

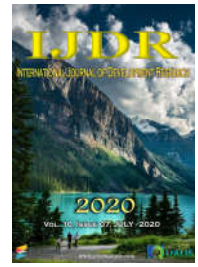


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RESEARCH ARTICLE

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THREE PHASE GRID CONNCTED PV SYSTEM USING INCREMENTAL CONDUCTANCE METHOD

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ABSTRACT

The goal of this project papers is to study the whole three phase grid connected system fed by PV panel using an MPPT algorithm to feed the maximum available power at different environmental conditions and to implement the same in Matlab/Simulink. Firstly, boost converter and MPPT implementation and secondly, the grid-side inverter and grid interconnection fed by a DC source. In the first part, the PV array was simulated in Matlab/Simulink and various tests carried out to determine the dependence of IV and PV curves on irradiance and temperature. Further on, simulations were done to accomplish Maximum Power Point Tracking (MPPT) using incremental conductance method (INC). In the second part, the three phase grid voltage was sensed and operated on by SRF-PLL algorithm to obtain grid frequency and angle. Corresponding to this information, Space Vector Modulation was implemented on a three phase inverter with DC source as input. The output of the inverter was filtered and fed to the grid using an interfacing step-up transformer.

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1. INTRODUCTION

1.1. THE PHOTOVOLTAIC CELL AND ARRAY

1.1.1. Photovoltaic Cell Equivalent Model: The equivalent circuit model of the solar cell is shown in the fig.1.1 in order to simulate the electrical behavior of the PV cell. A solar cell can be modeled as a DC current source in parallel with the diode to represent the current escaping due to diffusion and charge recombination. Two resistances R_s and R_p are included to account for the contact resistance, internal resistance and resistance of the shunt leakage path respectively. 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:

$$I = I_{ph} - I_D - I_{sh} \quad (1.1)$$

Where,

I = Output current (A)

I_{ph} = Photo generated current/light generated current (A)

I_D = Diode Current (A)

I_{sh} = Shunt current (A)

The current through the shunt element R_p is governed by the voltage across it, given by:

$$V_d = V + IR_s \quad (1.2)$$

Where,

V_d = Voltage across both diode and resistor R_p (V)

V = Voltage across the output terminals (V)

R_s = Series Resistance

The current which is diverted through the diode is given by:

$$I_D = I_0 \left\{ \exp \left[\frac{qV_d}{nkT} \right] - 1 \right\} \quad (1.3)$$

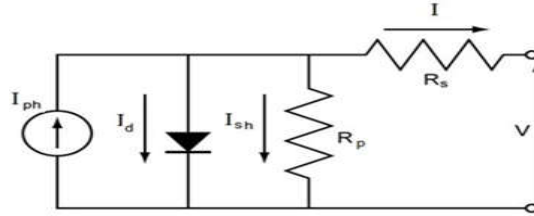


Fig. 1.1 Equivalent Circuit of Solar Cell

Where,

I_0 = Reverse saturation current (A)

n = Diode non-ideality factor (1 for an ideal diode)

q = Elementary Charge (C)

k = Boltzmanns constant

T = Absolute Temp ($^{\circ}F$)

At $25^{\circ}C$, $kT/q \cong 0.0259$ volt

The current diverted through the shunt resistor is:

$$I_{sh} = \frac{V_d}{R_p} \quad (1.4)$$

Where,

R_p = Shunt Resistance (Ω)

Substituting these into the equation, produces the characteristic equation of a solar cell, this relates solar cell parameters to the output current and voltage as:

$$I = I_{ph} - I_0 \left\{ \exp \left[\frac{q(V+IR_s)}{nkT} \right] - 1 \right\} - \frac{V+IR_s}{R_p} \quad (1.5)$$

1.1.2 Model of Photovoltaic Array: Normally a module consists of large number solar cell connected in series. PV array consists of large number PV modules connected in series and parallel. PV modules connected in parallel increases the output current and modules connected in series increases the output voltage of the PV array. If the array consists of N_{par} parallel connection of modules, the photovoltaic array current and saturation current can be expressed as:

$$I_{pvarray} = I_{pvmoule} \times N_{par} \quad (1.6)$$

$$I_{oarray} = I_{omoule} \times N_{par} \quad (1.7)$$

If the array consists of N_{ser} series connection of modules, the array output voltage, series resistance and shunt resistance can be expressed as:

$$V_{pvarray} = V_{pvmoule} \times N_{ser} \quad (1.8)$$

$$R_{sarray} = R_{smodule} \times \frac{N_{ser}}{N_{par}} \quad (1.9)$$

$$R_{parray} = R_{pmodule} \times \frac{N_{ser}}{N_{par}} \quad (1.10)$$

So the characteristic equation of the PV array can be written as:

$$I_{pvarray} = I_{pharray} - I_{oarray} \left\{ \exp \left[\frac{q(V_{pvarray} + I_{pvarray}R_{sarray})}{nkTN_{ser}} \right] - 1 \right\} - \frac{V_{pvarray} + I_{pvarray}R_{sarray}}{R_{parray}}$$

Where,

$I_{pvarray}, V_{pvarray}$ = Output current and voltage of the photovoltaic array respectively
 $I_{pharray}$ = Light generated current under a given irradiation.
 I_{0array} = Saturation current of the photovoltaic array
 R_{sarray} = Equivalent series resistance of the PV array
 R_{parray} = Equivalent shunt resistance of the PV array

The model of the PV array obtained from its characteristic equation is shown in the figure 1.2.

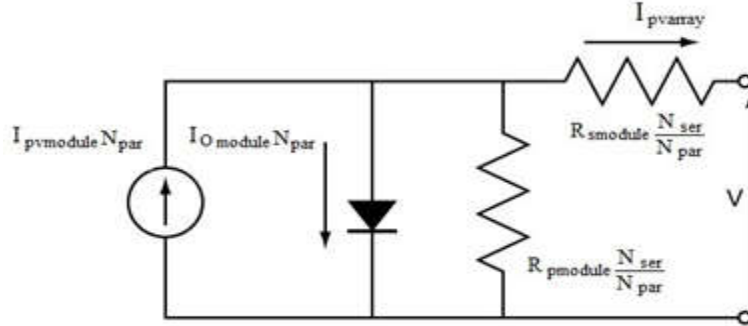


Figure 1.2. Equivalent circuit of PV Array

1.1.3 Modeling and Simulation in MATLAB: The parameters for the Model were taken from the module datasheet of BP-MSX120 panels produced by British Petrol as given in the table below. All the parameters are considered in Standard Test Conditions (STC), and they are given in the product datasheet, except the last three, R_s , R_{sh} and A , which have been calculated from the datasheet values.

Table 1.1. PV Module Parameters

PV Parameters	Values
Short circuit current $I_{sc} = I_{ph}$	3.87 A
Open circuit voltage V_{oc}	42 V
Current at maximum power point (I_{MPP})	3.56 A
Voltage at maximum power point (V_{MPP})	33.7 V
Number of cells in series N_s	72
STC Power Rating P_{max}	120 W
Panel series resistance R_s	0.47 Ω
Panel shunt resistance R_{sh}	1365 Ω
Diode quality (ideality) factor A	1.397

With these parameters of the PV module, a model is made in Simulink (fig. 1.3).

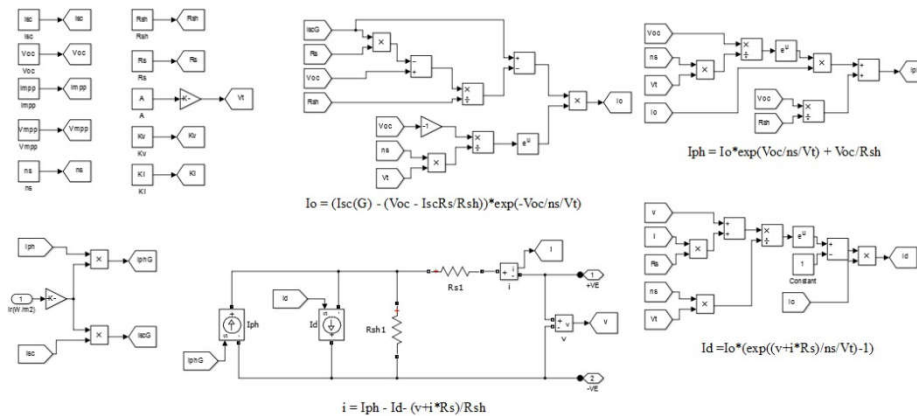


Fig. 1.3. Simulation of Solar Cell

1.2 BOOST CONVERTER

The MPPT tracker uses the DC/DC converter to adjust the PV operating voltage so that the PV array operates at MPP. Boost converter topology is used for this purpose. The output of the boost converter will be fed to the inverter.

1.2.1 Operation of the Boost Converter: Figure 1.4 shows the basic boost topology. When the switch SW is turned ON, energy is stored in the inductor L and the inductor current I_L ramps up with a slope determined by the input voltage. Diode D is OFF during the ON period of the switch. Once the switch turns OFF, diode starts to conduct and the energy stored in the inductor is transferred to the load and a portion is stored in capacitor. Current in the inductor ramps down with a slope decided by the difference of the input and the output voltage.

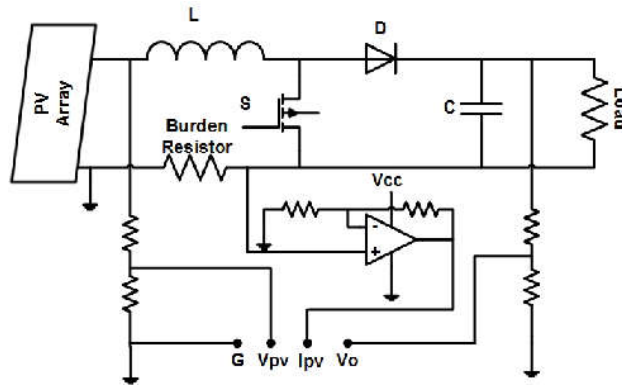


Fig. 1.4. Boost Converter

The voltage ratio for a boost converter is derived based on reasoning that the time integral of the inductor voltage is equal to zero over a switching period. The relationship between the input and output voltages is given by the following equations

$$V_{in}T_{on} + (V_{in} - V_{out})T_{off} = 0 \tag{1.12}$$

$$\frac{V_{out}}{V_{in}} = \frac{T_{on} + T_{off}}{T_{off}} = \frac{1}{1 - D} \tag{1.13}$$

It can be seen that the output voltage increases as D increases. The ideal boost converter is capable of producing any output voltage greater than the input voltage. Assuming a lossless circuit $P_{in} = P_{out}$, the relationship between the input and output current is given by:

$$\frac{I_{out}}{I_{in}} = 1 - D \tag{1.14}$$

Also, $I_{out} = \frac{P_{out}}{V_{out}}$ (1.15)

Table 1.2. Boost Converter Parameters

Converter Parameters	Ratings
Input Voltage Range (V_{in})	0 - 21.9V
Switching Frequency (f_s)	100 KHz
Inductance (L)	3mH
Capacitor (C)	1000 μ F
Rated Power (P)	40 W

1.3 MAXIMUM POWER POINT TRACKING

The power delivered by the PV module depends on the irradiance, temperature, and shadowing conditions. The PV panel has a nonlinear characteristic, also the power conversion ratio of the PV array is very low and so it becomes necessary to extract maximum power from the PV array. The power has a Maximum Power Point (MPP) at a certain working point, with coordinates VMPP voltage and IMPP current respectively. Thus in order to extract maximum power from the array a MPPT algorithm is required to operate simultaneously with the DC-DC converter. Different kinds of MPPT algorithms have been developed and put into application. The most popular ones are: constant voltage tracking (CVT), perturbation and observation method (P&O), Hill climbing method and incremental conductance method (INC). The simulation circuit of MPPT carried out in Simulink is shown in fig. 1.5.

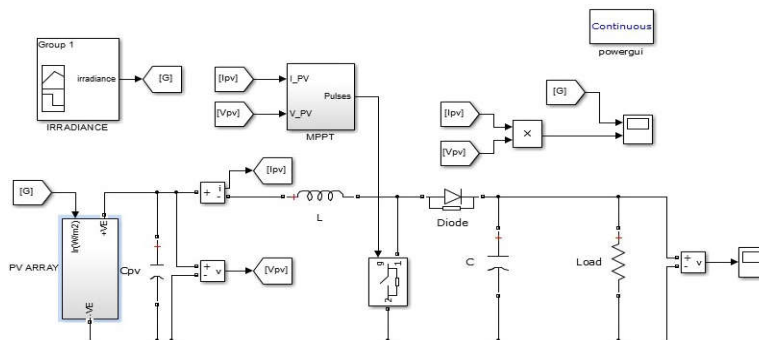


Fig.1.5 Simulation of Boost Converter with MPPT

INCREMENTAL CONDUCTANCE (INC) METHOD: Among all the MPPT strategies, the incremental conductance technique is widely used due to the high tracking accuracy at steady state and good adaptability to the rapidly changing

atmospheric conditions. Thus, under rapidly changing conditions, it can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. Although the INC method is a little more complicated compared with the P&O algorithm, it can be easily implemented due to the advancements of digital signal processor (DSPs).

Incremental method was used for the MPPT tracking of the PV array and is simulated in Matlab/Simulink environment. Incremental conductance method is selected as this method shows some advantages like

- High tracking accuracy under rapidly changing irradiation condition as compared to P&O method.
- It reaches steady state faster and avoids continuous oscillation around the MPPT suitable for grid connected application
- Avoids waste of energy around MPP as with P&O method,
- It actually knows the direction in which to perturb the operating point to reach the MPP of PV array.
- The perturb-and-observe, incremental conductance and fuzzy logic controller have very similar efficiencies but incremental conductance method has slightly better.

1.4 GRID SIDE INVERTER CONTROL

Electrical grids are complex and dynamic systems affected by multiple eventualities such as continuous connection and disconnection of loads, disturbances and resonances resulting from the harmonic currents owing through the lines, faults due to lightning strikes and mistakes in the operation of electrical equipment. Consequently, grid variables cannot be considered as constant magnitudes when a power converter is connected to the grid, but they should be continuously monitored in order to ensure that the grid state is suitable for the correct operation of the power converter. Monitoring of the grid variables is a necessary task to be implemented in the power converter interfacing renewable energy sources to the grid. The grid codes state the voltage and frequency boundaries within which the photovoltaic system should remain connected to the grid while ensuring stable operation. Hence, grid monitoring algorithms to be implemented in grid-connected converters should detect the grid state in a fast and precise way in order to full both precision and time response requirements demanded by the grid codes. Grid monitoring and grid synchronization are two closely linked concepts. Actually, grid synchronization of a power converter is not nothing but an instantaneous monitoring of the state of the grid to which the power converter is connected. Grid synchronization is an adaptive process by means of which an internal reference signal generated by the control algorithm of a grid-connected power converter is brought into line with a particular grid variable, usually the fundamental component of the grid voltage.

1.4.1 Simulation of Grid Side Inverter Control: The simulation circuit of Grid side inverter control carried out in Simulink is shown in fig. 1.8.

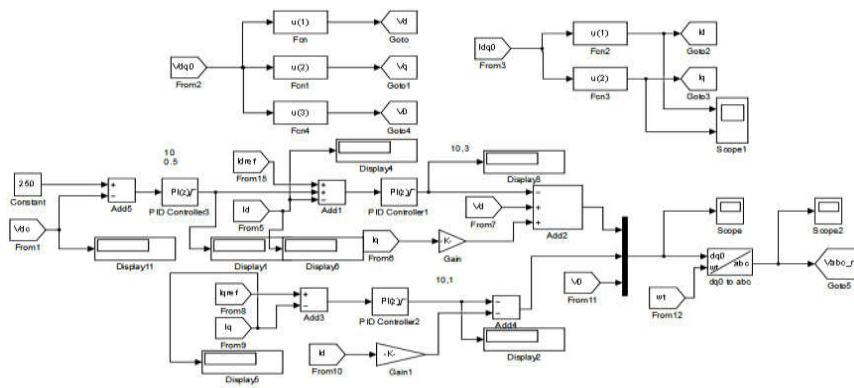


Fig.1.6. Simulation of Grid Side Inverter Control

1.5 SIMULATION OF THREE PHASE GRID CONNECTED PV SYSTEM

The simulation circuit of three phase grid connected PV system carried out in Simulink is shown in fig. 1.9.

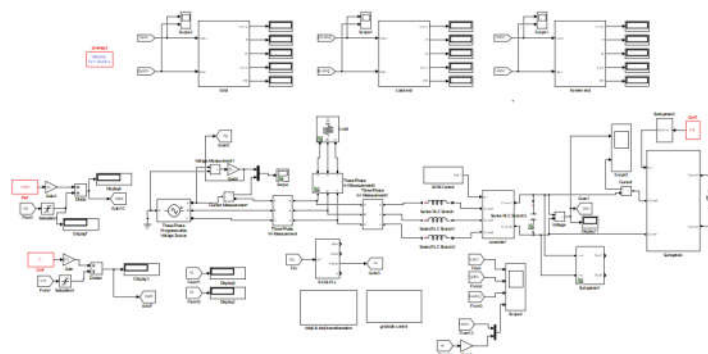


Fig. 1.7. Simulation of Three Phase Grid Connected PV System

2. Simulation Results

DC Power Supplied by the Solar PV System: Power supplied by solar PV system is dependent on the voltage and the current of solar panel which in turn are dependent on the irradiance and the temperature.

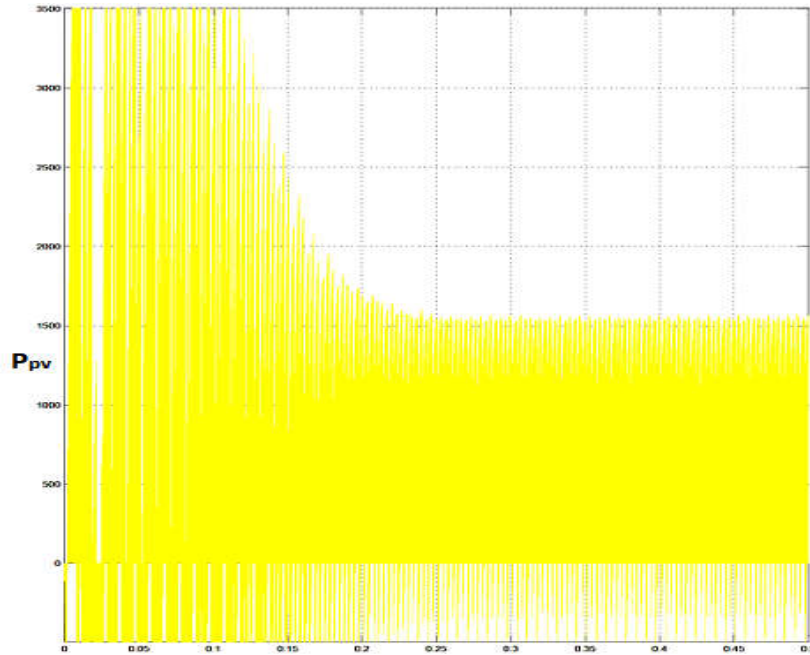


Fig.2.1 DC power of solar photovoltaic system

In our project simulation P_{ref} is actually the quantity of power obtained from the solar panel. So, as we vary the P_{ref} i.e., power obtained from solar panel (which in turn are dependent on the irradiance and the temperature) then our power supplied to grid also vary accordingly to P_{ref} as shown in table.

P_{pv} (watt)	P_{ref} (Power obtain from solar panel P_{pv}) (watt)	Power output at grid (watt)	Current at Inverter End (ampere)
1500	1500	1200	10
1000	1000	870	7

DC Link Voltage: The voltage which is applied to the inverter input is known as DC link voltage. For maintaining a desired value of DC link voltage, a DC-DC chopper is used. To sustain a constant DC link voltage, a large value of capacitor is utilized.

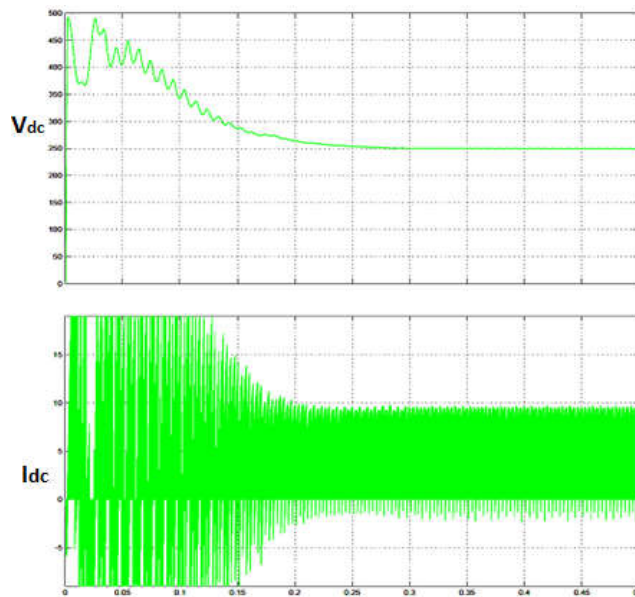


Fig.2.2 DC Link Voltage and current waveform

Point of common coupling (PCC) and phase angle (θ): V_{pcc} is the voltage at the point of common coupling. By performing park transformation we can transfer the dq reference quantity to a three phase signal. The figure shows the graphical representation of voltage at point of common coupling V_{pcc} and phase angle θ .

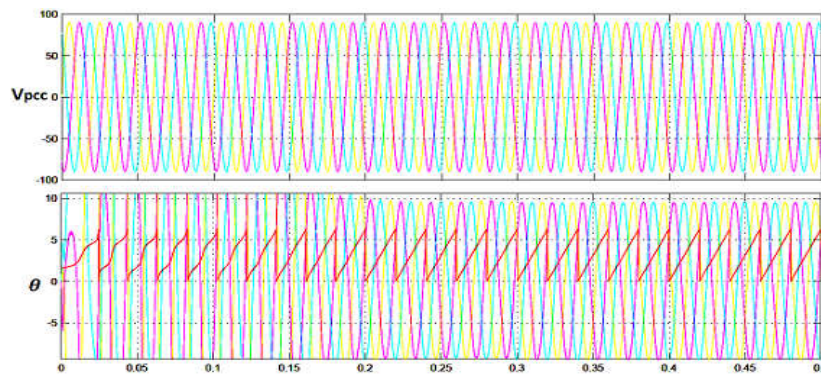


Fig.2.3 Voltage at point of common coupling V_{pcc} and phase angle θ

Inverter voltage and current: Inverter (VSI) produces a three phase ac voltage output to supply the grid. A three-phase universal bridge utilizing IGBT switch is used in MATLAB simulation work to convert DC link voltage to three phase ac.

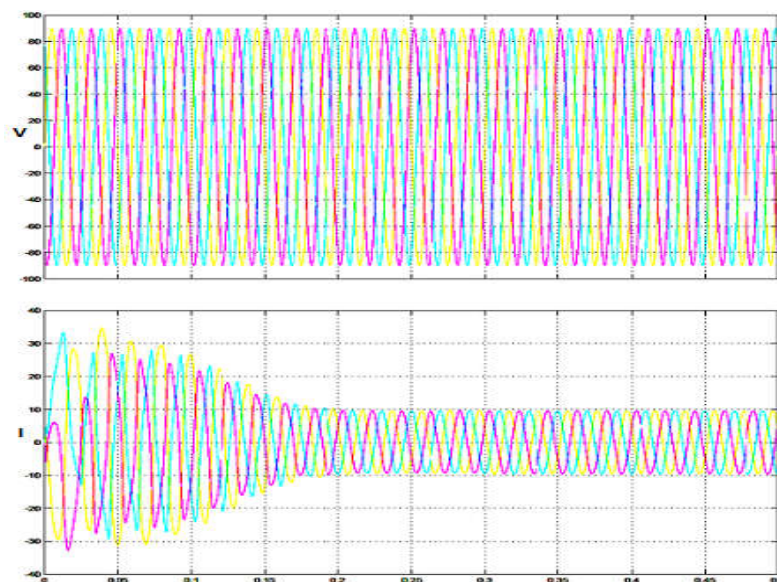


Fig.2.4 Inverter voltage and current waveform

Power Supplied to Grid: Active power are supplied by the system. The active power is reliant on the irradiance parameter.

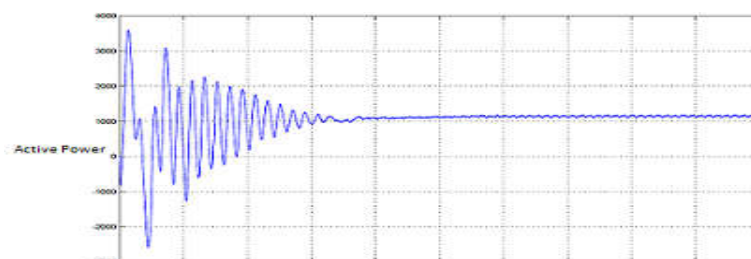


Fig.2.5 Power Injected at Grid

3. Conclusion

The goal of this project work was to study the whole three phase grid connected system fed by PV panel using an MPPT algorithm to feed the maximum available power at different environmental conditions and to implement the same in Matlab/Simulink. The Incremental conductance method tracked the MPP faster and once found there was less oscillations. If one wishes to pursue this project further, the tasks that can be undertaken are: Islanding techniques, Protection system, Different operating mode for handling grid faults, Ruggedized product with Human Machine Interface (HMI) for commercial purpose.

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