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Grid Connected PV System using Incremental Conductance MPPT Technique

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Abstract: **Solar system is an Eco-friendly system which helps in production of abundant energy with PV arrays. PV System comes under the category of distributed energy. This system helps the existing system to meet the power demand at some point of time. In this paper PV Standalone System is used and is interfaced with Power Grid which is a three-phase system. Observation on Pertub and Observe (P&O) MPPT technique and Incremental Conductance MPPT technique has been done to know the best MPPT technique for tracking maximum power from the PV System. In both the techniques boost converter is used to provide Duty Cycle for switching pulses generation. Inverter is used with 2-level configuration for DC to AC Power Conversion along with pulse width modulation technique. For synchronizing PV to Grid, Phase Lock Loop (PLL) technique is implemented. Active and Reactive Power is Supplied to the load depending on demand by the Control Circuit through PV System. P&O method and Incremental Conductance method is simulated in MATLAB and results of both the methods are used for analysis.**

Index Terms: **P&O, MPPT, PLL, PV**

I. INTRODUCTION

The Renewable energy like Solar, Wind, Tidal, Biomass has the capability to generate the power for supplying it to local areas. The combination of above systems is also taking the advantage to compensate the continuous availability of the renewable resources throughout the day. Specially the Solar Power is ever green resource among renewable resources which can be obtained almost consistently thorough out the day. Even the PV System maintenance [1] is also very less compared to other systems. If PV System can be connected to Grid when maximum power is generated and with minimizing phase unbalance, reactive power, power quality issues [9], then the power system becomes more efficient and dependency on the other non-renewable resources also reduces.

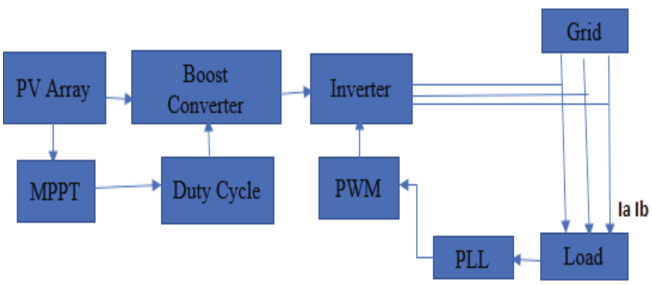

Figure 1. Block diagram of Grid Connected PV system

II. TYPES OF MPPT TECHNIQUES

A. Perturb and Observe

Perturb & Observe algorithm is mostly used in the PV maximum power tracking and to adjust Duty Cycle. P&O is a continuous process of observation and perturbation till maximum power point is obtained. In this algorithm comparison of the power and voltages at a time (t) with the sample taken at a time (t-1) and estimation is made to understand the time to approach MPPT. A small voltage perturbation changes the power of the solar panel if the power alteration is positive, voltage perturbation is continued in the same track. But if power is negative, it indicates that maximum time is needed to reach MPP and the perturbation is decreased to reach the MPP. So whole PV System is checked. Fig 2. Shows the flow chart of P&O technique.

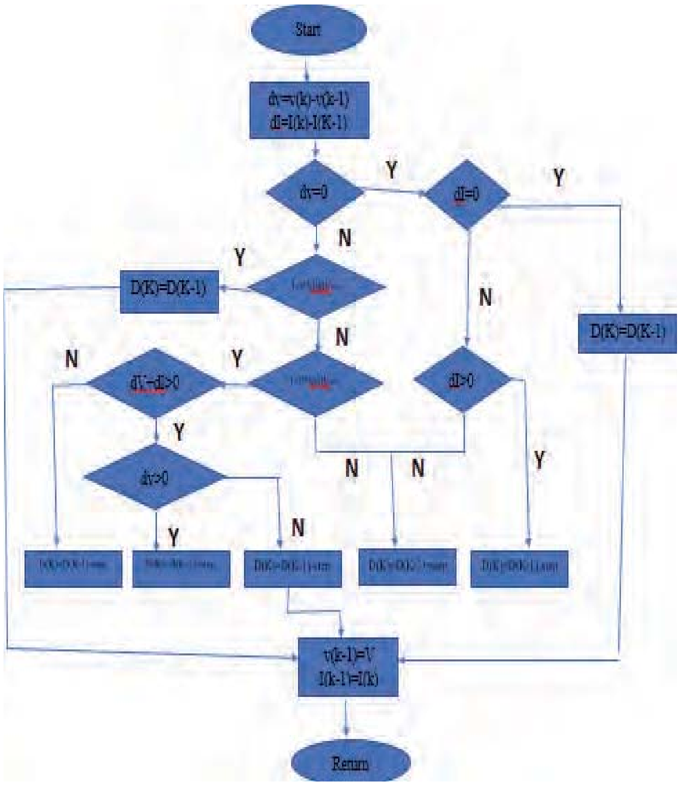

Figure 2. Flow chart of Perturb and Observe MPPT Technique

B. Incremental Conductance MPPT

The incremental conductance algorithm detects the slope of the P–V curve, and the MPP is tracked by searching the

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peak of the P–V curve. This algorithm uses the instantaneous conductance I/V and the incremental conductance dI/dV for MPPT [2]. Fig 3. Shows the flow chart of IC MPPT.

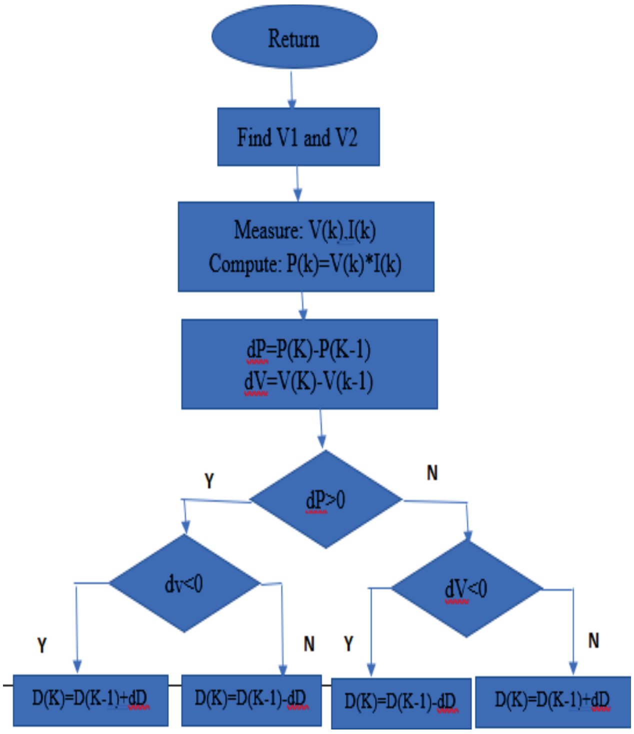

Figure 3. Flow chart of Incremental Conductance MPPT Technique

In incremental conductance method the terminal voltage control is done depending on the maximum voltage which in turn depends on the incremental conductance of PV. For the change in output conductance if dI/dV is negative then the voltage is decreased and if dI/dV is positive then voltage is increased to track the maximum power at every instant. Power=Voltage*Current. By differentiating power with respect to voltage.

$$\frac{dP}{dV} = \frac{V * I}{dV} \quad (1)$$

$$\frac{dP}{dV} = I + V(\frac{dI}{dV}) \quad (2)$$

For maximum power point is reached the slope. Thus, the condition would be.

For maximum power point is reached the slope.

$$I + V\left(\frac{dI}{dV}\right) = 0 \quad (3)$$

C. Fractional Open Circuit Voltage

This method will consider a linear dependency on array open circuit voltage which will give maximum power at various irradiation and temperatures. Compared to all other MPPT methods, it is the simple one. The drawback of this method is for sampling array voltage the PV array will get disconnected with load at regular intervals. Because of this, there are power losses. If sampling period is too long the losses also increases. After tracking MPP there will not be any change in MPP even if there is change in irradiation between two sampling periods [10].

D. Fractional Short Current

There is a linear relation always with short circuit current when MPP is considered. It is expressed as

$$I_{mpp} \sim KI_{sc} \quad (4)$$

here K is the constant of proportionality. The K value will be different for different PV modules 0.72 to 0.92 variation will be there. This is just an assumption so actual MPP will not be tracked. Efficiency is around 90% and even tracking speed is also fast. It is the cheapest and easy method to implement as it requires only one current sensor, only periodic measurement of I_{sc} is enough to track MPP [11].

III. Basic PV System and MPPT

A. PV System

It has solar cells which are connected in series and parallel to get the required voltage and currents [8][2]. The basic terminology and the constants used in the PV system are given in the equations which are represented from equation 5 to equation 12. Fig 4. Shows the single diode circuit used for the analysis.

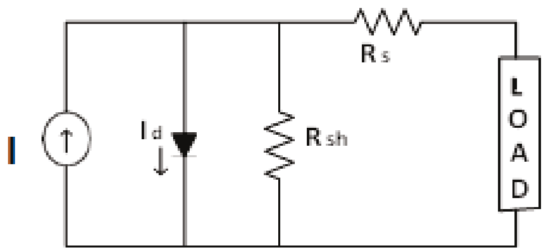

Figure 4. Single diode Circuit

I_{ph} = Photo Current (5)
I_d = Module saturation cells number (6)
N_p, N_s = Series and Parallel cell number (7)
T= Temperature in (Kelvin) (8)
K= Boltzmen Constant($1.381*10^{-23}$) (9)
A= Ideality Factor (10)
Q= charge of e^-($1.602*10^{-19}$) (11)
R_s= Series Resistance in Ω (12)

B. MPPT

Maximum Power Point: In Perturb and Observe (P &O) MPPT Power and Voltage values are used for perturbation. Perturb and Observe Control algorithm is designed in such a way that change in voltage measures the maximum power in forward direction, if power decreases for voltage change or back direction for maximum power. Fig 5. Shows the PV curve for MPPT.

dp /dv>0 then +ve slope which is left side of curve
dp /dv<0 then -ve slope which is right side of curve
dp /dv=0 then maximum power point MPP

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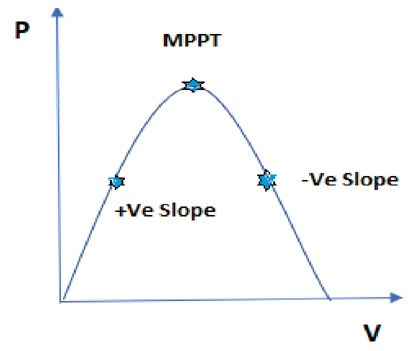

Figure 5. P-V Curve for MPPT

IV. Boost Converter

As DC voltage is needed to step up the AC voltage, Boost Converter is
Case 1: ON state of Switch, current flows will be through Inductor (L), Switch.
Case 2: OFF state of Switch, current flows will be through Inductor, Diode, Capacitor, Load. Here energy storage of Inductor flows through the circuit in mode2 operation. The circuit diagram of Boost Converter shown in Fig. 6.

Output of Boost Converter Voltage is

$$\frac{dI}{dV} = I \qquad (13)$$

$$\frac{dP}{dV} = 0 \qquad (14)$$

$$V_{out} = V_{in}/1 - D \qquad (15)$$

From above equation the Duty cycle is extracted and is given to IGBT switch which is used through PWM generator. Fig 6. shows the boost converter used in the circuit.

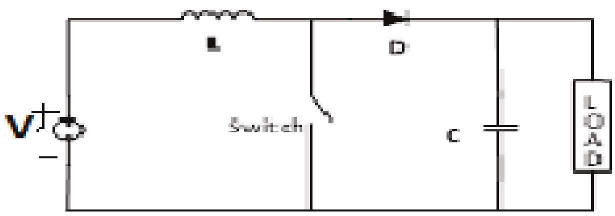

Figure 6. Boost Converter

V. PWM Inverter and Control Circuit

First stage is done by Boosting the DC voltage whereas this is second stage where 2- level inverter is used to convert 3 phase AC supply. Two Level Voltage Source Inverter (VSI) will convert fixed DC voltage to 3-Phase AC voltage. These types of inverters are employed in machines and converter control. The VSI inverter consists of three legs which has two IGBT switches on each leg and have DC Source and Load. Fig 7. Shows the Voltage Source Inverter.

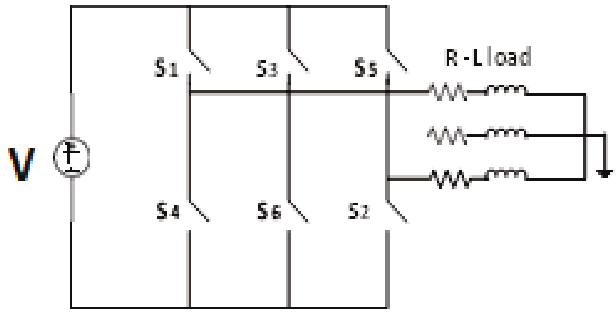

Figure 7. Voltage Source Inverter (VSI)

A. Pulse Width Modulation (PWM)

In this paper, for switching purpose the pulses of IGBT are driven by PulseWidth Modulation (PWM) Technique. In PWM Triangular Carrier Wave (fc) is compared with Sinusoidal Reference wave (fr) of desired frequency. Depending on the condition between fr & fc provides switching instant pulses to IGBT. VSI is equipped with DC link of capacitance bank which is used for grid synchronization purpose.

B. Controller Circuit

Interfacing the voltage source inverter with the grid, phase angle information is needed. For getting accurate results of phase angle, Phase Lock Loop (PLL) technique has been used. This PLL helps in load sharing between standalone PV and grid. It estimates the phase and frequency values [5]. Interfacing phase angle parameter is necessary for active and reactive power flow control [6]. The power flow is controlled by Current Control Scheme. Fig 8. Shows the PLL controller circuit.

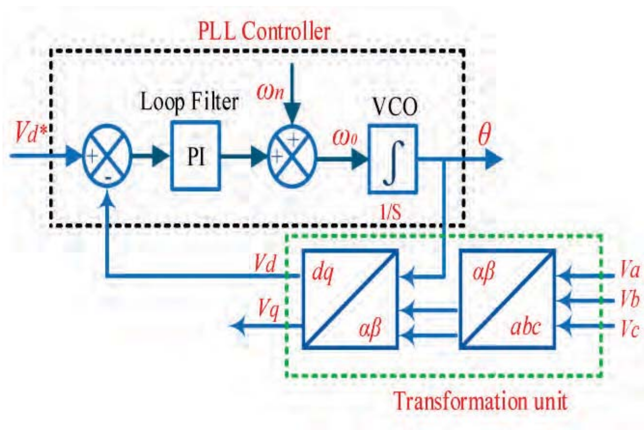

Figure 8. Phase Lock Loop

In PLL, Three-phase AC voltage (Va Vb Vc) are transformed to 2-phase stationary frame (Vds Vqs) using equation and again two-phase voltage are transformed to rotating frame of d, q axis (Vdr,Vqr). To transform from rotating frame to synchronous frame PI Controller and Integrator are used to estimate angular frequency and phase angle. The below equations are used for calculations.

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$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{16}$$

$$\begin{bmatrix} V_{dr} \\ V_{qr} \end{bmatrix} = \begin{bmatrix} Cos\theta & Sin\theta \\ -Sin\theta & Cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} \tag{17}$$

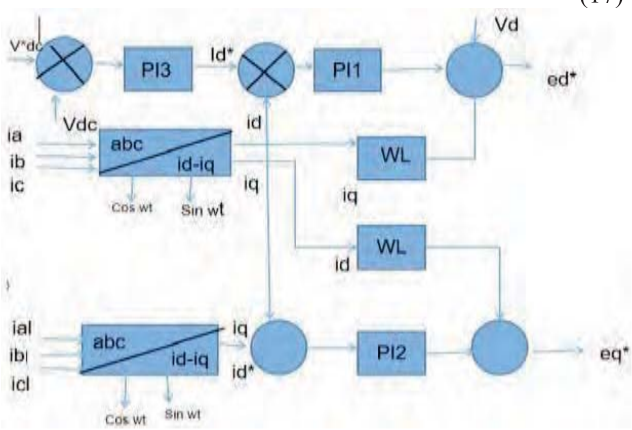

Figure 9. Three-phase to two-phase Transformation block diagram

VI. Standalone PV System Connected to the Grid

Standalone PV System consists of PV array, MPPT, Boost converter, Inverter, PWM, 3-phase load. Voltage (V) and currents (I) are grasped from PV array using MPPT for adjusting the duty cycle to provide gate pulses to IGBT switch of Boost converter. This process helps in boosting up the DC voltage. DC voltage obtained is supplied to dc link (capacitor). DC link acts as a source to the inverter (2- level) converting DC to AC voltages. For conversion process in inverter switching pulses to IGBT switches are given by Pulse Width Modulation (PWM) technique. Three phase voltage and currents from inverter are provided to 3-phase loads.

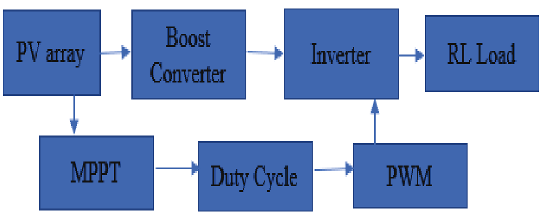

Figure 10. Standalone PV

The Standalone PV system simulation study is done using data provided to the system for the block diagram.

A. Values used in PV System

Array Irradiance—1000
Array Temperature—25^{0}C
Maximum Power (Pump)-- 83.2W
Maximum Im Voltage (Vmp)-- 10.3V
Maximum Current (Imp)-- 8.07A

B. PV System Connected to Grid

Grid connected; standalone system has grid which is connectedto load as shown in Fig. 11 For interfacing both PLL technique is used to maintain at same phase angle and frequency at inverter and grid side [7]. According to the load standalone PV the grid PV supplies necessary voltage and current.

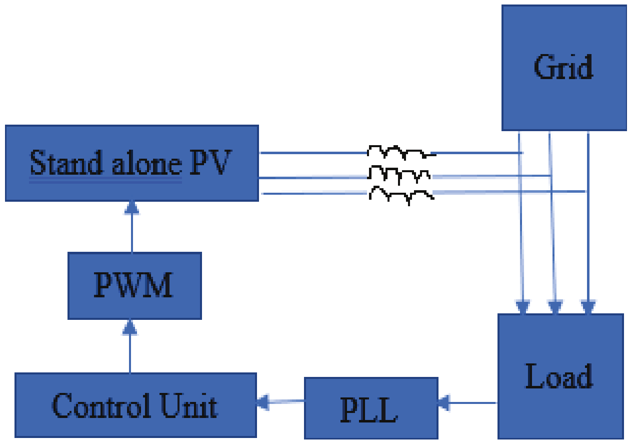

Figure 11. Grid side PV

For sharing the load among PV system and grid a dq current control scheme is used. In this control reference signals are estimated according to the load demand md and mq are estimated voltages given by equation value of voltage of 440 volts V_{dr} is calculated to 359 volts whereas V_{qr} is calculated to zero by using the above phase lock loop equations. To find the angular frequency of V_{qr}, it is calculated by $2\pi f$ where f is 50 hz which gives ω value as 314 rad/sec as shown in Fig 12. Unit vector of phase values are estimated by harmonic oscillator.

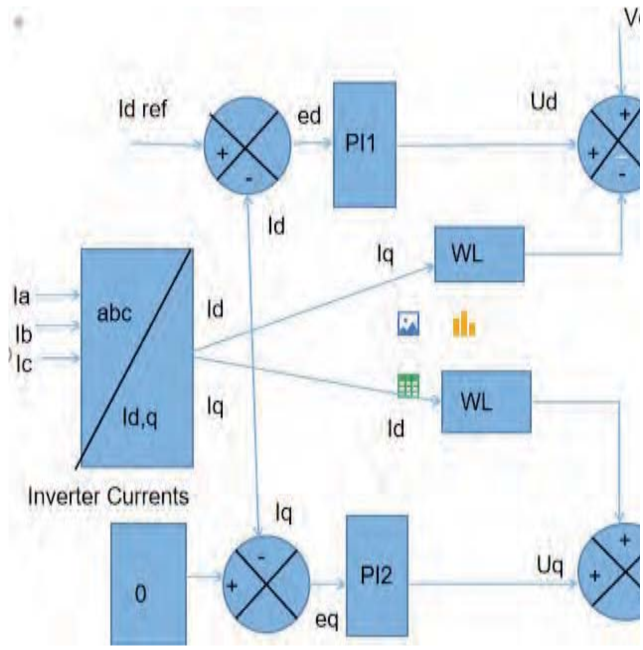

Figure 12. dq Current Control diagram

The phase lock voltages is shown in the Fig. 13 is in phase according to the simulation results obtained when d-q current control scheme is applied.

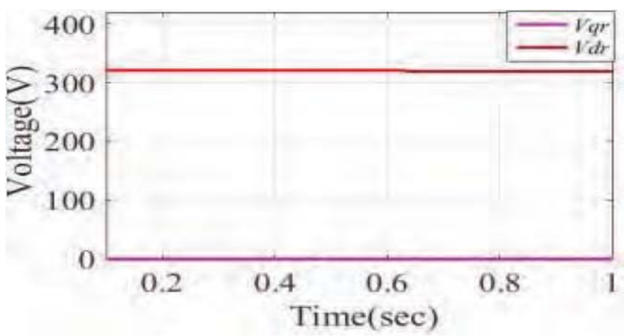

Figure 13. Phase Lock, voltages

TABLE I.
SIMULATION PARAMETERS

Parameters	Values
Grid Voltage	400V
Grid Frequency	50Hz
Load	R=4.6Ω, L=0.0146H
Inverter Capacitor	60e-6
PLL PI Control	P=50, I=100
Control PI	P=0.1, I=0.2

VII. SIMULATION RESULTS OF P&O TECHNIQUE

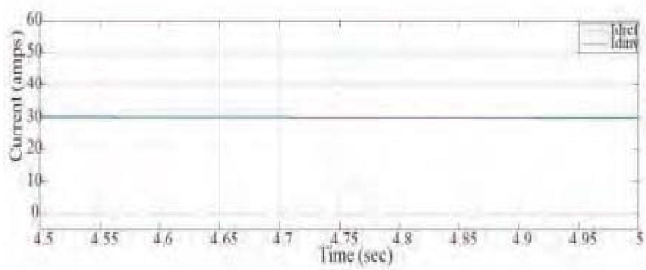

Figure 14. Idinv and Idref Currents

Fig 14. Shows the dq- currents of the circuit which are in inphase with eath other using dq control circuit used in the analysis.

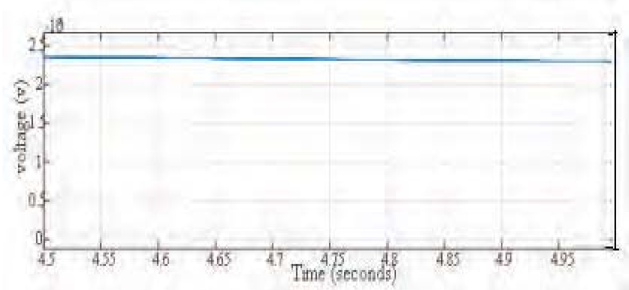

Figure 15. DC voltage (VDC)

Output of DC voltage waveform in the Fig 15. from the results obtained shows that the voltage is constant without any variations which is near to the ideal case.

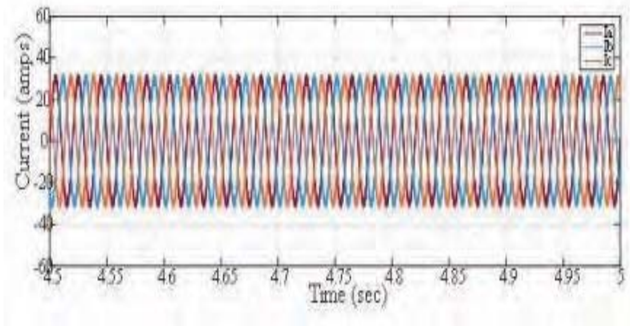

Figure 16. Inverter Current

Simulation results which is shown in Fig 16. is the current output of three phase Inverter. The output obtained from P&O technique is obtained as expected.

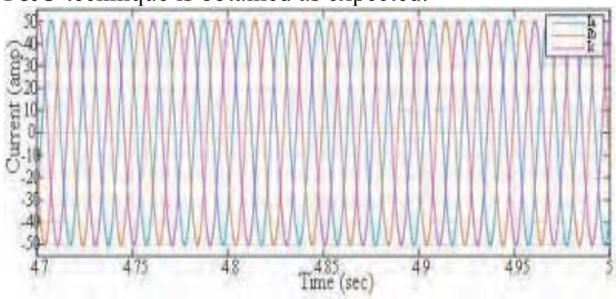

Figure 17. Load Current

The load currents of P&O results are obtained from simulation is obtained for all the three phases as expected in Fig 17.

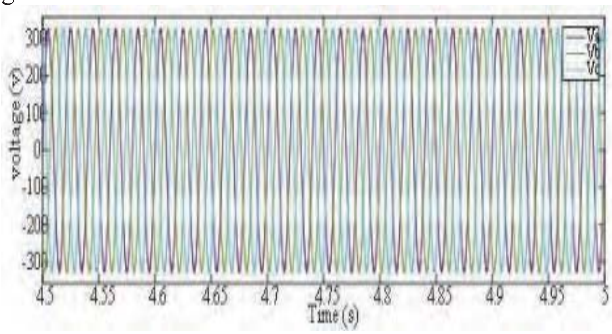

Figure 18. Grid Voltage

The PV output is connected to Grid using Phase lock method in P&O technique. The grid voltage waveform using P&O method is shown in Fig 18.

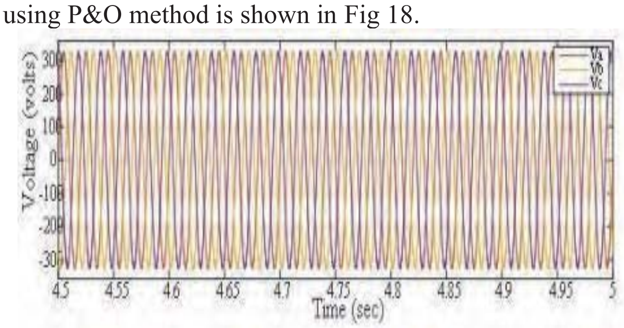

Figure 19. Inverter output Voltage

The inverter output voltage is shown in the Fig 19.

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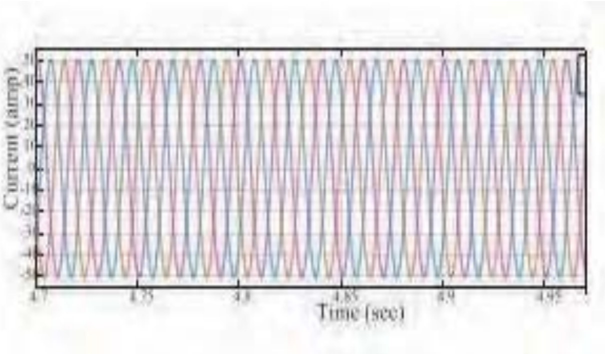

Figure 20. Inverter output currents

Fig 20. shows the three pahse inverter output currents using P&O method.

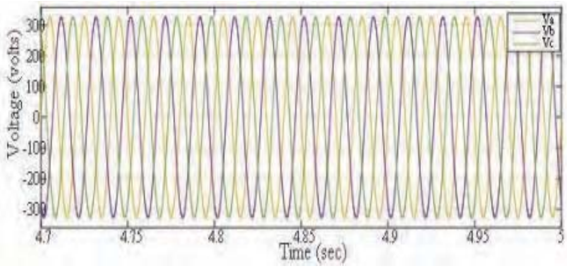

Figure 21. Load Voltage

The PV output is connected to Grid using Phase lock method in P&O technique. The Load voltage at all the three phases is also as expected which is shown in Fig 21.

VIII. Simulation Results of Incremental Conductance Technique

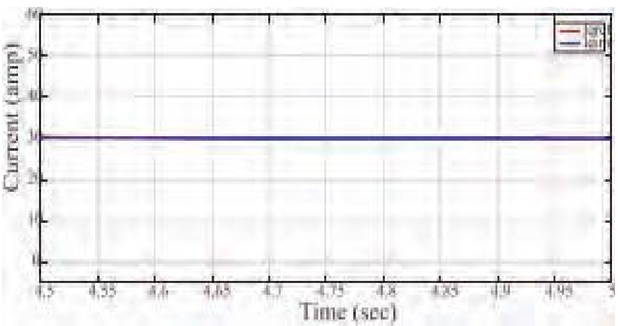

Figure 22. Idinv and Idref Currents

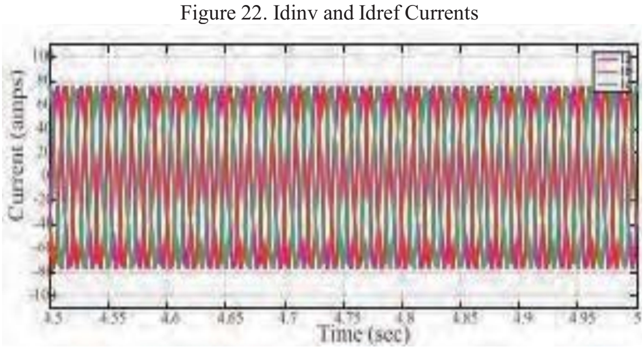

Figure 23. Grid Currents

The dq- currents are as shown in the Fig 22. for incremental Conductance method. The grid current waveforms of Incremental Conductance is shown in Fig 23. to observe the variations obtained with repecet to reference current. Grid voltage is also simulated for all the three phases for analysis in Fig. 24.

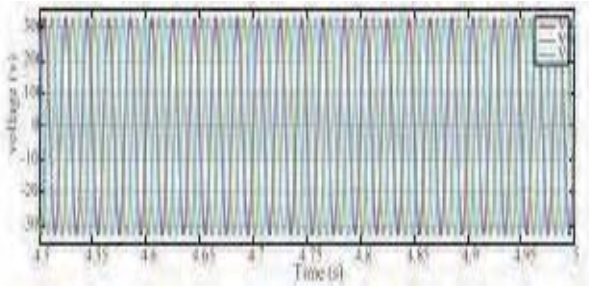

Figure 24. Grid Voltage

Fig 25. shows the simulation results obtained for the three phase inverter voltage in case of Incremental Conductance method.

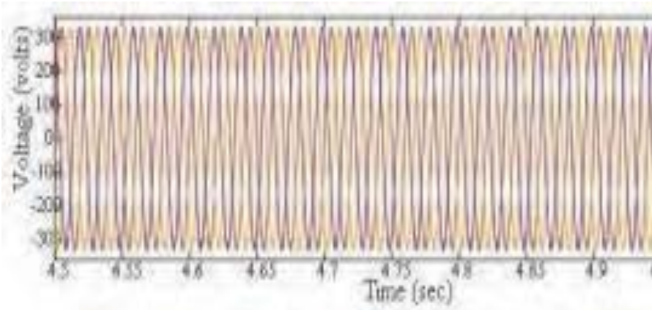

Figure 25. Inverter Voltage

Load voltage of the circuit for 3 phases is shown in Fig 26. for analysing the best method.

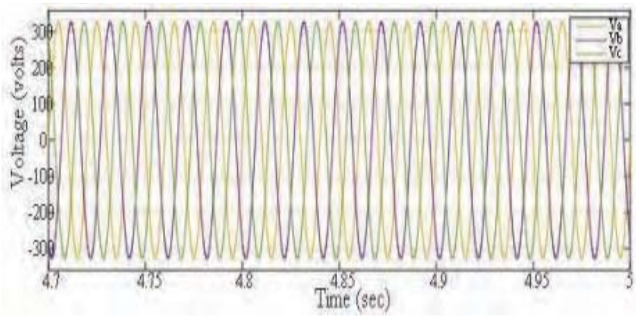

Figure 26. Load Voltage

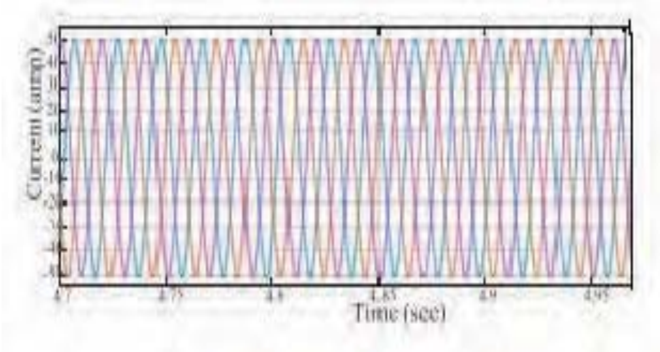

Figure 27. Load Current

The waveform obtained in Fig 27. is for load current of all the three phases for the Incremental Conductance method.

The voltage and currents of Inverter, load and Grid is simulated for both Incremental Conductance method and perturb and observation method for the same parameters. The main disadvantage of the P&O method is tracking the peak power under fast varying atmospheric condition, this can be overcome by using IC method. The IC method can identify when the MPPT has reached the MPP, whereas in P&O method the MPPT oscillates around MPP. The IC method also track the changes in irradiance with higher accuracy. From the results obtained for both the methods shown above and from the analysis it is observed that the Incremental Conductance method gives good tracking efficiency, high response with well controlled for the extracted power. The comparison between P&O and IC MPPT has done using the same conditions. When the atmospheric conditions are constant or changed slowly, the IC method is found to be accurate and the P&O method oscillates close to the MPP. The comparison between the two algorithms for various parameters are given in Table II.

TABLE II.
COMPARISION BETWEEN P&O AND IC MPPT ALGORITHMS

Parameter	P&O MPPT	IC MPPT
Output Current	0.073A	0.087
Output Voltage	36 V	45V
Output Power	2.6 W	3.8 W
Time Response	0.0175 sec	0.1 sec
Accuracy	Less	Accurate

IX. CONCLUSIONS

The P&O and the Incremental Conductance MPPT algorithms are used for the analysis and the simulation results of both the methods are presented. Both P&O and Incremental Conductance MPPT comparison is done with respect to Inverter current, Inverter voltage, Grid voltage, Grid Current, Load voltage and Load current. It is clear from the simulation waveforms that incremental conductance method has better performance than P&O method. These algorithms improve the steady state and the dynamic behaviour of the PV system and improves the efficiency of the DC-DC converter system. From the results obtained Incremental Conductance is showing better output in all terms. Incremental conductance is faster, and output obtained is more precise. In P&O technique the control logic is generating reference voltages and given to inverter to supply active power to the load. The P&O system is applicable for load variations under balanced condition.

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