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A Hybrid Islanding Detection Technique for an 8kW Solar Powered Single Inverter grid Connected Distributed Generation

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ABSTRACT: This paper develops of a modified hybrid islanding detection method for an 8kW single inverter solar powered grid connected distributed power generation for achieving faster detection time and also to study the impact of reactive power injection in islanding.In this method a passive and an active method are combined to form a modified Hybrid islanding scheme viz.., voltage unbalance and Total harmonic distortion which are a combination of passive methods combined in series with a modified continuous bilateral active power variation methodas active method for detection of islanding. Along with modified continuous bilateral reactive power variation an initial reactive power disturbance is also added with this method to get a more satisfactory performance in the project. Based on the modelling the active islanding method is triggered only when the passive methods detect the occurrence of Islanding due to series connection and the results shows that this method is suitable for solar powered inverter based grid connected distributed power generation. Based on the analysis it was found that the modified method provides satisfactory performance in terms of faster detection and reduced power quality disturbance. Project Simulation, results, parameter definition, performance of Hybrid islanding are based on standards IEC 62116, IEEE 929 and IEEE 1547 and modelling is done with the help of MATLAB/Simulink 2014 environment.

KEYWORDS: Distributed power generation, Solar power system, passive method, Active method, Hybrid method, reactive power variation, frequency variation, Quality factor, detection time.

I.INTRODUCTION

Modern power grids are becoming smart with the addition of Distributed sources such as solar, wind, fuel cell, micro turbine and the possibility of digital control. Grid connection of solar photovoltaic power generation systems has the advantage of efficient utilisation of power generated. [1]. The requirements of integrating such sources are outlined in national policies of many countries and is now a prerequisite for reducing the impact due to increased climate change and depletion of natural resources. Modern power electronics systems has shown a rapid development along with the introduction of digital control technologies. This has helped the development of many grid connected schemes and topologies. From the operational point of view of a system connected to grid with Distributed generation one of the major occurrence is islanding and it can happen due to avoidable or unavoidable circumstances. Islanding is a condition in which a portion of the utility system, which contains both load and generation, is isolated from the remaining portion of the utility system and continues to operate[1].Islanding causes disturbances in power system performance parameters due to the dynamics created by it after the instant of islanding. Out of the main reasons for detection of islanding safety, reliability and maintaining the quality of delivered power to customers ranks high on the list of reasons [1]. All such detection methods mainly depend upon knowledge of the variations in voltage, current, frequency and phase angle. This parameter changes directly affects the flow of active power and reactive power at PCC between distributed power generation, load and grid. A net measure of the variation in active and reactive power is normally indicated by a term Non-detection zone (NDZ). As the area of Non-detection zone increases the sensitivity decreases, since islanding occurs when the variation in active and reactive power is ideally reaches to zero. There for the detection time after islanding occurs mainly depends upon the variation in parameters like voltage, current, frequency and phase angle which directly impact the active power and reactive power exchange at PCC.

Therefore the purpose of Islanding detection is to detect the instant at which islanding occurs with minimal impact to local loads fed from the system without compromising the operating parameters and power quality. Several technologies are developed for detection of Islanding which are broadly classified under local and remote methods.

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Local islanding methods of detection are further divided into active methods and passive methods. Under thiscategory many methods are developed based on the type of distributed sources used and type of detecting parameter.Eventhough the passive method can create lesser detection time and low disturbance the disadvantages are threshold setting sensitivity, nuisance trips etc…, So active methods were developed to overcome this. Active methods creates known disturbance at PCC during islanding to detect the islanding condition. They have got small NDZ but low power quality due to the disturbance injected by this method. By considering the merits and demerits of active methods and passive methods Hybrid Islanding methods are developed to achieve better performance parameters during Islanding. The combination of passive method and active method can be in series or parallel depending on the requirements of the system. The remote islanding detection methods creates communication between grid and energy production but they are not practiced due to complexity and cost involved.

II.STANDARD TESTING REQUIREMENTS

The standard testing requirements for detection of islanding is mentioned in many international standards like IEEE Std.929 [4] and IEEE Std.1547 [5] . Figure below shows the generic block diagram specified in the above standards indicating a system consisting of a distributed generation, Voltage source inverter with local parallel RLC load in grid connected and disconnected mode as below.R_g, L_g are the resistance and inductance of grid.

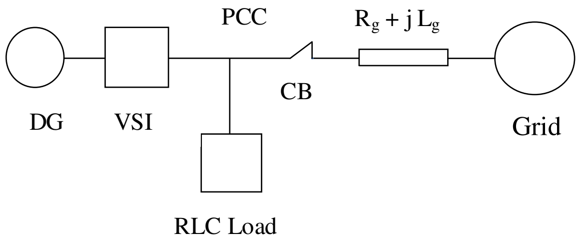

Fig.1 Generic block diagram for grid connected mode

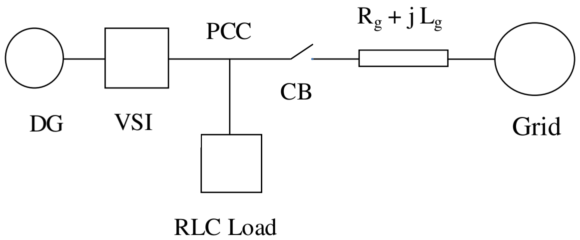

Fig.2 Generic block diagram for grid dis connected mode

As per the standard testing requirements for a grid connected system the proposed hybrid method should detect the islanding for a quality factor $Qf \leq 2.5$ [4] of load and time required for detection shall be less than 2s [5]. Where Qf is called quality factor of the load. The above block diagram is modelled to simulate system connected to grid and islanded mode of operation with parameter definitions matching the standard requirements.

III.PARAMETER VARIATION DURING ISLANDING

The parameters which vary generally during islanding are voltage, current, frequency, phase angle etc.., Passive methods usually detect the changes in these parameters to understand the instant of islanding. While an active method intentionally creates some disturbance in the system and measure the parameters at PCC to identify the islanding instant. The parameters can be selected from voltage frequency or impedance. During such variations by measuring the parameters the distributed generation can take a decision whether to continue the production or not. However in most of the scenarios the load needs to satisfied without interruption after the islanding is detected,so it continues to serve the load after the islanded mode. Based on the generic block system shown in section II there is always a mismatch exists in active power and reactive power before and after islanding instant. The relationships between voltage variation, frequency deviation along with active and reactive power mismatch can be defined based on the generic block diagram and analysis and derivation in various related literatures [2] [7] [8] [9] [10] as below :

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In grid connected mode:

$$Pload = Pdg + Pgrid = \frac{3\,Vpcc^2}{R}$$

$$Qload = Qdg + Qgrid = 3\,Vpcc^2\left(\frac{1}{XL} - XC\right) = Pload\,R\left(\frac{1}{XL} - XC\right)$$

Where $P_{load,}$ Q_{load} are the active and reactive power consumed by the load.P_{dg}, Q_{dg} are the active and reactive power from distributed generation and P_{grid} and Q_{grid} are the contribution by grid. ΔPandΔQ are the power mismatches at the instant before or after the islanding instant and they are defined as below:

$$\Delta P = Pload - Pdg = Pgrid$$

$$\Delta Q = Qload - Qdg = Qgrid \text{ and}$$

$$f0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Qf = R\sqrt{\frac{C}{L}}$$

Where $f_0$and $Q_f$are the frequency for resonance and quality factor of the load. By combining first two equations as explained above the frequency during grid connected and islanding mode can be derived as below:

$f = \frac{fo}{2}\left(\sqrt{\left(\frac{Qload}{QfPload}\right)^2 + 4} - \frac{Qload}{Qf\,Pload}\right)$and $fis = \frac{fo}{2}\left(\sqrt{\left(\frac{Q}{QfP}\right)^2 + 4} - \frac{Q}{Qf\,P}\right)$ from these two equations it can be seen that the frequency can be changed by changing the reactive power. As per the block diagram in section II there always exits an active and reactive power mismatches before or after islanding conditions. The islanding condition is specified in terms of the value of $Pgrid$ and $Qgrid$ before and after islanding. This mismatch will cause PCC voltage to vary causing mismatch in active power. As per the equations above a change in active power also affects the mismatch in reactive power. These two mismatches ΔP and ΔQ causes the frequency at PCC to vary. Based on the Q-f characteristics mentioned in [3] if PCC voltage is greater than or equal to the rated voltage the DG offer more reactive power than the load demanded. So the mismatch in active power and reactive power causes frequency to increase and if the PCC voltage is less than the rated voltage the DG offer more reactive power than the load demanded to improve the decrease in frequency happening. In this project the above frequency variation can be modified by an initial incremental contribution of frequency by an injection of reactive power before the islanding occurs. The corresponding frequency variation is taken as Δf .This is due to injection of a reactive power dQ which is selected approximately as 10% of actual load reactive power. Therefore the new frequency before islanding will be $f^* = f + \Delta f$ and $f_{is}* = f_{is} + \Delta f$ where f and f_{is}aredefinedabove in equations.

IV. PROPOSED METHODOLOGY

Figure below shows the basic block diagram for implementation of the project methodology. The passive methods selected are voltage unbalance and Total harmonic distortion as mentioned in [2], if both these methods can detect an instant of islanding then only the active method is initiated. The active method selected is the modified bilateral continuous reactive power variation. The literature [2] specifies about the use of Intermittent bilateral reactive power variation based Hybrid islanding system with a periodic variation of load reactive power to + Q and – Q while this project has considered a continuous bilateral reactive power injection and this result is further added up with and initial perturbation of dQ which is termed as reactive power reference. This reactive power disturbance dQ is already available to the system and is set at a very low value in order to avoid unnecessary changes in frequency before the islanding. After the islanding is detected this will be added along with the modified continuous bilateral reactive power variation to generate a new value of reactive power perturbation continuously after the islanding instant. This will help the system to provide a faster variation in frequency so that OFP/UFP can be detected in short time thereby almost eliminating NDZ. The reactive power alteration causes the increase in frequency to go above threshold limit as specified in IEC 62116 : 2014 to detect the OFP condition and to isolate the DG and load from grid at PCC.From that instant onwards the DG feeds only the load with no interaction with grid so that $P\ load = P\ dg$ and $Q\ load = Q\ dg$and power mismatches tending to zero. For the modelling set up of OFP is detected as per the parameter definition since frequency increase happening for the system after islanding.

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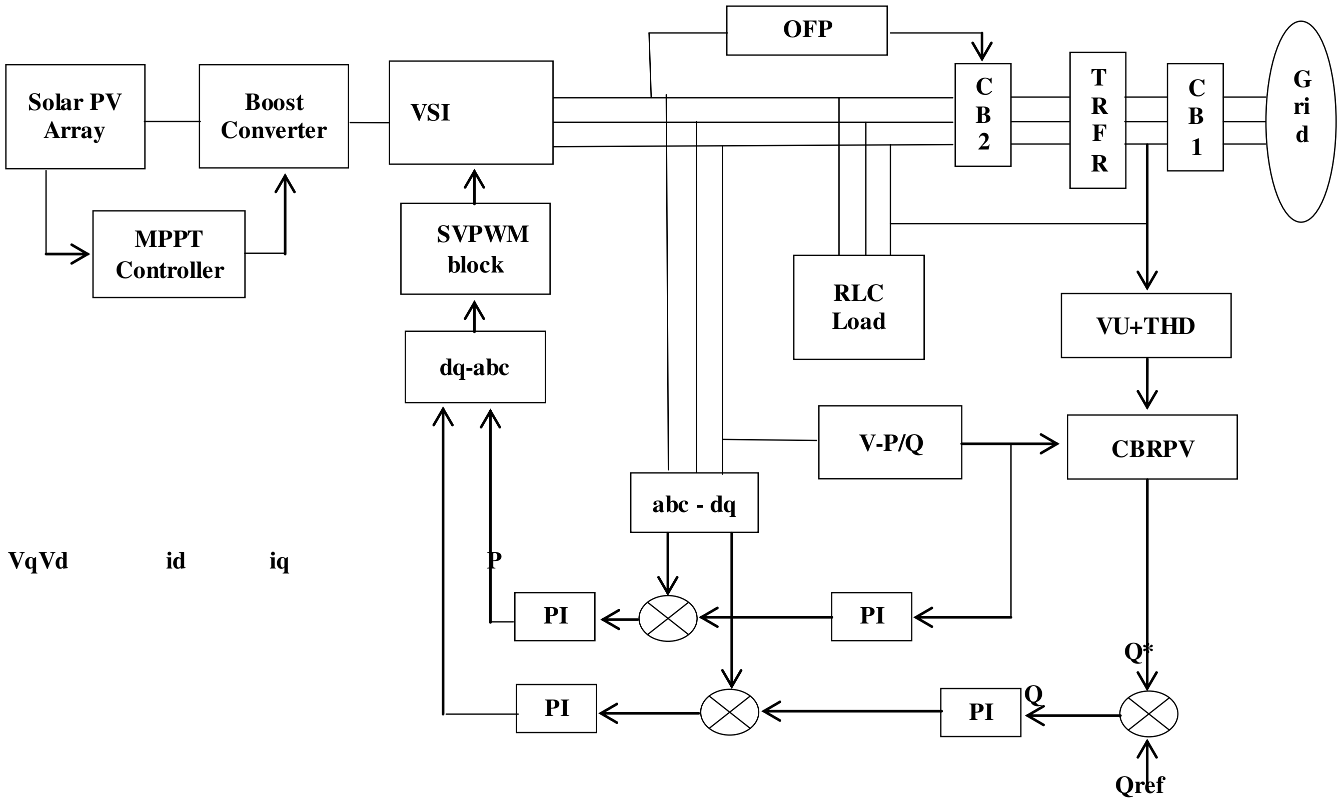

Fig.3 Block diagram of the proposed project

Terminology :
MPPT – Maximum power point tracking for Solar power system, VSI – Voltage source inverter
SVPWM – Space vector pulse width modulation, PI – Proportional and Integral controller
OFP – Over frequency protection, CB2 – Circuit breaker at PCC side
CB1 – Circuit breaker at Grid side, TRFR – Grid integration transformer
VU – Voltage unbalance passive method, THD – Total harmonic distortion passive method
CBRPV – Continuous bilateral reactive power active method
V-P/Q – Voltage to active/reactive power converter
Q* - Continuous bilateral reactive power, Qref – Injected reactive power.

V. MODELLING OF THE METHODOLOGY IN MATLAB / SIMULINK

The modelling of the project is done in Matlab / Simulink software Ver.2014.The PV array of rated capacity 8 kW is obtained from the mathematical model by 54 nos of cells in series forming a module and 11 numbers of such modules in parallel.Eventhough the rated capacity is 8 kW the power demand is set to be 3 kW based on the load and grid connecting parameters. The solar PV array is of rated voltage 207 V which is boosted to the rated voltage using a boost converter. The boost converter is controlled using an MPPT technique to make the DG source as constant voltage source providing constant active power. The output of boost converter is connected to an LC filter at input side of Voltage source inverter and the inverter block is controlled by SVPWM block in closed loop. The output of Inverter is also connected to an LC filter for smoothen out the waveform at PCC. At PCC and RLC parallel load block is defined. The continuous measurement of load current and its conversion to d-q parameters done at d-q block for use in closed loop. Using a voltage to P-Q converter block the active and reactive power drawn by load is also measured instantaneously before and after the islanding instant. The passive islanding detection block consists of two blocks namely voltage unbalance and Total harmonic distortion. The voltage unbalance block is modelled based on the following equation as mentioned in [2]

$$\Delta Vu = \frac{Vut-Vutd}{Vutd} \times 100 \text{and} \Delta THD = \frac{THDt-THDtd}{THDtd} \times 100$$

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Where Vut is the voltage at PCC/Grid side at current instant and Vutd is the voltage at PCC/grid one fundamental frequency before by applying one cycle delay. Similarly THD block is modelled using the formula and THDt is the voltage harmonic distortion at PCC/grid side at current instant and Vutd is the voltage at PCC/grid one fundamental frequency before by applying one cycle delay. As per IEC 62116 : 2014 [6] the ΔVu limit is set as 15 % whereas in [2] it is 50 %. Since this project follows the threshold setting as 15 % it will help for more faster detection of islanding. Similarly for ΔTHD limit is set as 50 % while in [2] it is set as 100 %. In general if the local RLC load is more resistive compared to the inductive/capacitive elements so the effect of THD variation can go more than 100 % but for a faster detection 50 % setting is selected. If both these two block detects islanding it initiates the active block. The active block takes the continuous measurement of reactive power and converts it to a continuous bilateral reactive power value with an adjustable gain. This when added with small value of the continuous reactive power dQ provides enough disturbance at PCC to increase the frequency above threshold value. In closed loop using two sets of PI controllers and transformation blocks the active and reactive power variations in closed loop can create signals at input side of SVPWM block. This block controls the frequency of output power of VSI at PCC and can be measured using a PLL block. The upper limit of frequency is set at 51.5 Hz as per IEC 62116:2014 [6] to initiate the breaker opening at PCC side to totally isolate the distributed power generation and local load from grid. Figure below shows the overall flow chart of the project.

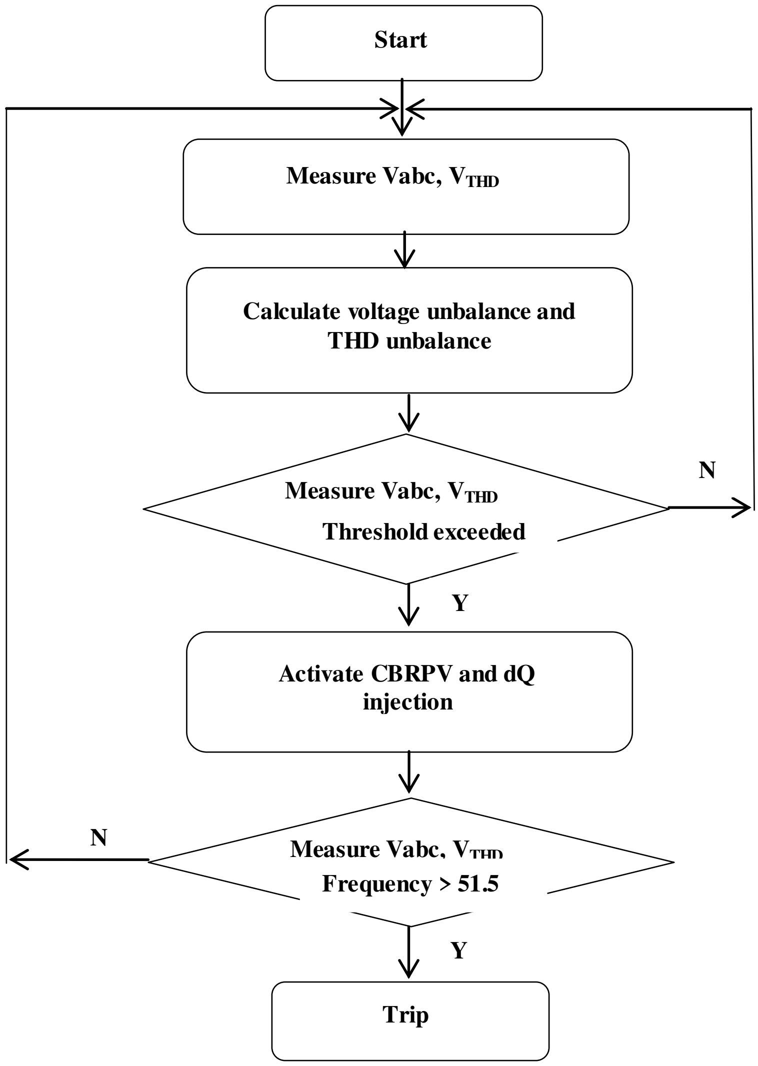

Fig.4 Overall flow chart of the project

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VI. RESULTS OF MODELLING

OPEN LOOP

The open loop model of the project consists of the PV array of rated capacity 8kW obtained from the mathematical model by 54 nos of cells in series forming a module and 11 numbers of such modules in parallel, which responds to change in temperature and irradiance. The performance of Solar PV module is verified for standard variation of irradiance from 800 to 1200 W/m2 and temperature variation of 10 - 35 ºC and the results were obtained. The standard test value of Irradiance and temperature is considered as 1000W/m2 and 25ºC. The solar PV array is of rated voltage 207 V which is boosted to the rated voltage using a boost converter. The boost converter is controlled using an MPPT technique to make the DG source as constant voltage source providing constant active power and the corresponding waveforms are obtained. Since the DC input voltage is modelled as a constant DC source voltage the output voltage is controlled with dedicated MPPT controller to so that the active power of the distributed generation is constant as per [2].The output voltage is given to an inverter controlled by six separate pulse generators in 120 degree conduction mode and the output waveforms in open loop are obtained for verifying the open loop operation.

Fig.5 Output waveforms of PV array voltage, current and power.

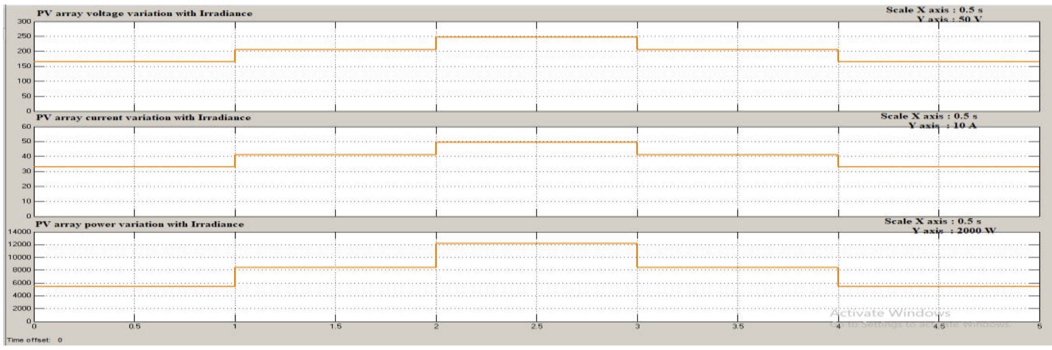

Fig.6 Output waveforms of PV array voltage, current and power.

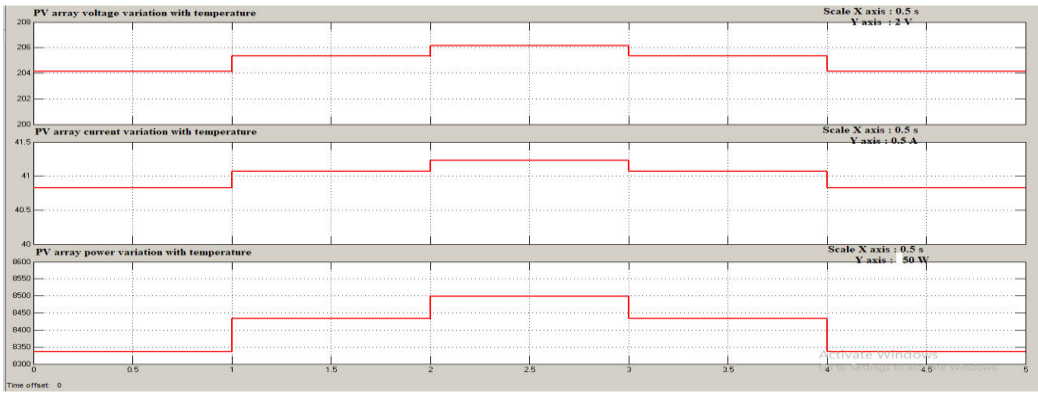

Fig.7 Output waveforms of PV array voltage, current and power.

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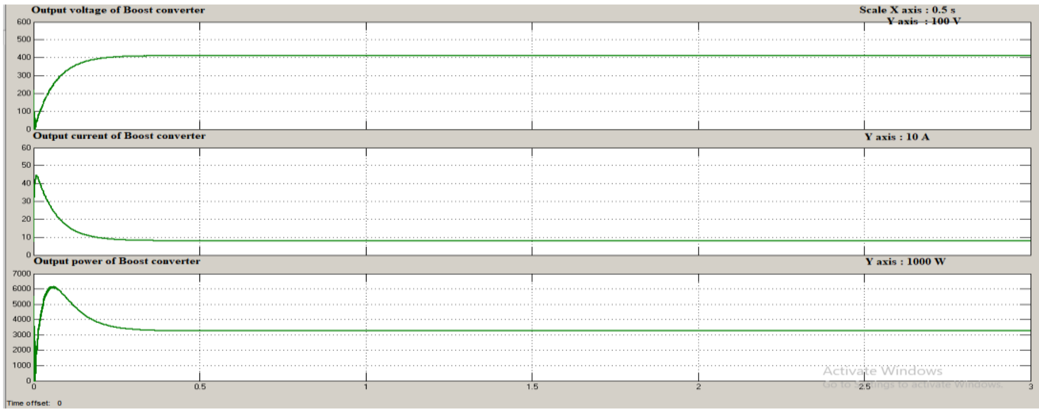

Fig.8 Output wave forms of Boost converter with MPPT.

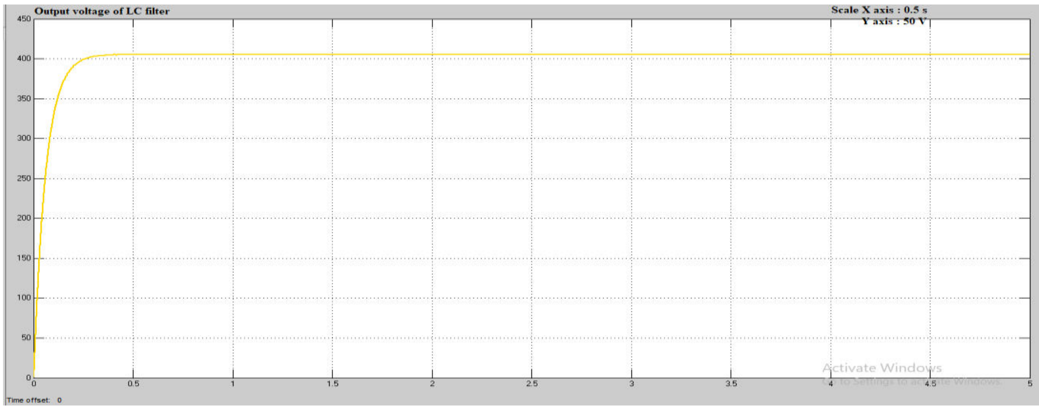

Fig.9 Output wave forms of LC filter at input side of Three phase VSI inverter.

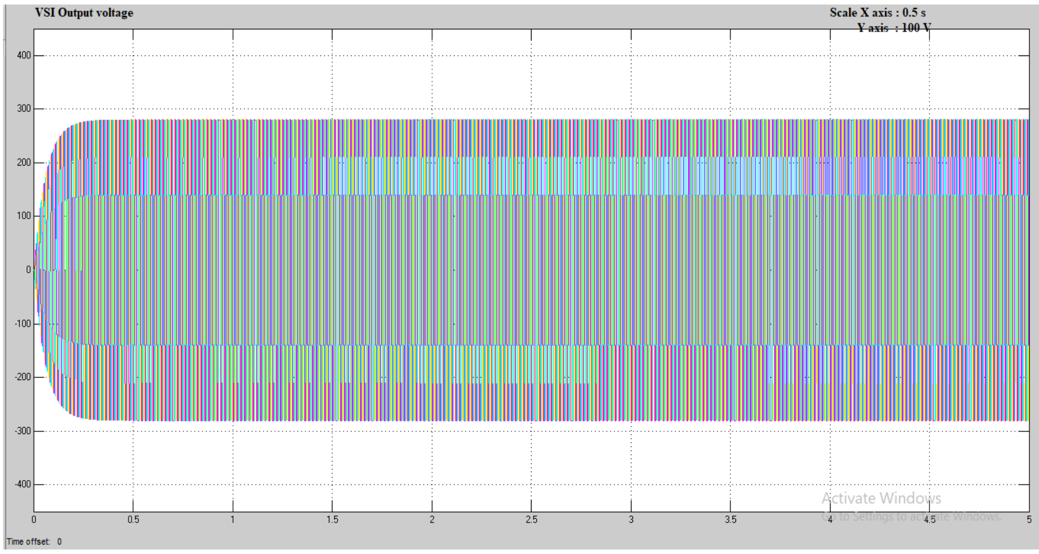

Fig.10 Output wave form of VSI

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CLOSED LOOP

In closed loop operation the grid side breakers are opened for a defined time period of 0.5 to 1.5 s during simulation and during this islanding period various wave forms of all the islanding detection blocks were taken. The continuous measurement of load active power and reactive power is considered and continuous bilateral reactive power injection is also added with a reference reactive power of dQ . This reference value is set as 10 Var (2 % of actual reactive power taken by load) and is given much before the islanding instant as a small disturbance. The disturbance due to the reactive power causes the output frequency to increase above the rated value of threshold as 51.5. It can also be noted as explained in section III if the PCC voltage tends to increase compared to the rated value during islanding then the reactive power and frequency increases as indicated in the last two wave forms shown below. After the islanding is properly detected by this hybrid method the PCC voltage falls to the rated value but with some distortion due to high impedance at PCC compared to grid. The overall time required for the islanding detection is coming around 0.5 s which is well within the 2 s mentioned in [5]. By further adjusting the threshold limits of THD and the continuous bilateral reactive power variation gain along with reactive power injection the time required for islanding detection can be further reduced less than 0.5 s, within the limits of power quality.

Fig.11 Wave forms of VU block

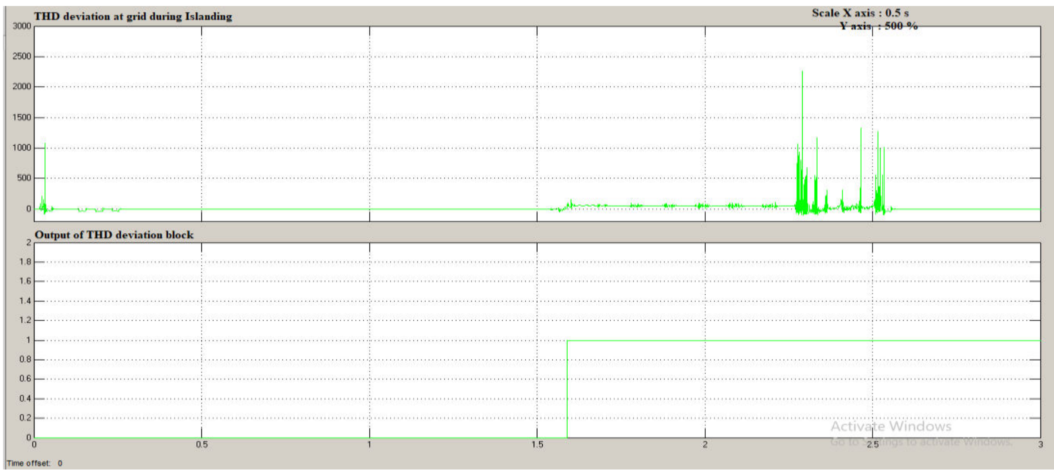

Fig.12 Wave forms of THD block

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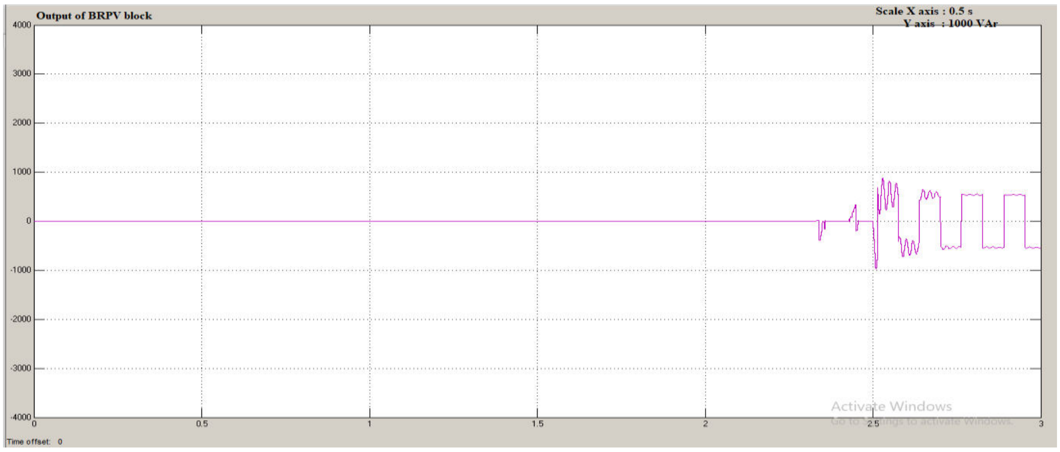

Fig.13 Wave forms of CBRPV block

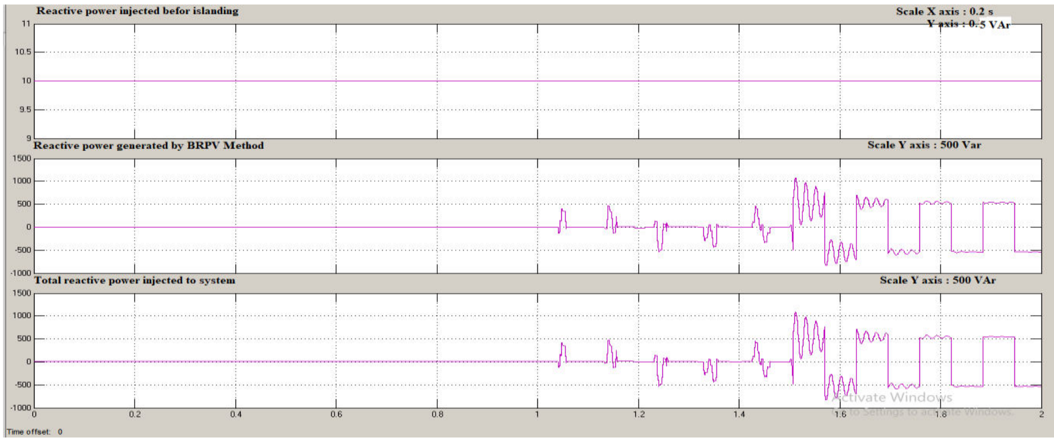

Fig.14 Wave forms of CBRPV and dQ injection block combined.

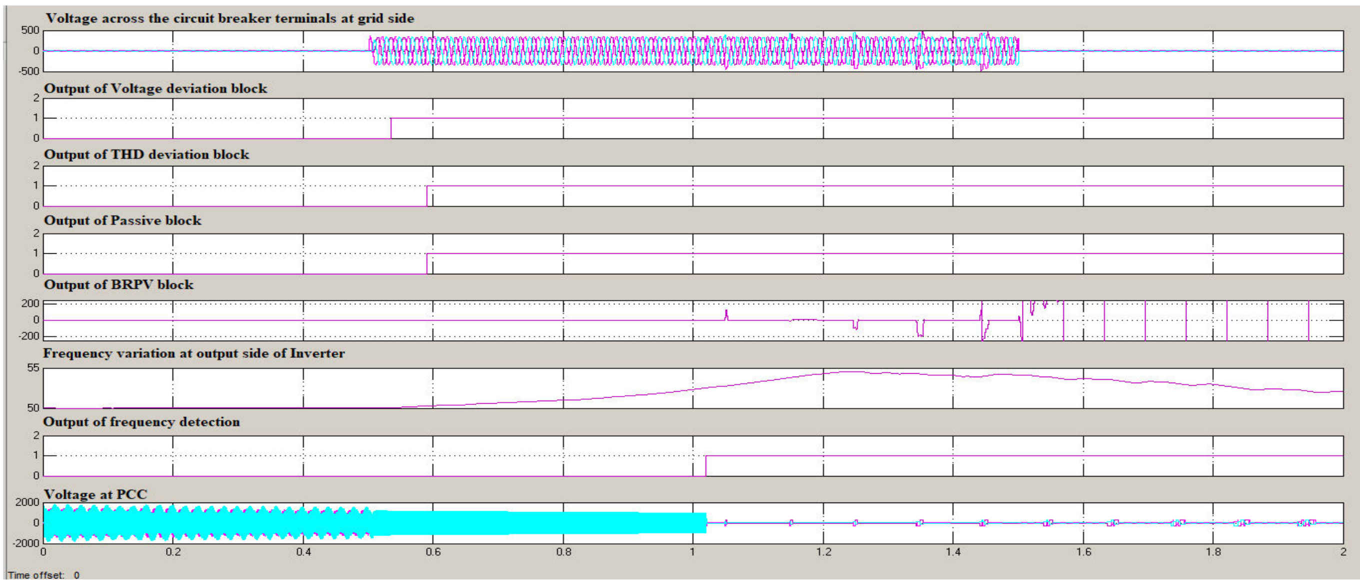

Fig.15 Wave forms of closed loop operation.

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VI.CONCLUSION

This paper makes a development of design principles of a modified hybrid islanding detection to achieve faster detection time and reduced NDZ.By suitable selection and modification in existing methods the islanding detection performance is improved significantly with reduced detection time and the effect of reactive power injection and frequency variation also studied. The reactive power injection method produced lesser harmonic distortion compared to other methods and makes this configuration suitable for solar powered inverter based grid connected distributed generation. Simulations are based on standards IEC 62116, IEEE 929 and IEEE 1547 were carried out to verify detection performance and found satisfactory.

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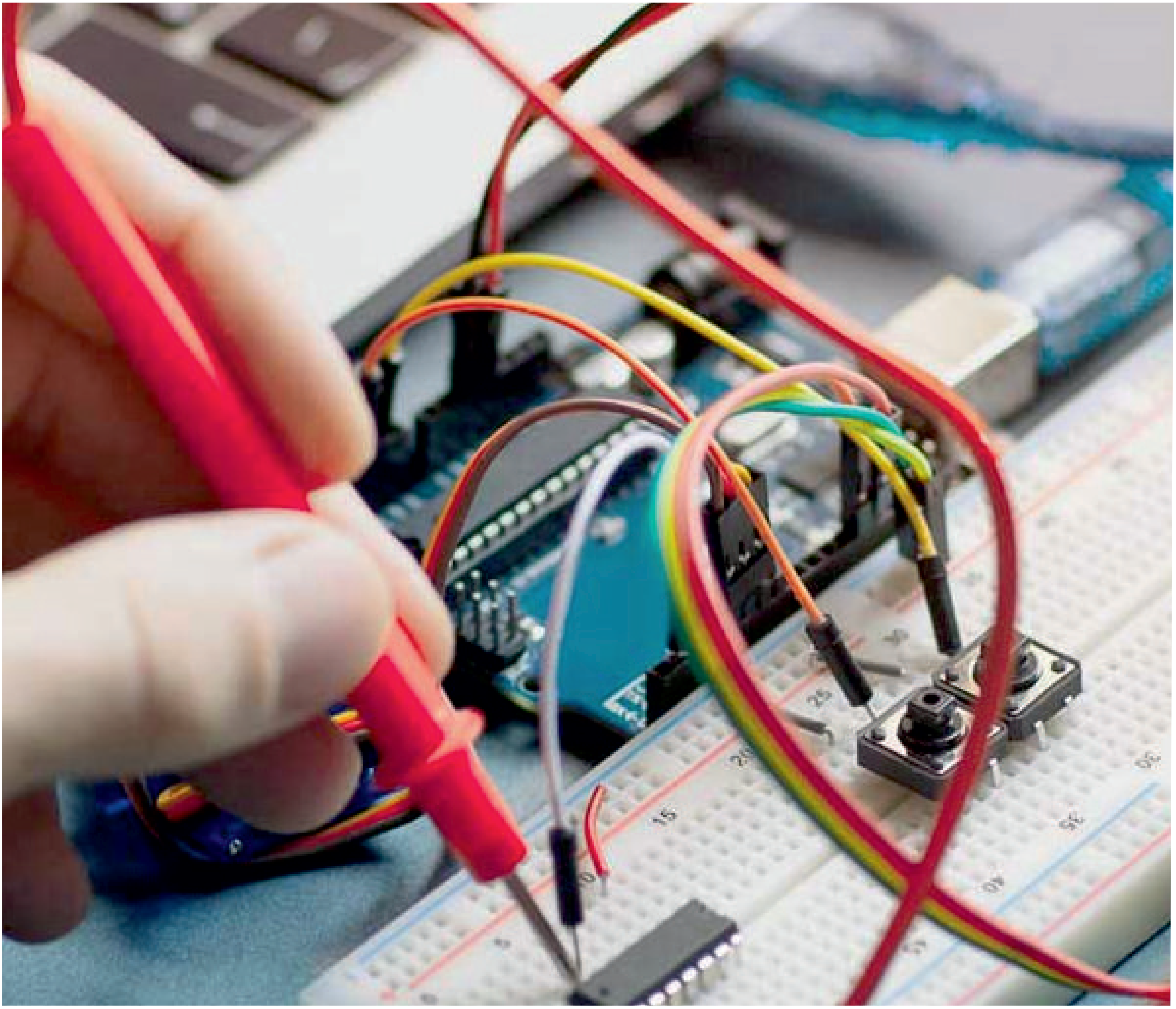

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