# Design & Simulation of Domestic Grid Connected PV System

[1] Ashutosh Gour [2] Dr. A.K.Sharma
[1]Research Scholar, [2] Professor
[1]High Voltage Engineering, [2]Dept. of EE, JEC, Jabalpur

*Abstract*: **A boost dc-ac inverter is extremely used in solar power conversion system. An efficient controller for single stage boost inverter will be useful in solar power generation system. The boost dc-ac inverter has distinguished features like boosting and inverting the low input dc voltage into high ac voltage in a single power conversion stage. Also the overall solar power generation system is improved due to the minimum number of power switching components. The conventional controllers namely double loop controller, sliding mode controller and averaged current controller for the boost dc-ac inverter have some disadvantages such as incapability to give instant response during abrupt load changes, complex theory, the variable switching frequency, the lack of an inductance averaged-current control the constraints to the controller parameter selection and complex implementation.**

*Keywords:* **modeling of PV, storage devices and energy management system.**

## I. INTRODUCTION

Since the growing demand and increasing price of fossil fuels have direct impact on economy of each and every country, there is a timely need to search for alternate for the fossil fuels. The various pollutions, created due to non-renewable energy sources, are disturbing the natural pattern of our ecosystem and have numerous adverse effects on human health. These all set additional challenges for engineering society to drive towards alternate energy sources. Among the various renewable energy sources the solar energy has been proven to be modest and advantageous because of its pollution free and free in nature (Bull 2001). Generally the voltage source inverter (VSI) has widely used for solar power generation but its output voltage is always lower than the input voltage. So the conventional solar power generation needs minimum two power conversion stages for getting proper voltage and frequency to synchronize with single phase grid or ac loads. In order to overcome the above said limitations of the conventional controllers, the proposed controller VSI has been used to give regulated output voltage of the boost dc-ac inverter in a single stage under variable loads. In this work we have taken 6-module (85 W each) PV array with full sun (1,000 W/m2 insolation). PV array operates at MPP: Ppv = 6*85 W = 510 W & AC grid RMS voltage: 120 V. The overall system is modelled and simulated in MATLAB/SIMULINK environment.

In order to design a grid connected PV system first of all PV module is modelled in MATLAB/Simulink based on the equivalent circuit in order to find best MPPT technique. Input to the PV module is solar insulation and temperature. From the solar panel voltage and current are extracted in order to find the power output. The simulation model is design for MPPT, PV module and Boost DC-DC, DC-AC converters. The various results simulated show the improvement in P&O algorithm for MPPT. Also the proposed simulated PV system requires less battery as the capacitor (feedback control) does reduce this requirement. Besides this, the solar energy is easy to adopt with the existing power converters (Arunkumar Verma et al 2010, Rong-Jong Wai et al 2008). The power electronic interface plays a vital role in bridging the solar energy with the domestic or single phase grid. The entire topology consists of MPPT solar charge controller; dc energy storage device and single stage boost dc-ac inverter. The single stage boost dc-ac inverter can be modelled by the bidirectional buck boost converter (Vazquez et al 2000). Initially the maximum energy from the solar photovoltaic array is extracted with the help of MPPT technique (Weidong Xiao et al 2007) and the extracted energy is stored in dc energy storage device (Yiwen He et al 2010) by solar charger. The existing control strategies, implemented for controlling the output of the boost dc-ac inverter, such as double loop control method (Domingo et al 2009 & Pablo Sanchis et al 2005) and sliding mode control method (Caceres et al 1999) involves difficulties like complex theory and variable switching frequency (Pablo Sanchis et al 2005). Therefore the main scope of this research work lies in the designing of a simple controller, MPPT and in the reduction of power conversion stages in grid connected solar power generation, since the conventional method consists of two power conversion stages (Rafia Akhter et al 2007) which results in more capital cost and more switching losses. There are four controllers such as Modified Non-Linear State Variable Structure (MNLSVS) controller, Sinusoidal Pulse Width Modulation (SPWM) technique based controller, Fuzzy Logic Controller (FLC) and Comparator based Non-Linear Variable Structure (NLVS) controller are proposed for boost dc-ac inverter. The proposed controllers are tested with inconsistent load and results are compared and analyzed in terms of inductor current, capacitor voltage and harmonic distortion.

## II. LITERATURE REVIEW

In paper [1] authors proposed an effective sizing methods for distributed battery energy storage system (BESS) in the distribution networks under high photovoltaic (PV) penetration level. The main objective of the proposed method is to optimize the size of the distributed BESS and derive the cost-bene fit analysis when the distributed BESS is applied for voltage regulation and peak load shaving. In particular, a system model that includes a physical battery model and a voltage regulation and peak load shaving oriented energy management system (EMS) is developed to apply the proposed strategy. The cost-benefit analysis presented in this paper considers factors of BESS influence on the work stress of voltage regulation devices, load shifting and peaking power generation, as well as individual BESS cost with its lifetime estimation. Based on the cost-bene fit analysis, the cost-bene fit size can be determined for the distributed BESS.

In [2] a new closed-loop scheme of 2-stage 4-phase switched-capacitor (SC) boost DC-AC inverter is proposed by combining 4-phase phase generator and sinusoidal pulse-frequency-modulation (SPFM) controller for low-power step-up inversion and regulation. In this SC inverter, the power part of the inverter is composed of 2-stage 4-phase SC booster and DC-link inverter. This SC booster contains 2 pumping capacitors and 4 switches operation for boosting the step-up gain up to 22 = 4 at most. For improving total harmonic distortion (THD), a 4x/3x/2x/1x selector is presented to select a proper gain in order to make the maximum of the practical output close to the desired output voltage as much as possible. The DC-link inverter like H-bridge structure consists of 4 switches controlled by SPFM to realize full-wave DC-AC operation. Besides, the SPFM is employed for the closed-loop realization to enhance the output realization capability for the different output peak and frequency. Finally, the 2-stage 4-phase SC boost inverter is simulated by OrCAD, and all results are illustrated to show the efficacy of the proposed scheme.

[3] presents a single-phase photovoltaic (PV) system integrating segmented energy storage (SES) using cascaded multilevel inverter. The system is designed to coordinate power allocation among PV, SES, and utility grid, mitigate the overvoltage at the Point of common point (PCC), and achieve wide range reactive power compensation. The power allocation principle between PV and SES is described by a vector diagram. An appropriate reactive power allocation coefficient (RPAC) is designed to avoid duty cycle saturation and over modulation so that wide range reactive power compensation and good power quality can be achieved simultaneously. The self-regulating power allocation control system integrating the preferred RPAC and an advanced active power control algorithm are developed to achieve the aforesaid objective. Simulation results are provided to demonstrate the effectiveness of the proposed cascaded PV system integrating SES.

[4] presents a new inverter based on three-phase Boost/Buck-boost single-stage inverter. The basic configuration of the new topology and their fundamental principle are firstly introduced, the method of design double-loop controller and sliding mode controller are clarified, analyzed and compared in the following. Finally, the validity and feasibility of the new topology are tested by simulation. The results indicate that regulation of the voltage transfer ratio and output frequency can be realized optionally by the new converter, furthermore the harmonic distortion of waveform is low. So the inherent drawback of low voltage transfer ratio of traditional converter is effectively settled. This study may provide inspiration for further engineering application.

[5] proposed an analysis and design of a high efficiency boost-inverter with bidirectional back-up battery storage in fuel cell. When low-voltage unregulated fuel cell (FC) output is conditioned to generate AC power, two stages are required: a boost stage and an inversion one. In this paper, the boost-inverter topology that achieves both boosting and inversion functions in a single-stage is used to develop an FC-based energy system which offers high conversion efficiency, low-cost and compactness. The proposed system incorporates additional battery-based energy storage and a DC-DC bi-directional converter to support instantaneous load changes. The output voltage of the boost-inverter is voltage-mode controlled and the DC-DC bidirectional converter is current-mode controlled. The load low frequency current ripple is supplied by the battery which minimizes the effects of such ripple being drawn directly from the FC itself. Analysis, simulation results are presented to confirm the operational performance of the proposed system.

The work proposed in [6], is a novel dc to ac boost inverter based on sinusoidal-pulse-width-modulation (SPWM) control to generate the output in single stage of conversion and whose peak value will be greater than the dc input one depending on the duty cycle of converters. The proposed inverter reduces the switching losses and has much higher efficiency with respect to conventional boost inverter, due to much reduction in the number of switches. The strategy of modulation of new proposed boost inverter will reduce the harmonics and the energy loss in the output of proposed inverter, thereby allowing the proposed inverter to become a new sufficient solution for many applications like automotive electronics, PV systems, solar home applications and other power supply systems.

[7] presents a simple electronic circuit for testing the photovoltaic (PV) modules by tracing their I-V characteristics. A precise PV module electrical model is also introduced. The circuit consists of a fast varying electronic load based on power MOSFET and operational amplifier. A DAQ system with LabVIEW application was developed for controlling the MOSFET gate-source voltage. The circuit is designed, implemented and tested under real conditions. The experimental results verified with simulation results and another way of testing which is resistor method.

[8] proposed a converter that achieves a high step-up voltage conversion ratio, which contains a coupled inductor, without extreme duty ratios and numerous turns-ratio; the leakage inductor energy of the coupled inductor is efficiently recycled to the load. Also, switch of the converter isolates energy from the PV panel when the ac module is off. This particular design protects installers and users from electrical hazards. These features explain module's high efficiency performance. A 15V input voltage, 200V output voltage, and 100W output power circuit of the proposed converter has been implemented in MATLAB.

## III. MAXIMUM POWER POINT TRACKING (MPPT)

The current-voltage behavior of solar panels nonlinearly depends on the solar irradiation intensity and environmental temperature. As shown in Fig.1, an increase in sun irradiation level and decrease in ambient temperature result in a higher output current and voltage. Consequently, the environmental condition variations change the maximum output power of solar panels.

There have been various models proposed for PV cells, and among these entire models one of the simplest (which characterizes the I-V behavior of a PV cell), uses a diode in parallel with a current source. Mathematical equations for this model have been discussed in next section.

As mentioned before, in the grid-connected PV system, the DC link capacitor is charged by solar array, and then power is switched out from the capacitor using the power converter (inverter) and the extracted power is injected to the utility grid. To ensure that solar arrays deliver maximum available power to the converter (inverter), an interface device between converter (inverter) and PV panels needs to be employed to control the flow of power.

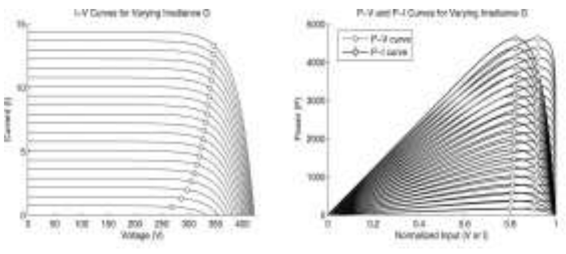

**Figure 1: Nonlinear Behavior of Voltage-Current & Power-Current of PV Panels for Various Sun Irradiations.**

Among various MPPT algorithms, convergence speed is one of the most important features which improves the efficiency and also increases the stability of the system. Brunton et al. have pointed out: "As irradiance decreases rapidly, the I-V curve shrinks and the MPV and MPI decrease. If the MPPT algorithm does not track fast enough, the control current or voltage will fall off the I-V curve."

Consequently, any improvement in the rise time of MPPT improves the reliability of the system, increases the power extraction and results higher efficiency of the whole system.

The peak power point tracking techniques vary in many aspects, such as: simplicity, convergence speed, digital or analog implementation, sensors required, cost, range of effectiveness, etc. The MPPT implementation topology greatly depends on the end-users' knowledge. In analog world, short current (SC), open voltage (OV), and temperature methods (temperature gradient (TG) and temperature parametric equation (TP)) are good options for MPPT, otherwise with digital circuits that require the use of micro-controllers, perturbation and observation (P&O), IC (incremental conductance), and temperature methods are easy to implement. Figure 2 and Table1 present the comparison among different MPPT methods considering the costs of sensors, micro-controller, and the additional power components. In this table, *A* means absence, *L* low, *M* medium, and *H* is high.

Currently, the most popular and the workhorse MPPT algorithm is perturb and observe (P&O), because of its balance between performance and simplicity. However, this method suffers from the lack of speed and adaptability which are necessary for tracking the fast transient under varying environmental conditions.

## PERTURB AND OBSERVE METHOD

As mentioned before, currently, the most popular MPPT method in the PV systems is perturb and observe. In this method, a small perturbation is injected to the system and if the output power increases, a perturbation with the same direction will be injected to the system and if the output power decreases, the next injected perturbation will be in the opposite direction. The scheme of P&O method is presented in Fig. 4.3.

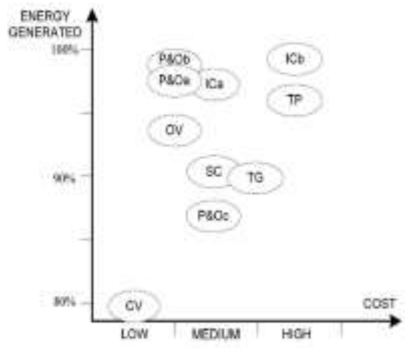


**Figure 2: Comparison of the MPPT Methods**

 

| MPPT Algorithm | Additional Compo-nents | Sensors | Micro-Controller | Total |
|---|---|---|---|---|
| CV | A | L | A/L | L |
| SC | H | M | A/L | M |
| OV | H | L/M | A/L | L/M |
| P&Oa | A | M | L | L/M |
| P&Ob | A | M | L | L/M |
| P&Oc | A | M | M | M |
| IC | A | M | M | M |
| TG | A | M/H | M | M/H |
| TP | A | H | M/H | H |

**Table 1: Comparison of MPPT Algorithms**

The P&O algorithm requires few mathematical calculations which make the implementation of this algorithm fairly simple. For this reason, P&O method is heavily used in renewable energy systems. However, the P&O algorithm is not able to distinguish the difference between the system perturbations (e.g. voltage regulation variations or environmental condition variations) and injected perturbation from P&O, and therefore it may make a wrong adjustment as the result, especially in the presence of rapid system variations.

Moreover, in the steady state operation, the power oscillates around the maximum power point; therefore the system can potentially jump to undesirable or even unstable modes. This phenomenon is another disadvantage of P&O method.

Recently, a new adaptive control scheme, called extreme seeking control, has been developed. In the next section, this method will be discussed and will be developed by using fractional order operators.

## IV. PROPOSED PERTURB AND OBSERVE METHOD

Perturb & Observe (P&O) is the simplest method and is widely used. In this technique we generally use only one sensor, that is the voltage sensor, to sense the PV module voltage and hence the cost of implementation is less and hence easy to implement without any complexity [3]. The time complexity of this algorithm is very less for calculating the maximum power but on reaching very close to the Maximum Power Point (MPP) it doesn't stop at the MPP and keeps on perturbing on both the directions so for that reason it have multiple local maximum at the very same point. First of all the algorithm which reads the value of the current and voltage from the photovoltaic module from that power is calculated the value of voltage and power at that instant is stored. Hence a slight perturbation is added in the increasing direction. The next values at the next instant are measured and power is again calculated. Hence by adjusting the maximum power duty cycle can be obtained based on it. In certain situations, like changing atmospheric conditions and change in irradiance the maximum power point shifts from its normal operating point. In the next iteration it changes its direction and goes away from the maximum power point and results in multiple local maxima at the same point. So the maximum power point deviates from its original position. This difficulty which can be overcome by using an improved P&O method.

### 4.1 PROPOSED GRID-CONNECTED PV SYSTEM ARCHITECTURE

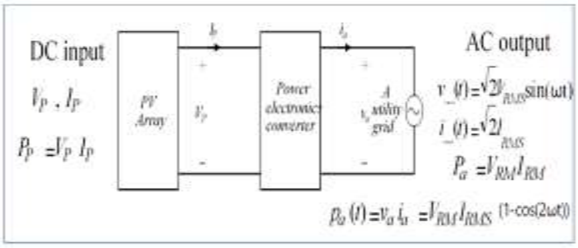


**Figure 3 : Grid Connected Pv System Architecture**

### 4.2 FUNCTIONS OF THE POWER ELECTRONICS CONVERTER

- Operate PV array at the maximum power point (MPP) under all conditions.
- Provide energy storage to balance the difference between and (t).
- Generate AC output current in phase with the AC utility grid voltage • Achieve power conversion efficiency close to 100%

### 4.3 DETAILED PROPOSED GRID-CONNECTED PV SYSTEM ARCHITECTURE:

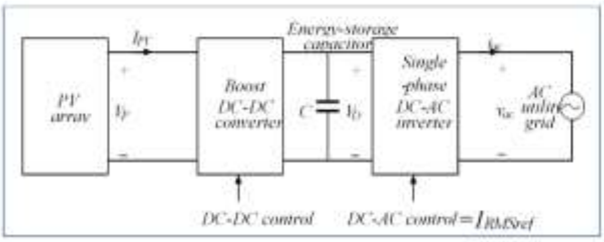


**Figure 4 : Detailed Architecture Of Grid Connected Pv System**

### 4.4 ROLE OF BOOST DC-DC CONVERTER

- Set the PV operating point (VPV, IPV) to MPP
- Efficiently step up VPV to a higher DC voltage VDC

### 4.5 ROLE OF DC-AC INVERTER

- Efficiently generate AC output current iac in phase with the AC grid voltage vac
- Balance the average power delivery from the PV array to the grid,

$$P_{ac} = P_{pv} * \eta_{DC\text{-}DC} * \eta_{DC\text{-}AC}$$

 

**PROPOSED SIMULINK MODEL OF GRID CONNECTED PV SYSTEM**

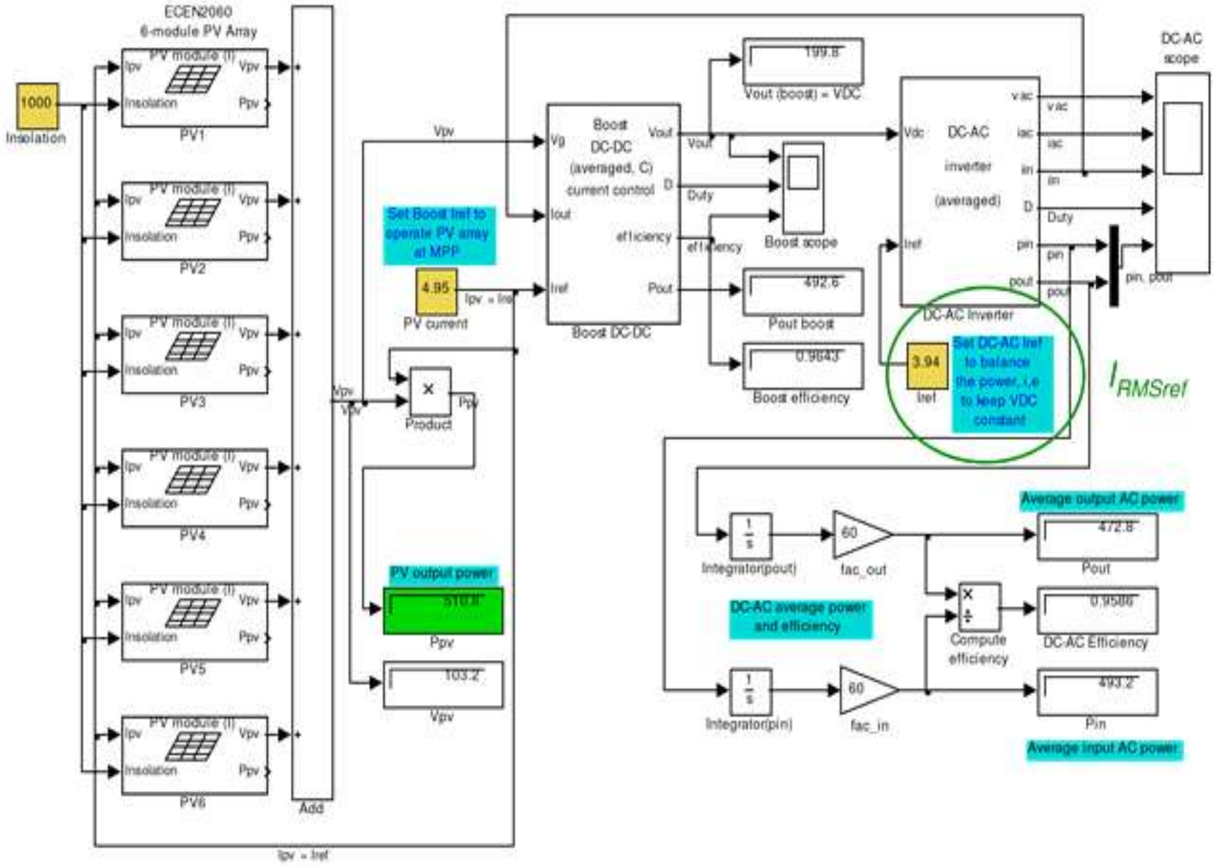


**Figure 5: Proposed Implementation Model of Grid Connected PV System**

### 4.6 BALANCING OF POWER BY AUTOMATIC FEEDBACK CONTROL

- Voltage $V_{DC}$ is sensed and compared to a reference value $V_{DC}$ref (e.g. $V_{DC}$ref = 200 V).r
- The difference $V_{DC}$ – $V_{DC}$ref is the error signal for the feedback controller.
- If the error is positive, i.e. if VDC is greater than $V_{DC}$ref, the compensator increases IRMSref.
- If the error is negative, i.e. if $V_{DC}$ is less than $V_{DC}$ref, the compensator decreases IRMSref.
- In steady-state, IRMSref adjusted by the automatic feedback controller is just right so that $V_{DC}$ = $V_{DC}$ref, error signal is zero, and the average power Pac delivered to the AC grid matches the power generated by the PV array.

### 4.7 ANALYSIS OF ENERGY STORAGE CAPACITOR (C)

Capacitor C provides energy storage necessary to balance instantaneous power delivered to the grid. Magnitude of the resulting voltage ripple $\Delta V_{DC}$ at twice the line frequency (2 x 60 = 120 Hz) depends on the average power Pac and capacitance C.

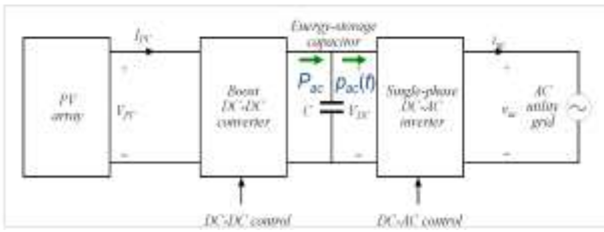


**Figure 6 : Energy Storage Capacitor In Pv Systems**

Pac − Pac (t) = Pac − Pac (1−cos (2ωt)) = Pac cos (2ωt)

Energy supplied to the capacitor during the time when Pac > Pac(t), i.e. when the capacitor is charged from $V_{DC}$min to $V_{DC}$max :

$$\Delta E_C = \int_{-T_{ac}/8}^{T_{ac}/8} P_{ac} \cos 2\omega t \, dt = \frac{P_{ac}}{2\omega} \int_{-\pi/2}^{\pi/2} \cos\theta \, d\theta = \frac{P_{ac}}{\omega}$$

This energy must match the change in energy stored on the capacitor given as:

 

$$\Delta E_C = \frac{1}{2}CV_{DC\max}^2 - \frac{1}{2}CV_{DC\min}^2 = C(V_{DC\max} - V_{DC\min})\frac{V_{DC\max}+V_{DC\min}}{2} \approx CV_{DC}\Delta V_{DC}$$

Ripple Voltage can be given as:

$$CV_{DC}\Delta V_{DC} = \frac{P_{ac}}{\omega}$$

$$\Delta V_{DC} = \frac{P_{ac}}{CV_{DC}\omega}$$

### 4.8 SIMULATION MODEL DESIGN PARAMETERS CALCULATIONS

- DC-AC inverter input voltage: $V_{DC}$ = 200 V
- Average power delivered to the grid: $P_{ac}$ = 600 W
- Value of C so that ΔVDC = 40 V (i.e. +/-10% of the DC voltage at the input of the DC-AC inverter) from equation 6.7:

$$C = \frac{P_{ac}}{\Delta V_{DC} V_{DC}\omega} = \frac{600\ \text{W}}{40\ \text{V} * 200\ \text{V} * 2\pi 60\ \text{Hz}} = 200\ \mu\text{F}$$

Energy supplied (or absorbed) by the capacitor is relatively small & can be given as:

$$\Delta E_C = \frac{P_{ac}}{\omega} = \frac{600}{2\pi 60} = 1.6\ \text{J}$$

The total energy stored on the capacitor is given as:

$$E_C = \frac{1}{2}CV_{DC}^2 = 4\ \text{J}$$

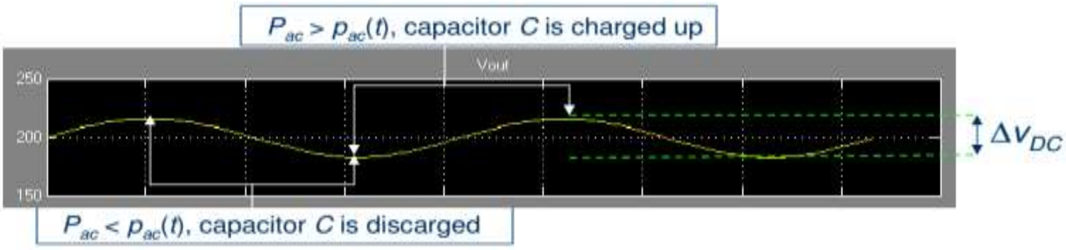


**Figure 7 : Energy Storage Capacitor Waveform**

### 4.9 MAXIMUM POWER POINT TRACKING (MPPT)

The objective of the MPP tracking algorithm is to adjust the DC-DC control variable so that the PV array operates at the maximum power point. It is assumed that the Boost output voltage Vout = $V_{DC}$ is constant. Iref is used as the control variable for the Boost DC-DC converter. The PV array current ideally tracks the Boost input current reference: $I_{PV}$ = Iref.

### 4.10 "PERTURB & OBSERVE" MPP TRACKING ALGORITHM USED FOR SIMULATION

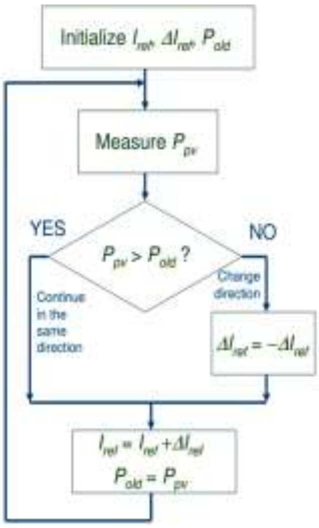


**Figure 8 : "Perturb & Observe" Mpp Tracking Algorithm**

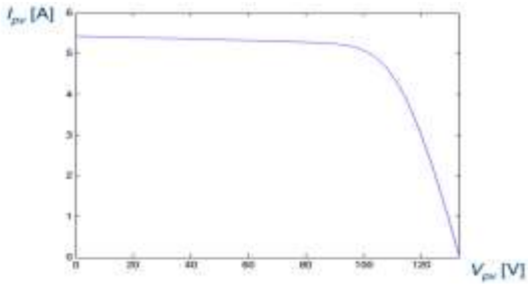


**Figure 9 : I-V Characteristics Of Pv System (Six 85 W Modules In Series, Full Sun)**

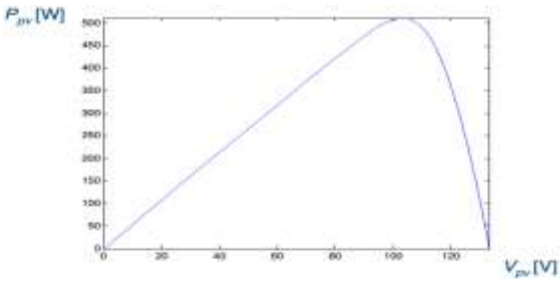


**Figure 10 : P-V Characteristics Of Pv System (Six 85 W Modules In Series, Full Sun)**

 

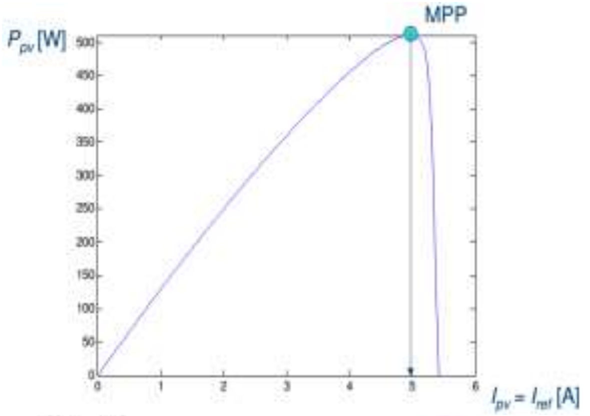


Figure 11 : P-I Characteristics Of Pv System ($I_{Pv}$= $I_{Ref}$ At Mpp)

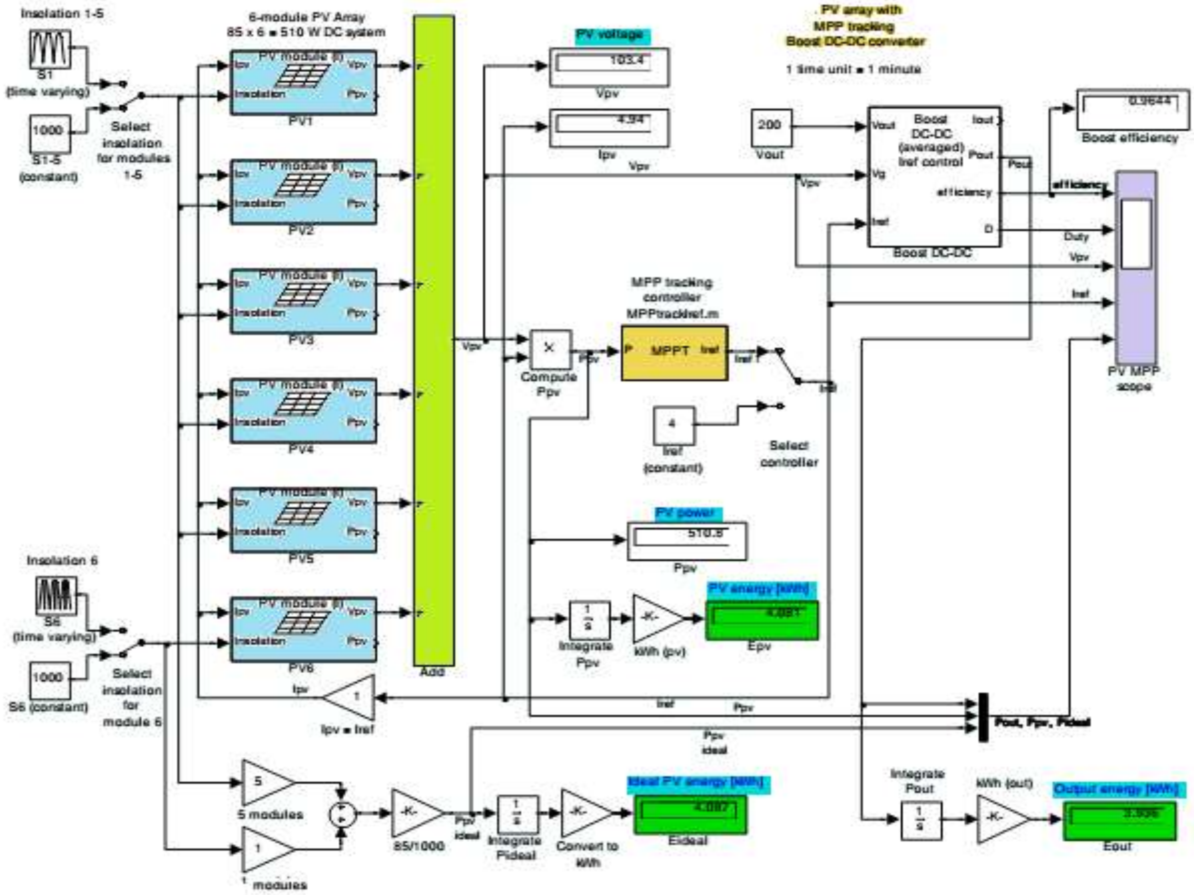


**Figure 12 : Simulation Model for PV Boost MPP**

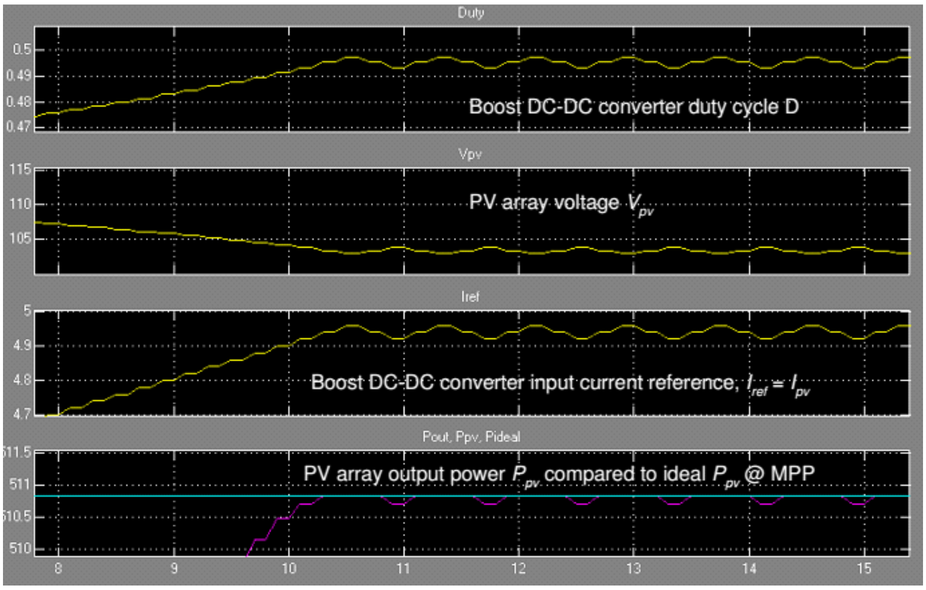


**Figure 13 : MPP Tracking Operation**

Also we have calculated the power and load analysis which is required in general. The detailed data analysis for house load along with a tentative cost is given in table 2. From the table 2 we can observe that total a.c. watt requirement is around, what our proposed model generates.

| Load Estimation Sheet | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S No | Individual | Time Hours | Qty | Volts | Amp | Watt | Total Watt | | Use | Use | Div /7 | Watt Hours | |
| | Load | | | | | | AC | DC | Hr/Day | Day/Week | | AC | DC |
| 1 | Light (Bulb) | 6-11 PM | 5 | | | 9 | 45 | | 6 | 5 | 7 | 192.86 | |
| 2 | Fan | 3-7 Am | 2 | | | 25 | 50 | | 16 | 5 | 7 | 571.43 | |
| 3 | TV | 7-10 PM | 1 | | | 150 | 150 | | 3 | 7 | 7 | 450.00 | |
| 4 | Fridge | 24 Hrs | 1 | | | 250 | 250 | | 3 | 7 | 7 | 750.00 | |
| 5 | Laptop | | | | | | 0 | | | | 7 | 0.00 | |
| 6 | E. Motor | | | | | 0 | 0 | | 0 | 0 | 7 | 0.00 | |
| 7 | Tube light | 6-11 PM | 2 | | | 40 | 80 | | 5 | 6 | 7 | 342.86 | |
| 8 | | | 0 | | | | 0 | | | | 7 | 0.00 | |
| 9 | | | | | | | 0 | | | | 7 | 0.00 | |
| 10 | | | | | | | 0 | | | | 7 | 0.00 | |
| 11 | | | | | | | 0 | | | | 7 | 0.00 | |
| 12 | | | | | | | 0 | | | | 7 | 0.00 | |
| 13 | | | | | | | 0 | | | | 7 | 0.00 | |
| 14 | | | | | | | 0 | | | | 7 | 0.00 | |
| 15 | | | | | | | 0 | | | | 7 | 0.00 | |
| 16 | | | | | | | 0 | | | | 7 | 0.00 | |
| 17 | | | | | | | 0 | | | | 7 | 0.00 | |
| 18 | | | | | | | 0 | | | | 7 | 0.00 | |
| Total | | | 11 | | | 474 | 575 | 0 | | | | 2307.14 | 0 |

**Table 2: Load estimation sheet**

## V. CONCLUSION

In order to design a grid connected PV system first of all PV module is modelled in MATLAB/Simulink based on the equivalent circuit in order to find best MPPT technique. Input to the PV module is solar insolation and temperature. From the solar panel voltage and current are extracted in order to find the power output. The proposed grid system is designed for domestic load purpose and delivers 600 W average power. For a grid connected Photo voltaic system Maximum Power Point Tracking algorithm which place a major role. A most suitable MPPT P&O technique is chosen based on the implementation cost, number of sensors required, complexity. Input to the PV module is solar insolation and temperature. From the solar panel voltage and current are extracted in order to find the power output. The simulation model is design for MPPT, PV module and Boost DC-DC, DC-AC converters. The various results simulated shows the improvement in P&O algorithm for MPP. Also the proposed simulated PV system requires less battery as the capacitor (feedback control) does reduce this requirement.

 

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