedback schemes is to create a technique that, when the inverter senses a change it should command more real power. Because of the load characteristics

$$P = V^2 / R \quad \ldots\ldots\ldots\ldots\ldots (1)$$

the voltage will steadily increase or decrease in order to balance the real power. Finally, the voltage will exceed its limits upon sensing this change the passive controller will confirm the Islanding. Figure 4 shows the active controller in details.

This mechanism, however, will not be effective when the grid is connected. Because of the DQ implementation, two voltages, Vd and Vq, can be used as the feedback signals. In Figure 4 for example, Vd is chosen as the feedback signal. One positive feedback can be designed as follows: the voltage feedback Vd is passed through a band-pass filter (BPF), a gain block, and a limiter, and then injected to the current reference Idref. This feedback will establish the mechanism that is, the changing voltage will be fed back, the inverter will then respond with active power changing (by commanding more current), and in turn causing further voltage change due to the load characteristic .

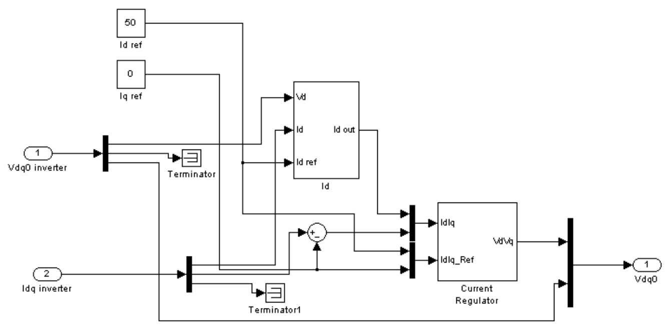

Figure 4. Active scheme controller

Figure 5 shows the current regulator used. It is composed of PID controllers, two input signals Id and Iq, and two injection signals Idref and Iqref.

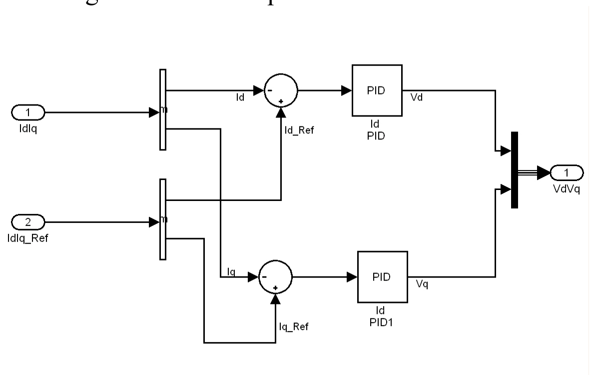

Figure 5.Current regulator with PID controller

2). Passive *Scheme design implementation*

This scheme's task is to measure the thresholds for parameters and in case the controller exceeds the limits to order the controller to stop PWM generation and stop power generation from DG side. This controller is constructed from logical controller in MATLAB. After measuring the voltage if the voltage is not between 0.88 to 1.1 V_{pu} (which is normal range according to standards) the system will check the frequency. If the frequency is the in range of 60.5 to 59.3 Hz then the system checks active power and reactive power based on DQ. If the variation in active and reactive power is (ΔP and ΔQ) more than 15 % then the system checks if the THD is more than 0.3 %. The system's islanding can be confirmed with any of the two control parameters. Islanding can be confirmed if the conditions are satisfied for the voltage plus any of the remaining four parameters, starting with frequency and active power, reactive power and total harmonic distortion. This scheme is explained in the flow chart given in Figure 6.

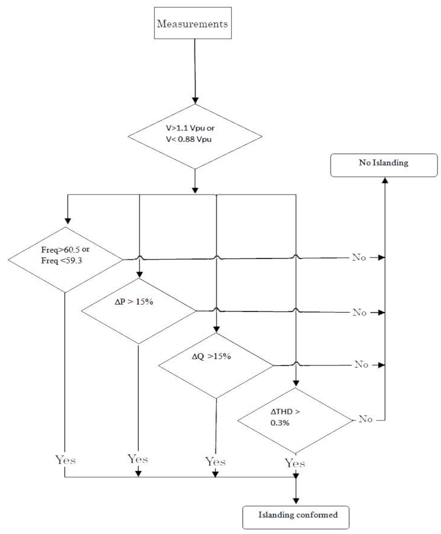

Figure6. Flow chart for passive detection scheme

III.

IV. ANALYSIS AND SIMULATION

Simulations are done in MATLAB in order to analyze the proposed method by different types of loads as in the following simulation. The utility voltage used in simulation is 208V and 60Hz, the capacity of power 50KW and the maximum value of output current is limited at 50 A. In order to confirm the protection of the power converter from over current the effect of the controller on the system and the behavior of the system after and before islanding should be observed. This is done by focusing on the passive parameters of the system voltage, frequency, active and reactive power and THD. In addition to this increase in inverter current and decrease in the utility and inverter voltage are given in Figure 7. With the help of RLC load the changes in angles of the gird and inverter and the difference between the angles after islanding can be observed. In Figure 8, the blue plot represents grid angle and green one represents inverter angle. Inverter and grid frequency behaviors after islanding also can be seen in Figure 8.

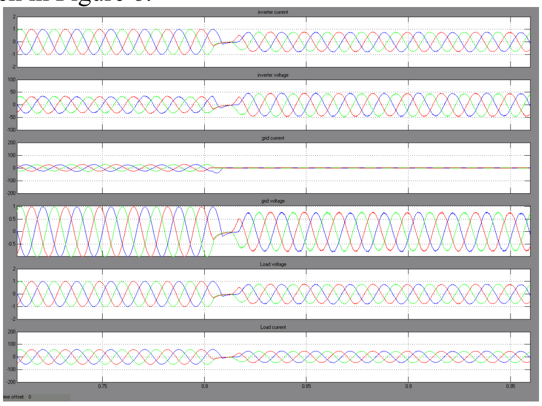

Figure 7. Inverter current, inverter voltage, grid current, gird voltage, load current and load voltage.

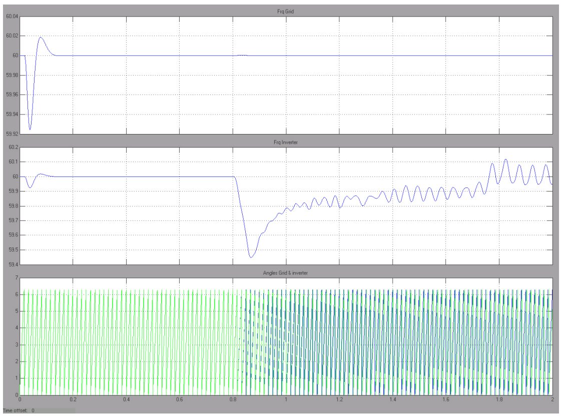

Figure 8. Grid frequency, inverter frequency and angles for gird and inverter

Firstly, pure resistive load (R) is used in the simulation monitoring voltage, frequency, active power and reactive power and THD. For resistive load case it is observed that after switching off the grid (Islanding the system) at 0.8s all the parameters has changed and disturbed. It is also clearly seen that the voltage is drop less than it is normal range. It drops below it is threshold 0.88 Vpu and goes out of its limits in a few milliseconds as shown in Figure 9. Frequency has also decreased until it reaches 59.46Hz and then it is unbalanced during the course of islanding. Active and reactive powers have also exceeded their limits after interruption of the utility. They keep increasing during islanding. The threshold for the total harmonic distortion is 0.3%. When the utility is interrupted at 0.8s the THD suddenly reaches 0.56 as shown in Figure 9. After that it declines to 0.034 but it does not settle while the system is islanded. All of these parameters can be used to confirm islanding and if any frailer occurs in the system can be easy detected.

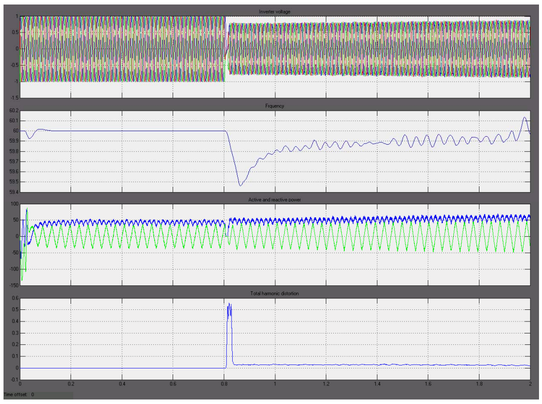

Figure 9.Passive detection parameters voltage, frequency, active and reactive power and THD with pure resistive load(R)

Secondly, a resistive-inductive (R-L) load is used in the simulation. This load is composed of a resistor and an inductor connected in parallel. Figure 10 shows the parameters of the controller which are voltage, frequency, active power and reactive powers and THD. For the system under the resistive-inductive load case after interruption of the utility at 0.8s it can be said that voltage amplitude clearly drops and voltage amplitude becomes less than 0.8Vpu as shown in Figure 10. This will sure trigger the islanding detection controller system. Frequency in this case has also decreased as in resistive load but in this case it reaches 59.53Hz and it returns back to 60Hz in 0.275 seconds which much faster than the pure resistive case. Active power and reactive power as shown in Figure 10 increase after islanding but the difference is less than that of the pure resistive load. THD also shoots up suddenly to 0.54 after islanding at 0.8s and then it declines and reaches 0.03.

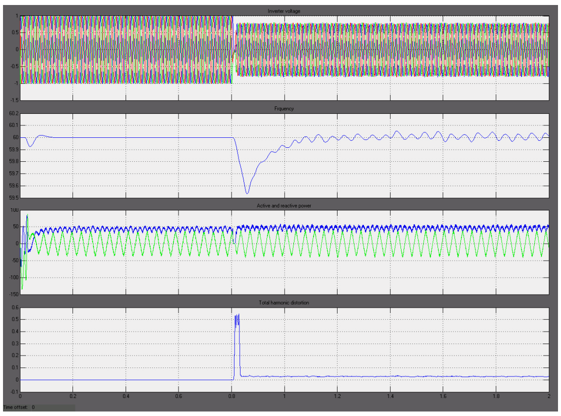

Figure10. Passive detection parameters voltage, frequency, active and reactive power and THD with resistive-inductive (R-L) load

Thirdly, a resistive-capacitive (R-C) load is used in the simulation. This load is composed of a resistor and a capacitor connected in parallel. The Figure 11 shows the parameters of the controller which are voltage, frequency, active power and reactive powers and THD. After interruption of the utility at 0.8s the voltage amplitude decreases and the voltage amplitude after the interruption becomes less than 0.8Vpu and eventually increases gradually until it reaches 0.85Vpu. Frequency in this case also declines as previous two cases but in this case reaches at 59.34Hz and returns back to 60Hz in 0.636s. This is faster than the first case but slower than the second one. Active and reactive powers increased after islanding more than they did in R-only and R-L load cases. The magnitude of the swing increases in time and this can trigger islanding detection much faster than other parameters. As in other cases THD had an abrupt overshoot and reached 0.55 after islanding and then it declines to reach at 0.035 as shown in Figure 11.

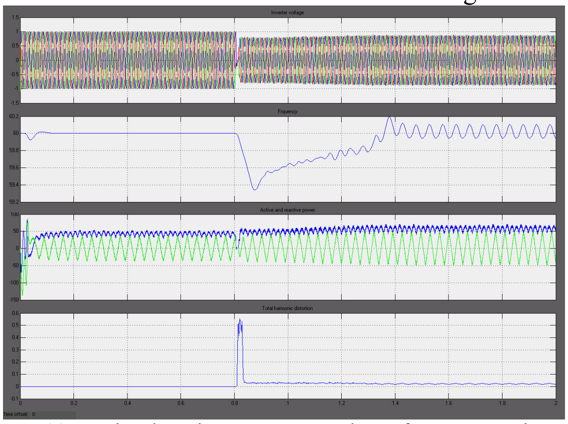

Figure 11. Passive detection parameters voltage, frequency, active and reactive power and THD with resistive-capacitive (R-C) load

Finally, a resistive-inductive-capacitive (R-L-C) load is used in the simulation. This load is composed of a resistor, an inductor and a capacitor connected in parallel. Figure 12 shows the parameters of the controller which is voltage, frequency, active power and reactive power and THD. After interrupting the utility at 0.8s voltage amplitude decreases until it reaches at 0.8Vpu and then it has a little gradual increase and reaches 0.84Vpu. The frequency also decreases as in previous cases and in this case reaches 59.46Hz and returns back to 60Hz after 1.07s. Active power and reactive power have increased after islanding more than first two cases and less than third case. As usual THD had a sudden overshot and reached at 0.54 after islanding and then it declined to reach 0.03 as shown in Figure 12.

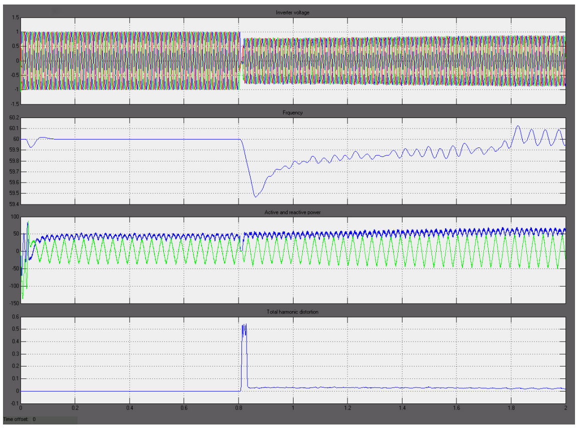

Figure 12. Passive detection parameters voltage, frequency, active and reactive power and THD with a resistive-inductive-capacitive (R-L-C) load

V. CONCLUSION

The investigations reported in this paper show that hybrid Anti-islanding algorithm for utility interconnection of distributed generation can be satisfactorily implemented. The logical rules used in this paper for islanding detection simply consist of two rules. Which are to inject disturbance to the system and keep the disturbances to confirm the islanding. Then the islanding is detected by monitoring the system parameters. In this fashion the islanding can successfully be detected under various types of loads. Islanding phenomenon varied obviously after the utility is interrupted. Hence, the islanding can be detected in just a few milliseconds and the distributed generation can be shut down quickly. Furthermore, this method has a small non-detection zone therefore the proposed method is expected to be an effective islanding detection approach for implementation in industrial fields.

ACKNOWLEDGMENT

The authors would like to acknowledge that this research has been supported by PPP University of Malaya with project number PS134/2008C. Current injection for active islanding detection of electronically-interfaced distributed resources.

REFERENCES

[1] L- A. C. Lopes, Y. Zhang "Islanding Detection Assessment of Multi-Inverter Systems with Active Frequency Drifting Methods", IEEE Transactions on power Delivery, Volume 23, Issue 1, Page(s):480 – 486 Jan. 2008.

[2] IEEE 929 - 2000, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, 2000.

[3] IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems, 2003.

[4] H-G González and R. Iravani "Current injection for active islanding detection of electronically-interfaced distributed resources", IEEE Transactions on power delivery Volume 21, Issue 3, Page(s):1698 – 1 705 July 2006.

[5] Ye Z.; et al, "Evaluation of Anti-Islanding Schemes based on Non detection Zone Concept", IEEE Transactions on Power Electronics, Vol: 19, Issue: 5, Sept 2004

[6] S-I. Jang; K-H. Kim, "Development of a Logical Rule-Based Islanding Detection Method for Distributed Resources", IEEE Power Engineering Society Winter Meeting, Page(s):800 - 806 vol.2, Jan 2002.

[7] Jang S.-I.; Kim K.-H., "An Islanding Detection Method for Distributed Generations using Voltage Unbalance and Total Harmonic Distortion of Current", IEEE Transactions on Power Delivery, Vol: 19, Issue: 2, April 2004

[8] Z. Ye, L. Li, L. Garces, C. Wang, R. Zhang, M. Dame R. Walling, N. Miller "A New Family of Active Anti-Islanding Schemes Based on DQ Implementation For Grid-Connected Inverters",35th Annul IEEE Power Electronics Specialists Conference, 2004.

[9] W-J. Chiang; H-L .Jou; J-C. Wu; Y-T. Feng "Novel Active Islanding Detection Method for Distributed Power Generation System" International Conference on Power System Technology, Page(s):1 – 7 22-26 Oct. 2006.

[10] P. Mahat, Z. Chen, B.B-Jensen. "A Hybrid Islanding Detection Technique Using Average Rate of Voltage Change and Real Power Shift ", IEEE Transactions on Power Delivery, vol. 24, Issue 2, Page(s):764 - 771 April 2009

[11] T. N. T Chairman; D. Boroyevich" Control of Power Conversion Systems For The Intentional Islanding of Distributed Generation Units" Blacksburg, Virginia September 26, 2005.

[12] P. Mahat;Z.Chen; B.B-Jensen "Review of Islanding Detection Methods for Distributed Generation" Electric Utility Deregulation and Restructuring and Power Technologies, Page(s):2743 – 2748 6-9 April 2008.