

# GRID TIED PV INVERTER WITH INTELLIGENT ANTI - ISLANDING CONTROL AND LOAD SHARING TECHNIQUE

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**Abstract**— This paper aims to improve the anti-islanding detection response time and to reduce the total harmonic distortion induced by the solar PV grid tied inverter. Load sharing methodology was also strategized to improve the efficiency of the inverter by supplying only real power to the load whereas the reactive power demand of the load is supplied from the electric utility grid supply. The proposed model uses an accurate modeling of commercially available polycrystalline solar PV module using specifications sourced from SAM software of NREL, USA. MPPT algorithm is based on incremental conductance with integral voltage control technique. An improved PFD anti-islanding detection method is proposed to improve the power quality. The proposed method has shorter island detection time and improved NDZ compared with the classic PFD method when they have the same THD. The performance of the proposed method is verified by simulation using MATLAB/SIMULINK.

**Index Terms**— Anti-islanding, Load sharing, SAM software of NREL, MPPT, incremental conductance with integral voltage control technique, PFD anti-islanding detection method, improved NDZ, MATLAB/SIMULINK.

## I. INTRODUCTION

India has one of the highest potentials for effectively using renewable energy sources. Greater reliance on renewable energy sources offers enormous economic, social, and environmental benefits. The Sun is an abundant, inexhaustible and cost and pollution free source of power for mankind. Sunlight has by far the highest theoretical potential of the earth's renewable energy sources. Within the basket of Renewable Energy resources, Solar Photovoltaic Power plays an important role. Photovoltaic's offer consumers the ability to generate electricity in a clean, quiet and reliable way.

## II. STATEMENT OF THE PROBLEM

Grid Tied Solar Systems possesses inherent advantages; conversely it's not without disadvantages. As a result, DG

(distributed generation) inverter interconnection results in operating situation which does not occur in centralized power systems. These operating situation present unique engineering challenges to DG interconnection. This project deals with this particular operating situation that occurs at the interconnection or Point of Common Coupling (PCC) between grid tied solar PV plant and the rest of the power system in the event of a faulted condition, a situation hereafter refer to as Islanding. One of the new technical issues created by DG interconnection is unintentional islanding. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by DG connected to the isolated subsystem.

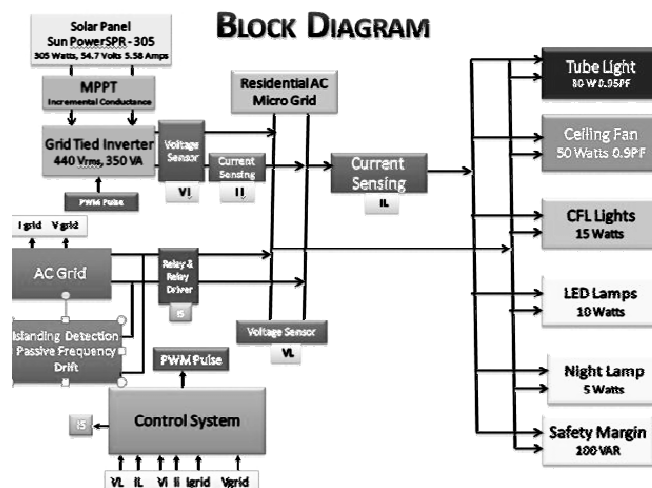


Fig 1. Block Diagram

## III. SCOPE OF WORK

This project will involve examining the national utility network to identify potential unintentional islanding conditions; subsequently an equivalent of all the portions of the network with potential for islanding will be produced.

This equivalent prototype model of the network containing the island/s will then be used to develop a Matlab/Simulink model. The model will contain anti islanding relays, such as, rate of change of frequency (ROCOF), vector surge, over/under voltage relays, over/under current relays and over/under frequency relays based on the principal governing their operation. The model will be simulated under a predefined or intentional islanding condition, so as to evaluate and determine the performance of these relays for the purpose of assisting electrical protection engineers in selecting the most appropriate protective devices and their corresponding settings for DG systems. Also the power sharing between PV system and the utility grid will be designed to provide maximum reliability and maximum power transfer to the load.

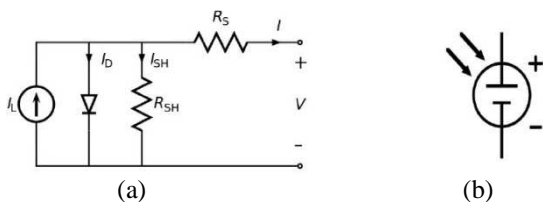


Fig 2. (a) Equivalent circuit of a solar cell (b) The schematic symbol of a solar cell

#### IV. MODELING OF PV PANEL

To understand the electronic behavior of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behavior is well known. An ideal solar cell may be modeled by a current source  $I_L$  in parallel with a diode  $I_D$  in practice no solar cell is ideal, so a shunt resistance  $R_{SH}$  and a series resistance  $R_S$  component are added to the model. In Fig 2, the resulting equivalent circuit of a solar cell is shown on the left. Also shown, on the right, is the schematic representation of a solar cell for use in circuit diagrams. From the equivalent circuit it is evident that the current produced by the solar cell is equal to that produced by the current source, minus that which flows through the diode, minus that which flows through the shunt resistor.

$$I = I_L - I_D - I_{SH} \quad (1)$$

Where

- $I$  - output current
- $I_L$  - photo generated current
- $I_D$  - diode current
- $I_{SH}$  - shunt current

The current through these elements is governed by the voltage across them:

$$V_j = V + I R_S \quad (2)$$

Where

- $V_j$  = voltage across both diode and resistor  $R_{SH}$
- $V$  = voltage across the output terminals
- $I$  = output current
- $R_S$  = series resistance

By the Shockley diode equation, the current diverted through the diode is:

$$I_D = I_0 \left\{ e^{\left[ \frac{qV_j}{nKT} \right]} - 1 \right\} \quad (3)$$

Where

- $I_0$  = reverse saturation current (ampere)
- $n$  = diode ideality factor (1 for an ideal diode)
- $q$  = elementary charge
- $k$  = Boltzmann's constant
- $T$  = absolute temperature At 25°C,  $\frac{KT}{q} \approx 0.0259$  volt.

By Ohm's law, the current diverted through the shunt resistor is

$$I_{SH} = \frac{V_j}{R_{SH}} \quad (4)$$

Where

$R_{SH}$  = shunt resistance.

Substituting these into the first equation produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage

$$I = I_L - I_0 \left\{ \exp \left[ \frac{q(V+I R_S)}{nKT} \right] - 1 \right\} - \frac{V+I R_S}{R_{SH}} \quad (5)$$

MATLAB Simulink was used to model the PV Module by constructing its equivalent circuit. Shockley diode equation was used to exactly model the internal diode in the equivalent circuit.

$$I_d = I_{sat} \left( e^{\frac{V_d}{nV_T}} - 1 \right) \quad (6)$$

Where

- $I_d$  – Diode current
- $I_{sat}$ – Reverse Saturation Current
- $V_d$ – The voltage across the diode
- $V_T$ – The thermal voltage
- $n$  – The ideality factor, also known as the quality factor

Thermal Voltage is given by the equation

$$V_T = \frac{KT}{q} \quad (7)$$

Where

- $q$  – Elementary charge
- $k$  – Boltzmann's constant
- $T$  – Absolute temperature

Sunpower SPR-305-WHT Module for further proceedings in this paper.

#### V. PROPOSED MPPT METHOD

The In order to operate a photovoltaic (PV) system within its MPP, and considering the irradiance and temperature variation, a maximum power point tracking algorithm is needed to search and maintain the peak power. The Incremental Conductance comes from the fact that it uses the derivative of the PV system conductance, in order to determine the operating point position in relation to MPP. In this work, the algorithm was modified in order to include an integral regulator. The integral regulator minimizes the error  $\partial I/\partial V + I/V$  where the regulator output will be equal to duty cycle correction. The power output from the solar PV modules is:

$$P = V \times I \quad (8)$$

Maximum power point is obtained when  $\frac{\partial I}{\partial V} = 0$

$$\frac{\partial P_{PV}}{\partial V_{PV}} = \frac{\partial (V_{PV} \times I_{PV})}{\partial V_{PV}} = V_{PV} \times \frac{\partial I_{PV}}{\partial V_{PV}} + I_{PV} \quad (9)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} > 0 \text{ if } \frac{I_{PV}}{V_{PV}} > -\frac{\partial I_{PV}}{\partial V_{PV}}, \text{ on the left of MPP;} \quad (10)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} = 0 \text{ if } \frac{I_{PV}}{V_{PV}} = -\frac{\partial I_{PV}}{\partial V_{PV}}, \text{ at the MPP;} \quad (11)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} < 0 \text{ if } \frac{I_{PV}}{V_{PV}} < -\frac{\partial I_{PV}}{\partial V_{PV}}, \text{ on the right of MPP;} \quad (12)$$

$$-\frac{\partial (V_{PV} \times I_{PV})}{\partial V_{PV}} = I_{PV} + V_{PV} \times \frac{\partial I_{PV}}{\partial V_{PV}} = 0 \quad (13)$$

$$\frac{\partial I_{PV}}{\partial V_{PV}} = -\frac{I_{PV}}{V_{PV}} \quad (14)$$

The present value and the previous value of the solar module voltage and current are used to calculate the values  $\partial I_{PV}$  of and  $V_{PV}$ . If  $\partial V_{PV}=0$  and  $I_{PV}=0$ , then the atmospheric conditions have not changed and the MPPT is still operating at the MPP. If  $\partial V_{PV}=0$  and  $\partial I_{PV}>0$ , the amount of radiation has increased, raising the MPP voltage. This requires the MPPT to increase the PV module operating voltage to track the MPP. Otherwise, if  $\partial I_{PV}<0$ , the amount of radiation has decreased, lowering the MPP voltage and requires the MPPT to decrease the PV module operating voltage. If  $(\partial I_{PV})/(\partial V_{PV}) = -I_{PV}/V_{PV}$ , then  $(\partial P_{PV})/(\partial V_{PV}) > 0$ , and the PV module operating point is to the left of the MPP on the P-V curve. Thus, the PV module voltage must be increased to reach the MPP. Similarly, if  $(\partial I_{PV})/(\partial V_{PV}) = -I_{PV}/V_{PV}$ , then  $(\partial P_{PV})/(\partial V_{PV}) < 0$  and the PV module operating point lies to the right of the MPP on the P-V curve, showing that the voltage must be reduced to reach the MPP. In this work, a small marginal error could be added to the maximum power conditions such that the MPP is assumed to occur if

$$\left[ \frac{\partial I_{PV}}{\partial V_{PV}} + \frac{I_{PV}}{V_{PV}} \right] < \varepsilon \quad (15)$$

The value  $\varepsilon$  of was determined with consideration of the trade-off between the problem of not operating exactly at the MPP and the possibility of oscillating around it. This also depends on the chosen perturbation step size. The implementation of this method can be done adding a controller to improve the incremental conductance method minimizing the error between the actual conductance and the incremental conductance, because the compensator can be adjusted and updated according to the system necessity. Besides, this controller can reduce the ripple oscillations in steady-state minimizing the issues involving digital resolution implementation. This method can be seen as an adaptative solution once it presents large step sizes when the PV operating point is far from the MPP, then the step sizes are reduced according to the distance of MPP and finally

when the MPP is achieved the system operation point is not changed, unless the climate conditions are also changed. The controller can control the duty cycle (d) of the converter directly to find the MPP. Fig 3 shows the Flow Chart of the Incremental Conductance Algorithm.

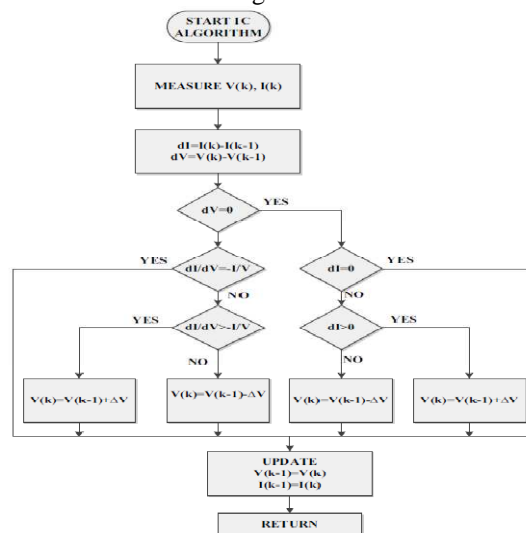


Fig 3. Flowchart of the Incremental Conductance MPPT algorithm.

## VI. GRID-TIED INVERTER

A solar grid-tied inverter converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical BOS (Balance of System)–component in a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

### A. Phase Lock Loops

Phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. The phase detector compares the phase of that signal with the phase of the input periodic signal and adjusts the oscillator to keep the phases matched. Bringing the output signal back toward the input signal for comparison is called a feedback loop since the output is 'fed back' toward the input forming a loop. Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same. Consequently, in addition to synchronizing signals, a phase-locked loop can track an input frequency, or it can generate a frequency that is a multiple of the input frequency. The simple block diagram of PLL is shown in fig 4.



VIII. RESULTS AND ANALYSES

A. Output of the Proposed MPPT Algorithm

The effectiveness of the MPPT algorithm used in this project has been evaluated based on varying the solar irradiance in real time. From the fig 7, it is clearly seen that the Solar Module starts to produce the maximum power that could be extracted from the irradiance available at that point of time. The MPPT block is triggered on at 1.5 seconds, to illustrate the variation of power output of the panel with and without MPPT.

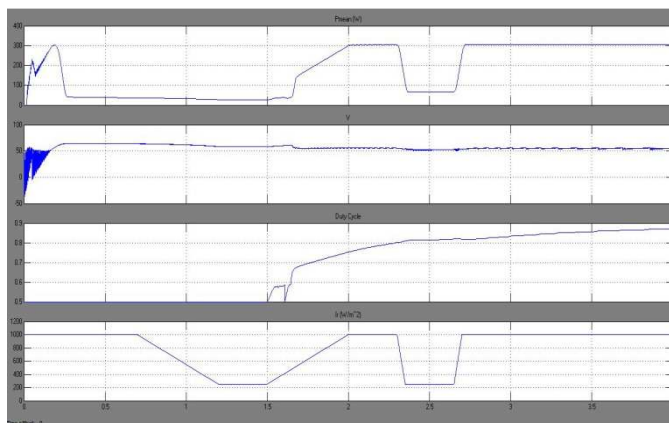


Fig 7. Output Power of Solar Module with variation in Irradiance

B. Output Voltages and Current during Normal Operation

It can be clearly seen from the output voltages and currents of the inverter and grid in figures 9, 10, 11, 12 respectively the voltages remain almost constant at an peak to peak value of 622 Volts, in other words equal to 440 Volts line to line rms ac voltage. The inverter output current varies according to the variation of the solar irradiance and the remaining current is being supplied from the grid, there by maintaining the load voltage and current as constant values as shown in fig 8. The MPPT block is enabled at 0.25 seconds for this simulation and it is clearly evident that after the turning on of MPPT the inverter output starts to current reach its maximum rated value.

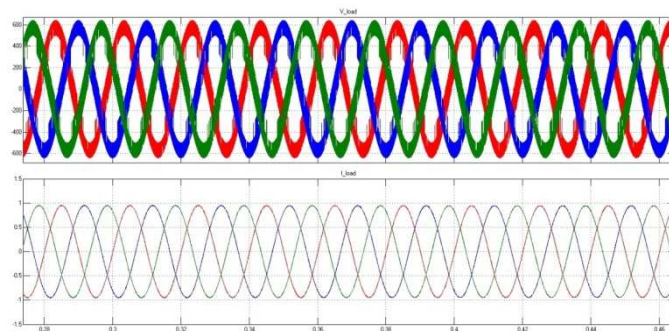


Fig 8. Load Voltage and Current

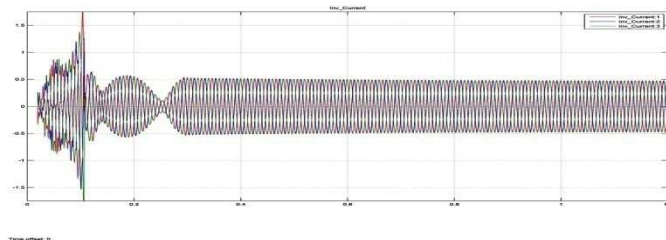


Fig 9. Inverter Current

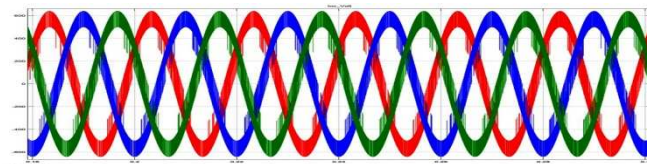


Fig 10. Inverter Voltage

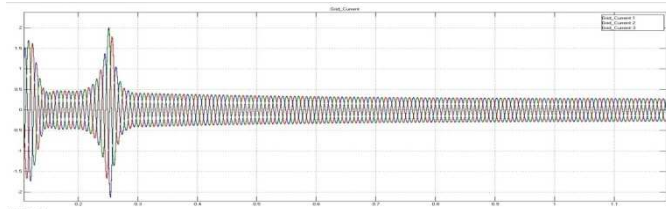


Fig 11. Grid Current

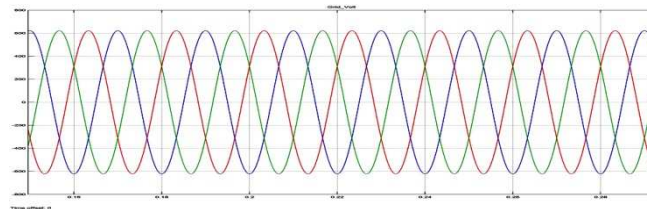


Fig 12. Grid Voltage

C. Anti-Islanding Response

The response of the system to prevent itself forming an uncontrolled island in the power system during the event of grid outage has been evaluated by simulating the utility circuit breaker to open at 0.4 seconds and the Anti-Islanding response of the proposed method in this project has a response time of 9 milliseconds. The figures 13 and 14 clearly illustrate the shutdown of the system after detecting the grid outage. Figure 15 clearly shows the opening of the load side circuit breaker at 0.409 seconds which makes the response time to be 9 milliseconds which is very much less than 2 cycles (i.e., 40 milliseconds).

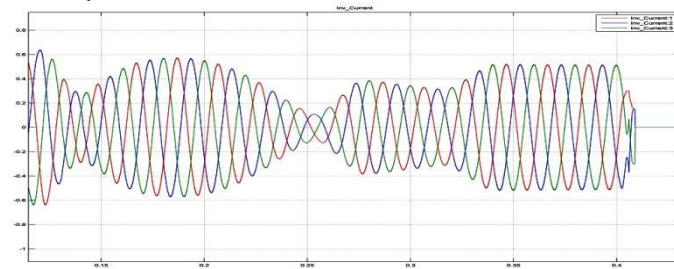


Fig 13. Inverter Current during Islanding Detection

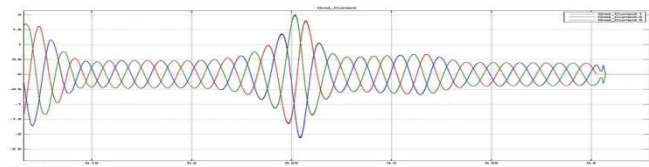


Fig 14. Grid Current during Islanding Detection

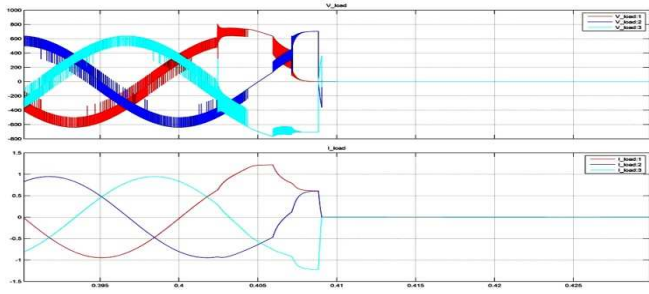


Fig 15. Load Current during Islanding Detection.

The figure 16 shows the variation in the grid frequency and voltage at the time of grid outage, these signals are used by the anti-islanding protection relay to sense the grid outage effectively.

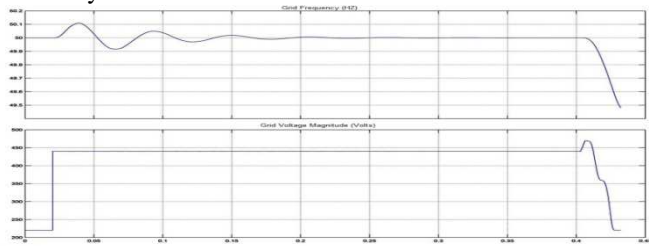


Fig 16. Frequency and Magnitude of grid voltage during Grid Outage

### IX. CONCLUSION

In this paper, an improved frequency drift islanding detection method is proposed, in which a current waveform approximates to cosine is injected to the original reference to reduce the grid-injected current THD. The comparison of THD values of the critical parameters are clearly shown in Chart 1. The response time is achieved below one cycle, which enhances the safety of distributed generation. Furthermore the Solar PV module was perfectly modeled as per commercial availability and the MPPT technique proved to be robust even under drastic climatic changes. The prototype model of the anti-islanding detection system was found to be adoptable in any of the distributed generation facility.

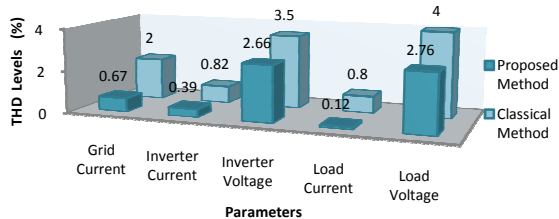


Chart 1. Comparison of THD levels

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