Simulation and Analysis of Photovoltaic Stand-Alone Systems

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Simulation and Analysis of Photovoltaic Stand- Alone Systems

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Dedicated to

My Maa

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ABSTRACT

Energy saving is biggest issue now a days, renewable energy is playing a big role in producing electricity, among them wind and solar are popular renewable energy sources. Fast tracking of global maximum power point (MPP) is a challenge, many research is going on this direction.

MPP highly depends on atmospheric conditions, so our maximum power point tracking (MPPT) technique should be good enough to track MPP in dynamic atmospheric conditions. Perturb and Observer (P & O) and Incremental conductance (INC) are widely used MPPT techniques, we used INC method and simulated solar photovoltaic system in dynamic atmospheric conditions.

Partial shading gives local MPPs and one global MPP, power loss occur in a shaded module because of that efficiency reduces, most of the conventional MPPT are failed to track global MPP ,to deal with this problem two kind of control strategies found in literature first one modular MPPT and second one two controller structure.

MPP also highly depends on the load, as the load changes MPP changes. Extra power need to store because sometimes load requirement is lesser than the generation, in this situation a battery is needed and in night time when PV module not able to generate, power can draw from the battery.

In this thesis we have discussed about the INC MPPT method for different atmospheric conditions and partial shading.

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CHAPTER 1

Introduction

1.1 Motivation

In 21st century energy crises, drag every researchers concentration towards the renewable energies, renewable energy is a source of clean and green energy. Among all renewable energies photovoltaic (PV) and wind are considered to be good sources of energy. Many researches are going on in the area of PV system, big challenge in this area is to track maximum power point (MPP) in the dynamic atmospheric conditions and shading condition because MPP varies with change in temperature and insolation.

To track maximum power point, technique use called maximum power point tracking technique (MPPT).In literature we found many MPPT tracking techniques in which main concentration is towards the fast tracking of MPP and operate PV system in global maximum power point.

Perturb and observer (P&O) and incremental conductance (INC), these two methods are frequently found in literature because of its easy implementation and effective tracking. In this thesis we described about INC. Boost converter is used as intermediate converter to perform switching and regulated output. In many literatures it has proved that boost converter has more advantages over the buck converter.

To understand PV system easily, it is operated under the constant load condition and avoids battery. Battery is used to store extra power from PV system. Partial shading is problem which interrupts PV system to operate in global MPP and system efficiency reduces because of this. Effect of partial shading in I-V and P-V curves also explained in this thesis.

Analog implementation of MPPT makes system’s transient response faster and it is cheaper, this also discussed with results.

1.2 Literature review

Many literatures are on the topic modelling of solar photovoltaic (PV) array M. G. Villalva *et.al.* [1] proposed a method of modelling and simulation of photovoltaic arrays. The main objective of this paper was to find the parameters of nonlinear I-V equation. In this paper effect of temperature and irradiation on the parameters of the I-V equation also discussed. S. J. Chiang *et.al.* [8] introduces a residential photovoltaic energy storage system, in which the PV power is controlled by a DC-DC controller with MPPT and transferred to a small battery energy storage system. C. Rodriguez *et.al.* [7] derived an analytic solution for finding the point which is in a close vicinity of the MPP.

T. Esram *et.al.* [2] discussed and compared different MPPT techniques available in literature and explained about nineteen MPPT methods. The author has given summary of these MPPT techniques and their implementation methods which serve as a useful guide in choosing the right MPPT method for specific PV systems. Shading is a big problem in the photovoltaic system W. Xiao *et.al.* [3] discussed the topologies used for photovoltaic power systems to optimize the operation of MPPT. The author proposed an individual power interface for each photovoltaic module and recommended a structure suitable for the photovoltaic features and MPPT to minimize the performance reduction caused by non-ideal conditions.

M. Chen *et.al.* [12] proposed an accurate, intuitive, and comprehensive electrical model to capture the entire dynamic characteristics of a battery, from nonlinear open-circuit voltage, current, temperature, cycle number, and storage time-dependent capacity to transient response. I.-S. Kim *et.al.* [13] proposed a sliding mode controller for the single-phase grid connected photovoltaic system. The sliding mode controller has been constructed based on a time-varying sliding surface to control the inductor current and solar array power simultaneously. R. Gules *et.al.* [14] analysed, designed and implemented a parallel connected MPPT system for a stand-alone photovoltaic power generation.

A. Safari *et.al.* [11] discussed incremental conductance (INC) method and practical implementation of this method. H. Patel *et.al.* [15] have discussed about specifically partial shading condition and extensive study about the partial shading condition has been done by the author. They made a generalised programme for PV array simulation.

1.3 The system under consideration

PV system under constant temperature and irradiation

As shown in Figure 1.1 system consist of a PV module, DC-DC boost converter, MPPT with constant resistive load. Boost converter consist of two switches S_1 and S_2, an inductor L, two capacitors C_1 and C_2 and load resistance R. Switches are operate by control logic, develop by MPPT. Matlab coding is use to make MPPT, its purpose is to track maximum power so that PV module utilizes maximum.

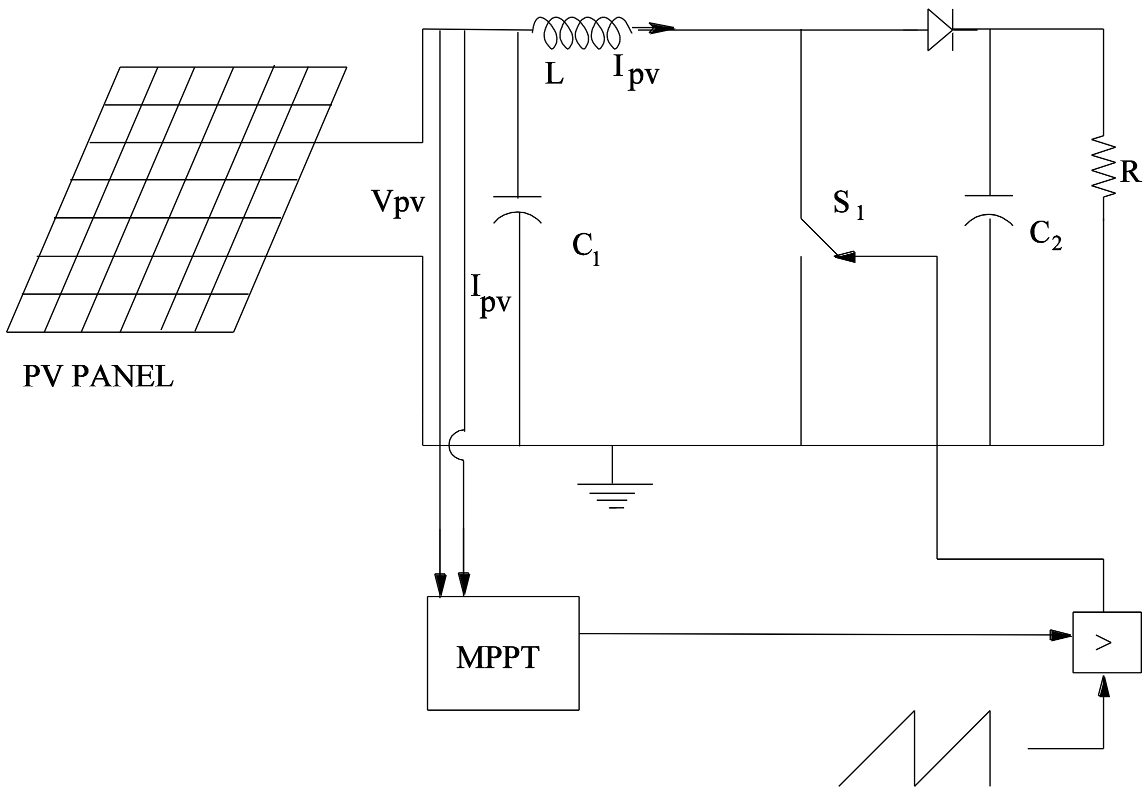

Figure 1.1: PV module with boost converter

PV system under constant temperature and varying irradiation

Dynamic atmospheric condition affects the output of PV panel, so output of boost converter also, our purpose is to track maximum power deliver by the module in any atmospheric conditions. Our MPPT should be robust enough to track MPP. System discussed in previous section is for constant atmospheric condition, same system consider again but for different irradiations and constant temperature.

PV system under varying temperature and constant irradiation

Temperature is inversely proportional to the voltage, so as the temperature increases voltage decreases, it affects the output power.

PV system under partial shading condition

Figure 1.2 shows two modules in a array , one module is shaded, because of shaded module P-V and I-V curve changes; we will have one local maxima and other global maxima. How this partial shading condition is affecting the P-V and I-V curves we will discuss in this section. Figure 1.3 shows the circuit diagram of partial shaded module.

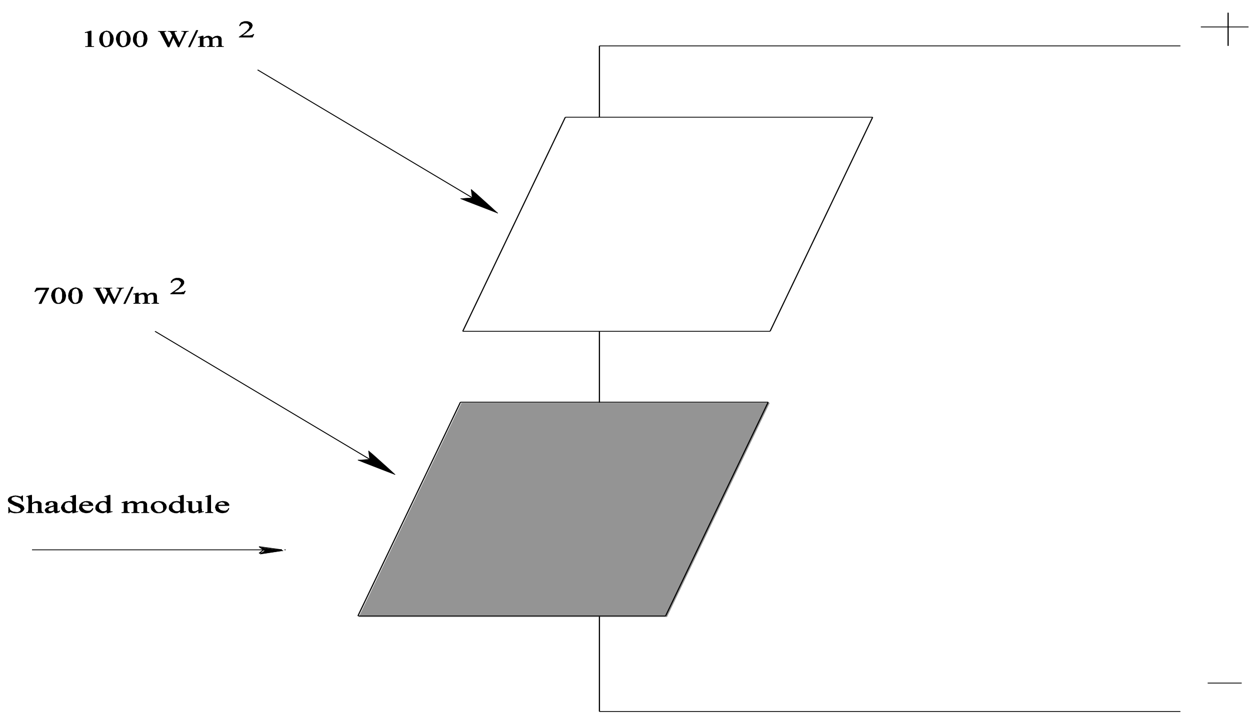

Figure 1.2: Block diagram of partial shaded module

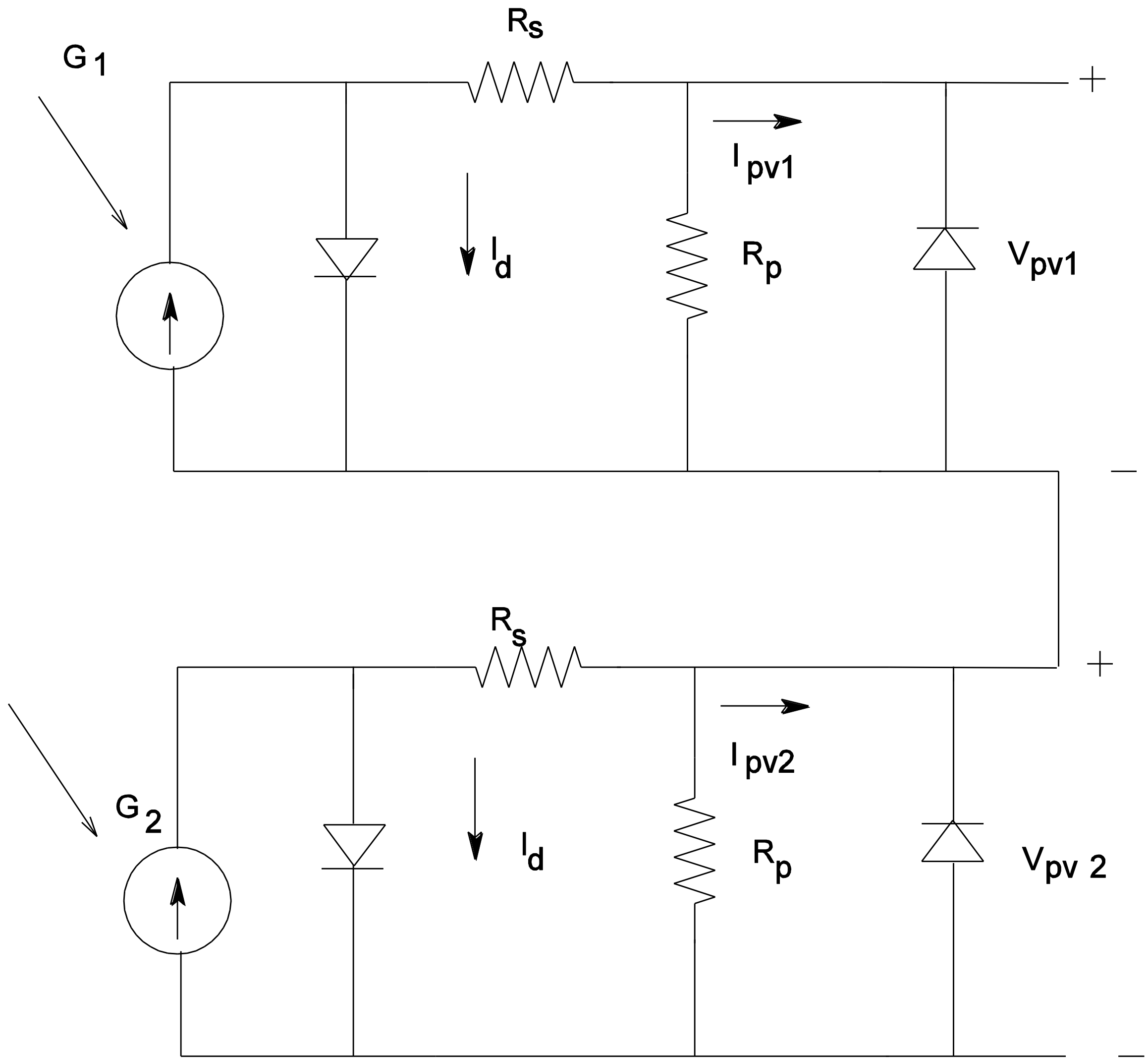

Figure 1.3: Circuit diagram of partially shaded module connected in series

Analog implementation of MPPT

Analog implementation of MPPT is faster and cheaper, MPPT consist of differentiator, comparator, XOR gate and D flip flop.

1.4 Objective and scope of this dissertation

Objective of this thesis is to check incremental conductance (INC) algorithm in dynamic atmospheric conditions, INC method is capable of tracking maximum power point or not. For efficient tracking or utilize PV array fully, it need to operate in maximum power point. For that

INC method is implemented first with constant temperature, constant irradiation, after constant temperature; varying irradiation and varying temperature; constant irradiation.

Partial shading of array is a big problem because in this condition we have many local maxima and one global maxima, so it's tough to get global maxima in P-V curve. In this we simulated two modules one is fully shaded and other is partially shaded, P-V curve and I-V curves plotted in this situation.

Analog implementation of MPPT is easy, cheap and faster.

In **chapter 2**, we described what PV system is and types of PV system, we concentrated on PV stand-alone system. We discuss, what are differences in stand-alone, grid connected and hybrid photovoltaic system.

In **chapter 3**, modeling of the solar photovoltaic system has discussed, how the parameter of PV equation depends on the temperature and irradiation has been discussed.

In **chapter 4**, MPPT techniques are described, why we have chosen INC method, although we found many MPPT techniques in literature but INC method is simple and easy to implement. In this chapter we discussed various MPPT techniques.

In **chapter 5**, which type of DC-DC converter used is discussed, it's purpose to find accurate and cost effective DC-DC converter for PV system for perfect modeling. State space equation is derived for boost converter with PV system.

In **chapter 6**, INC method is discussed in brief advantage of this method over other methods. Results of simulation for steady and dynamic atmospheric condition are also discuss in this chapter.

In **chapter 7**, discuss the phenomena of partial shading with two modules and three modules of PV array and its simulation results has shown.

CHAPTER 2

Classifications of solar photovoltaic system

2.1 Introduction solar PV system

PV system is design to give the electric supply to load and load can be ac type or dc type. Supply can be needed in day time or evening time or both time. PV system can give supply only in day time for night hours we needed supply for that we have batteries, where power can store and utilize [13].

2.2 Types of PV system

2.2.1 Stand-alone PV system

Depending on the type of load, cost, resources availability and requirements of the load stand-alone system divided into several categories, which are describe below

a) Unregulated standalone system with DC load

Usually this type of system is for low power applications. A PV system is directly connected to the load without any MPPT controller, night hours it will not provide any supply because of the absence of the battery.

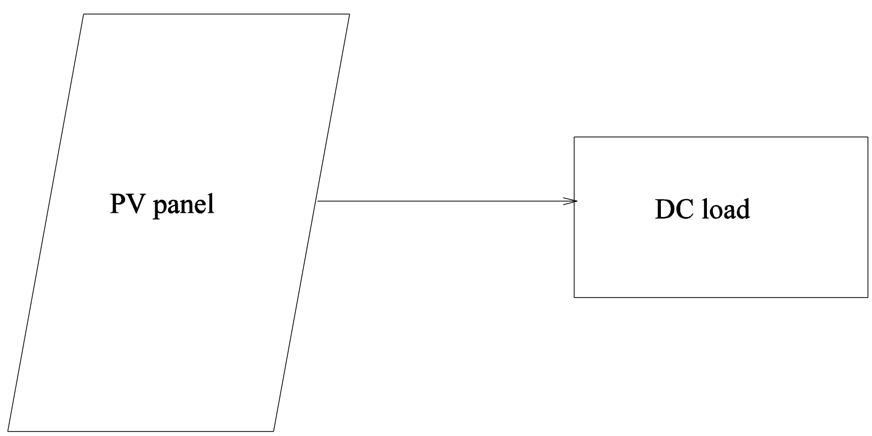

Figure 2.1: Unregulated standalone system with DC load

b) Regulated standalone system with DC load

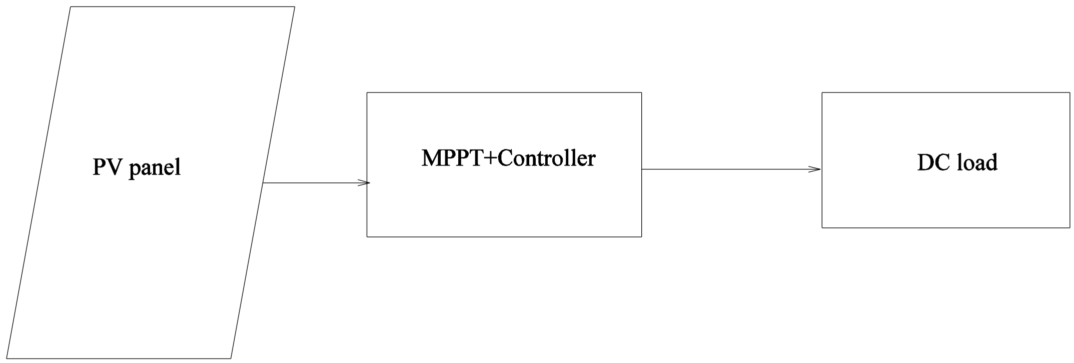

Figure 2.2: Regulated standalone system with DC load

It is similar to unregulated standalone system with DC load but basic difference between this and previous one that this system requires a MPPT technique. Usually system with MPPT should have one battery otherwise extra power will be waste.

c) Regulated standalone system with battery and DC load

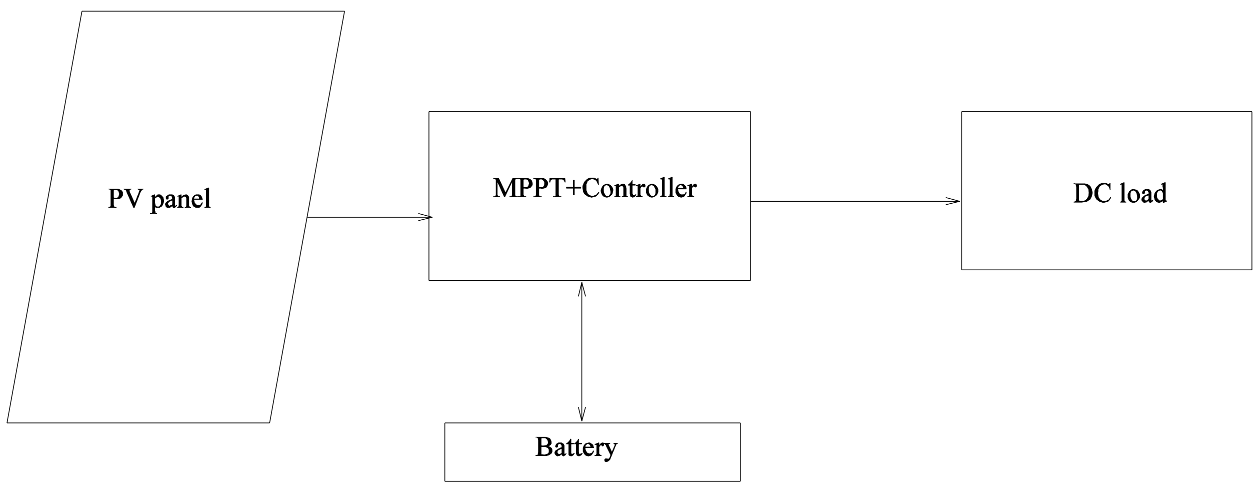

Figure 2.3: Regulated standalone system with battery and DC load

Most common configuration PV array, battery, MPPT and DC load. Battery use to store the extra power of PV system, this will increase the cost of PV system. A charge controller is must for this type of system because battery life is less compare to PV module, extra charging deep discharging can reduce the life of battery [12].

d) Regulated standalone system with battery, AC and DC loads

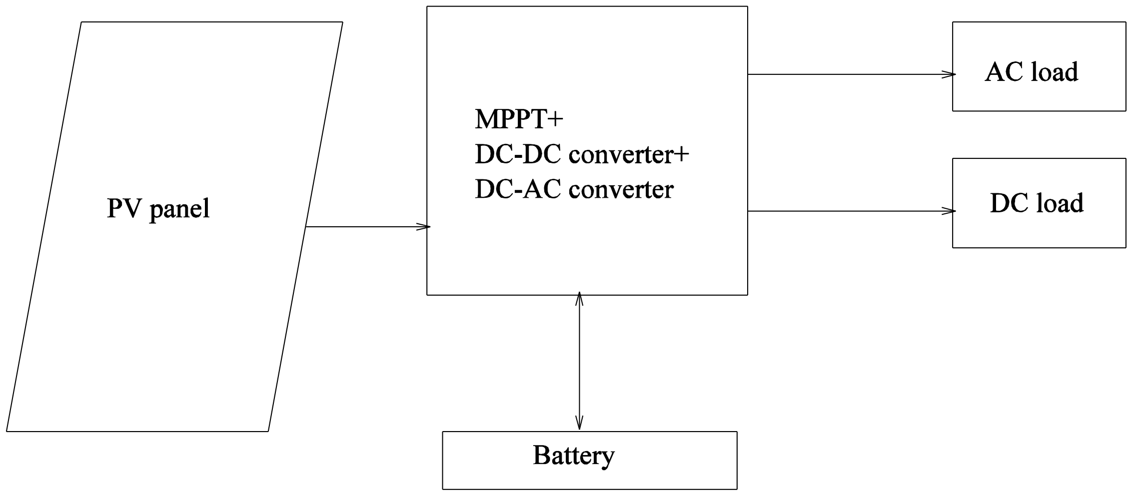

Figure 2.4: Regulated standalone system with battery, AC and DC loads

This system is similar to previous one but here AC load can also draw the power from PV system and inverter (DC to AC converter) is require, it will increase the cost.

2.2.2 Grid interactive PV system

Grid connected PV system is a system when grid is connected to PV system .In this type of system consist PV array and inverter. Figure 2.5 shows grid connected PV system. Grid connected system deals with AC. Grid connected system deals with very high power applications, so is tough to store this much of power in battery [13].

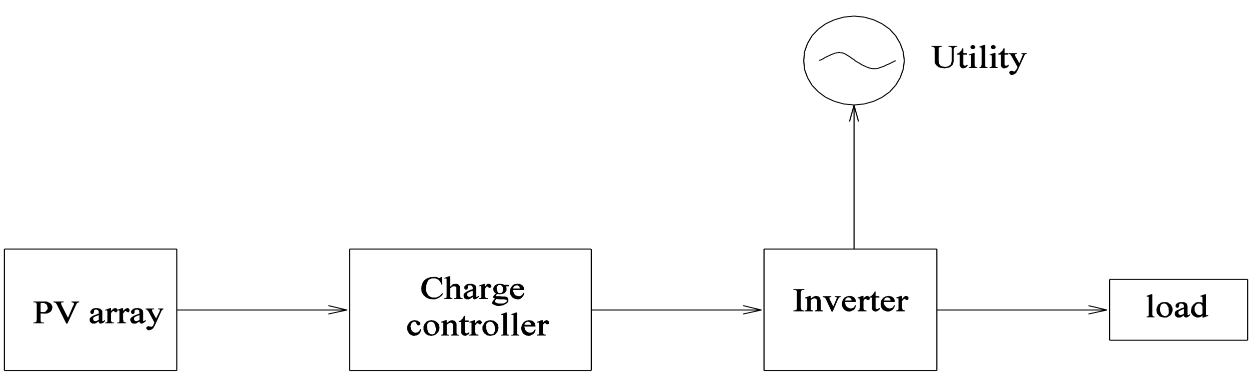

Figure 2.5: Grid interactive PV system

2.2.3 Hybrid system

When PV system is use in conjunction with diesel generator, wind generator, micro turbines, fuel cells etc., system is called hybrid system

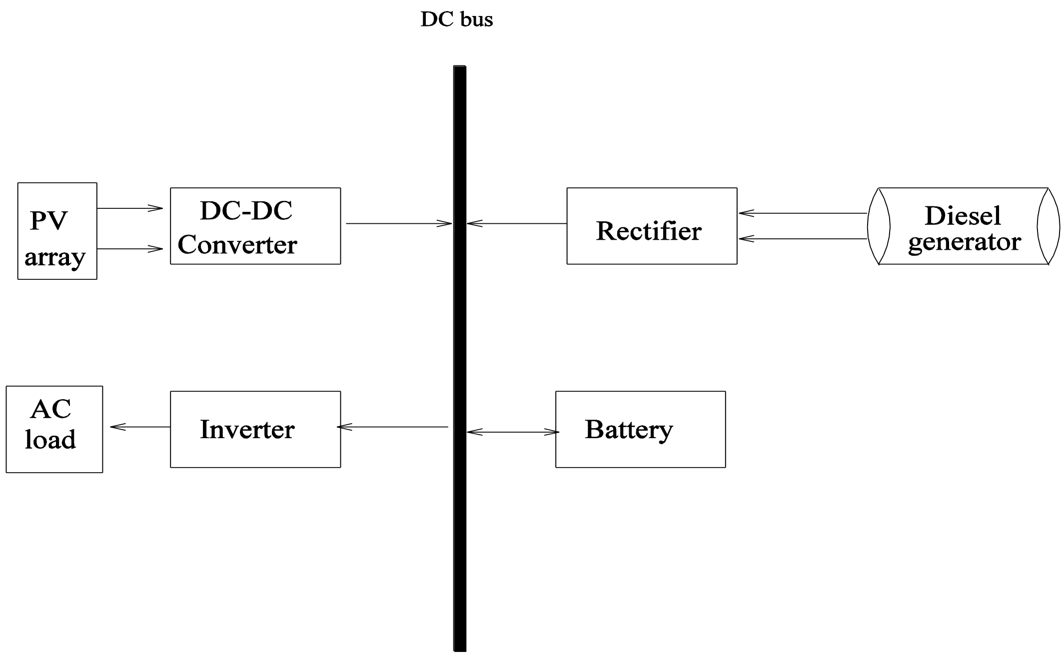

Figure 2.6: Hybrid system

CHAPTER 3

Modeling of PV array and simulation

3.1 Modeling of PV array

PV array consist several modules, modules made of cells, each PV cell generates approximately 2W of power. Cells connected in series to increase voltage rating, these are connected in parallel to increase current rating. Figure 3.2 shows PV cell, module and array.

Photovoltaic cell

Solar cells are the building blocks of the PV system. It is made up of semiconductor, when light strikes to the surface of semiconductor electron knocked off, it collected from metal connected to this cell.

Photovoltaic module

Power generated by cell is very less so number of cells connected in series to increase power rating. Diode can be antiparallel connected to avoid the damage caused by partial shading.

Photovoltaic array

Power generated by a module is not sufficient for some applications, so module can be connected in series or parallel, to meet desire value.

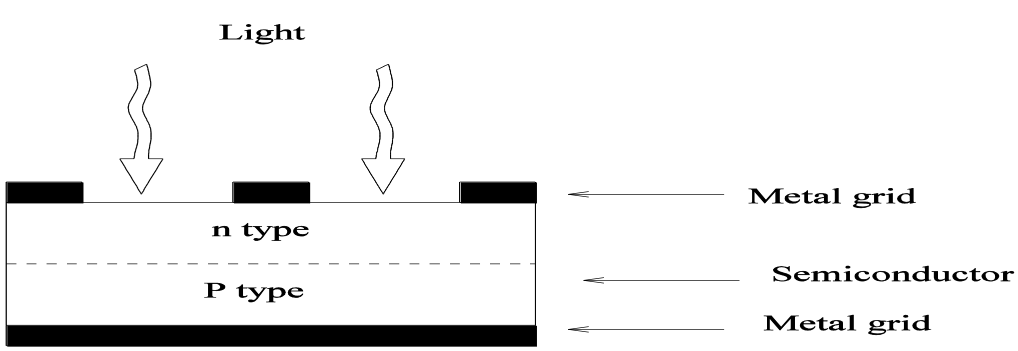

Figure 3.1: PV cell structure

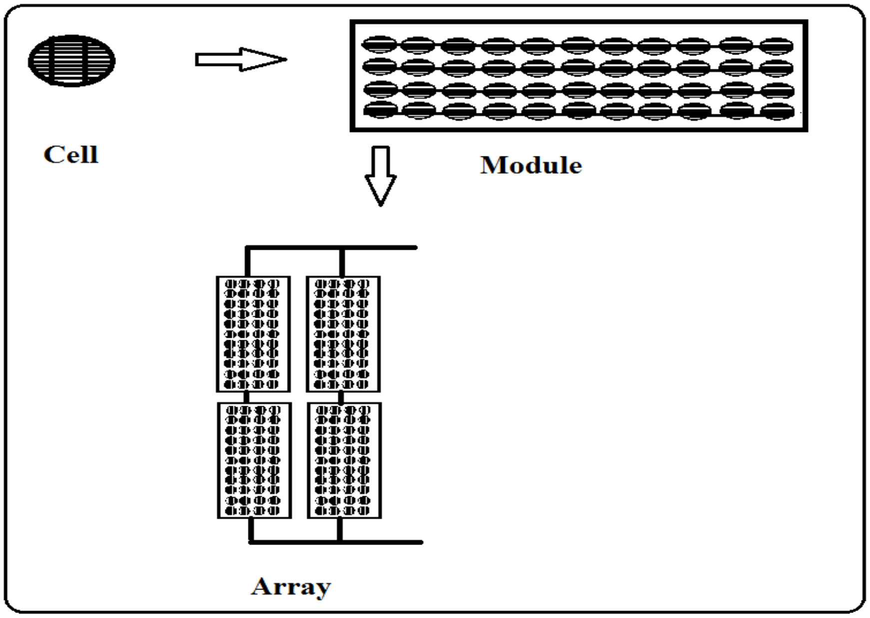

Figure 3.2: PV array, cell and module

PV cell and array model represented in electrical equivalent circuit shown in Figure 3.2 .It is represented by the PV equation (3.1)

$$I_{pv} = I - I_0 \left[\exp\left(\frac{V_{pv}+I_{pv}R_S}{aV_t}\right) - 1\right] - \frac{V_{pv}+I_{pv}R_S}{R_P} \qquad (3.1)$$

Where I and I_0 the photovoltaic output and saturation currents of array respectively and V_t is the thermal voltage of array ,R_s is the series equivalent resistance R_p is the parallel equivalent resistance ,a is the diode ideality factor, V_{pv} and I_{pv} are the photovoltaic output voltage and current respectively**.** I current generated from the light.

To increase voltage rating of array N_s cell connected in series than thermal voltage $V_t=N_skT/q$. To increase output current of the PV array N_p cell connected in parallel .$I=I_{,cell}N_p$,$I_0=I_{0,cell}N_p$

In literature we found single diode, two diode and three diode model. Single diode model is a good combination of simplicity and accuracy. For considering various effects extra diodes consider. For power electronics practitioner single diode model is accurate and easy for doing analysis.

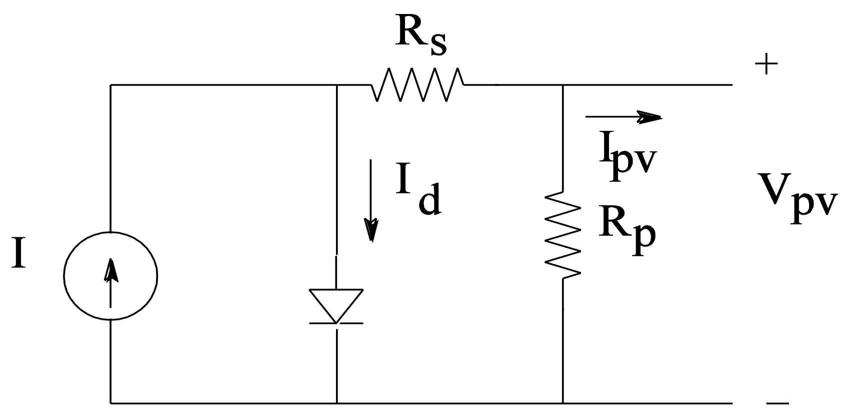

Figure 3.3: Equivalent circuit of practical PV device

3.2 Parameters of PV array affected by the Temperature and irradiance

$$I = \left(I_{,n} + K_I \Delta_T\right)\frac{G}{G_n} \qquad (3.2)$$

Where $I_{,n}$ = light generated current at nominal condition (25ºC and 1000 W/m^2)

K_I = Short circuit current/temperature coefficient

$\Delta_T = T - T_n$ (Actual and nominal temperature respectively)

G = irradiation on the device surface

G_n = nominal irradiation

$$I_0 = I_{0,n}\left(\frac{T_n}{T}\right)^3 e^{\left[\frac{qE_g}{ak}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right]} \qquad (3.3)$$

Where E_g =Bandgap energy of semiconductor

$I_{0,n}$ = Saturation current in nominal condition

$$V_t = \frac{kT}{q} \qquad (3.4)$$

Where k= Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)

q = electron charge ($1.60217646 \times 10^{-19}$ C)

Conclusions from above equations and literature

- Diode saturation current (I_0), PV current (I_{pv}) and thermal voltage (V_t) are temperature dependent.
- PV current (I_{pv}) directly proportional to the irradiance
- R_s gives accurate shape between mpp and open circuit voltage
- a expresses the degree of ideality of the diode and it is totally empirical, any initial value of a can be chosen in order to adjust the model

3.3 Module ratings use for simulation

We use Solarex MSX -60 parameters for simulation, whose parameter ratings are given below:

Table 3.1 Module Ratings

Typical peak power (P_p)	60W
Voltage @ peak power (V_{pp})	17.1V
Current @ peak power (I_{pp})	3.5 A
Guaranteed minimum peak power	58W
Short-circuit current (I_{sc})	3.8A
Open-circuit voltage (V_{oc})	21.1V
Temperature coefficient of open-circuit	-(80±10)mV/ºC
Temperature coefficient of short-circuit	(0.065±0.015)%/ºC
Approximate effect of temperature on power	–(0.5±0.05)%/ºC

3.4 Simulation results of one module

3.4.1 I-V curve of PV panel

I-V (Current-Voltage) curve originated from the equation (3.1) for particular value of the voltage current value we get and plot the curve this curve gives at what value of the voltage what should be the current. When the I_{pv}=0 we will get open circuit voltage (V_{oc}) of PV panel, when V_{oc}=0 we will get short circuit current (I_{sc}).In I-V curve star point represents the maximum power point corresponding voltage V_{mpp} and corresponding current I_{mpp} .

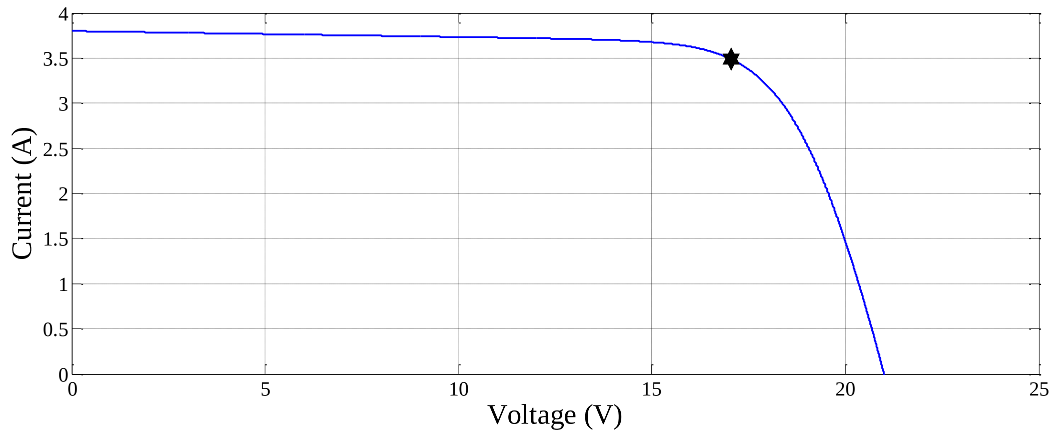

Figure 3.4: I-V curve of PV panel

3.4.2 P-V curve of PV panel

Multiplication of output current and output voltage gives the output power, at particular value of current (I_{mpp}) and voltage (V_{mpp}), will give maximum power P_{mpp}. Figure 3.5 shows P-V (Power-Voltage) curve of PV panel, star point shows the maximum power point of the panel.

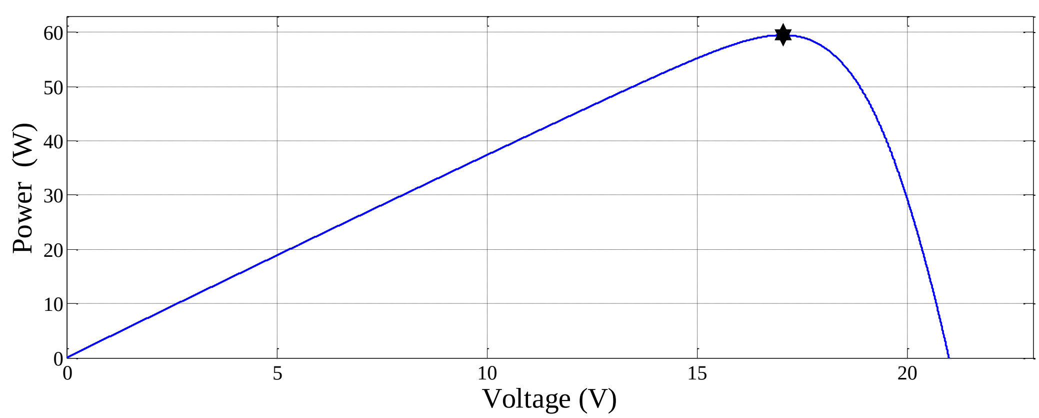

Figure 3.5: P-V curve of PV panel

CHAPTER 4

Maximum power point tracking technique

PV system's efficiency depends on MPPT [2].MPPT is the most important in PV system; efficient tracking is the key issue. Many literature we found who has taken care of irradiation and temperature changes because these are key factors of shifting of MPP, in chapter 3 we already have described about the effect of temperature and irradiation on the parameters of current equation, roughly we can say temperature is inversely proportional and irradiation directly proportional to output power. In partial shading condition we have multiple local maxima and one global maxima and it's tough to track the global maxima through one MPPT, without using it in distributed manner. Fast tracking of MPPT is also a big problem.

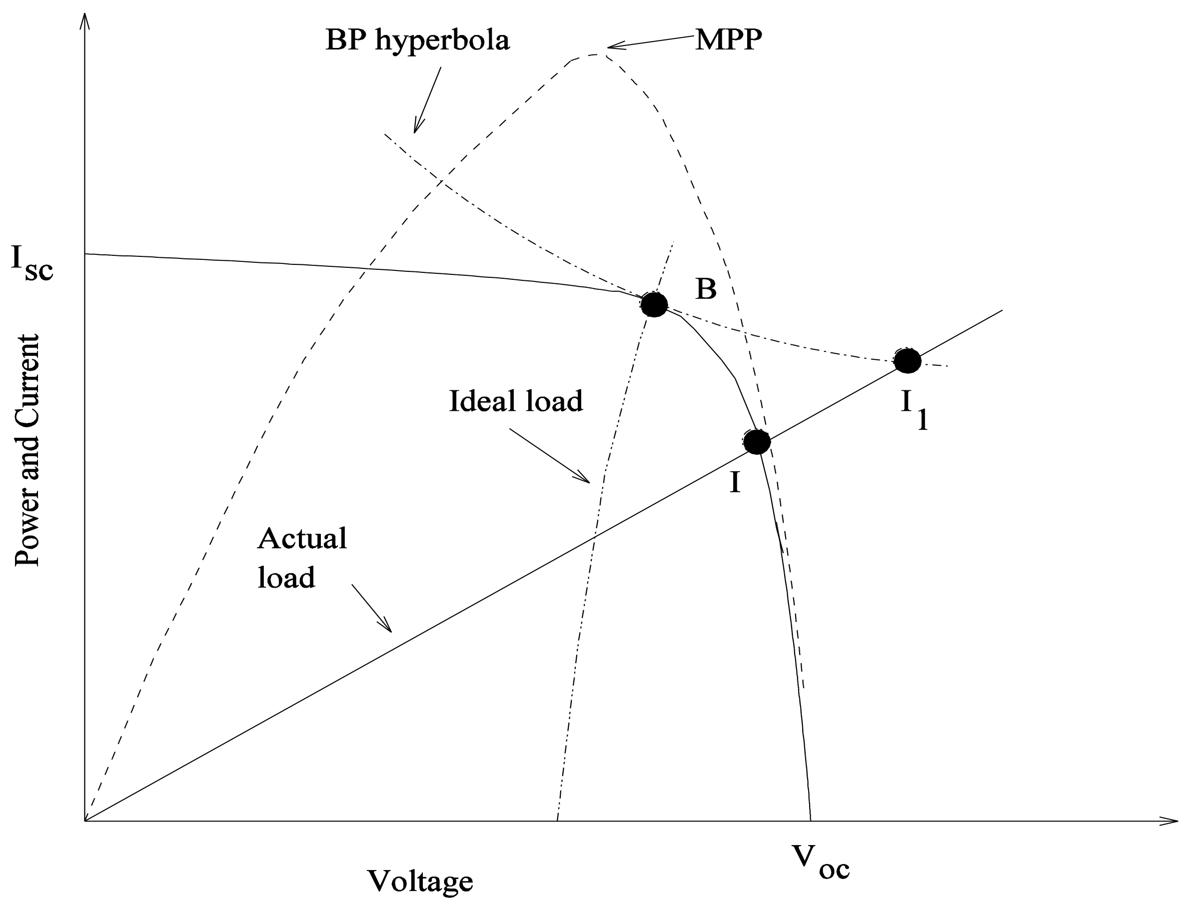

Figure 4.1: The concept of load-mismatch and MPP tracking

Figure 4.1 Maximum power hyperbola BP intersects I-V curve at point B, load mismatch can cause PV array to operate in sub-optimal point. Actual load line intersects I-V curve in I, ideal load curve in B [4].

Few MPPT methods we discussed below

A. Hill climbing

Figure 3.5 shows PV curve, a hill climbing method is method to track the power through perturbation in duty cycle. Perturbation in duty cycle will continue unless maximum power reaches. Fixed step size can be use but oscillation around the MPP may occur, variable step size will be beneficial but its though to vary the step size, as we reach closer to the MPP step size decreases.

B. Perturb and observe (P&O)

P&O is similar to the hill climbing method only one difference is that hill climbing method deals with perturbation in duty cycle and P&O method deals with perturbation in voltage. Disadvantage of this method is it is unable to track MPP in varying weather conditions.

C. Incremental conductance (INC)

Increment in conductance in I-V curve is the basis of this method, we already know

$$\text{At maximum power point } \frac{dP}{dV} = 0 \ldots\ldots\ldots (4.1)$$

$$\text{Since} P = VI \ldots\ldots\ldots (4.2)$$

$$\text{So } \frac{dI}{dV} = -\frac{I}{V} \ldots\ldots\ldots (4.3)$$

This technique we will briefly discuss in chapter 6.

D. Fractional open-circuit voltage

V_{oc} and V_{mpp} are directly proportional

$$V_{mpp} = k_1 V_{oc} \ldots\ldots\ldots (4.4)$$

$k_1 \cong 71\%$ to 78% , for measuring V_{oc} converter should off. Frequently we have to do this, it causes power loss and efficiency is less and this method is not useful in partial shading condition. Advantage of this method it is easy to implement and it is cheap.

E. Fractional short-circuit current

This method is similar to fractional open circuit voltage method .current I_{mpp} is proportional to I_{sc}

$$I_{mpp} = k_2 I_{sc} \qquad (4.5)$$

$k_2 \cong 78\%$ to $92\ \%$ .measuring I_{sc} during operation is though need one extra switch. It will increase the cost and calculated value is also not so accurate.

CHAPTER 5

DC-DC converters

DC to DC converters are used for converting one level of input voltage to other level of DC output voltage. DC-DC converter consist of inductor, capacitors and switches,

DC-DC Converter interface with PV system is very essential for that we need a good converter. These converters play a role of charge controller, MPP trackers and PV interface with load. We have many types' isolated and non-isolated converters among that buck and boost non-isolated DC-DC converters frequently use in literature, because of their easy structure and less components .Figure 5.1 and figure 5.2 shows buck and boost DC-DC converter with their PV interface [3].Among these two boost converter is advantageous [3],[9].

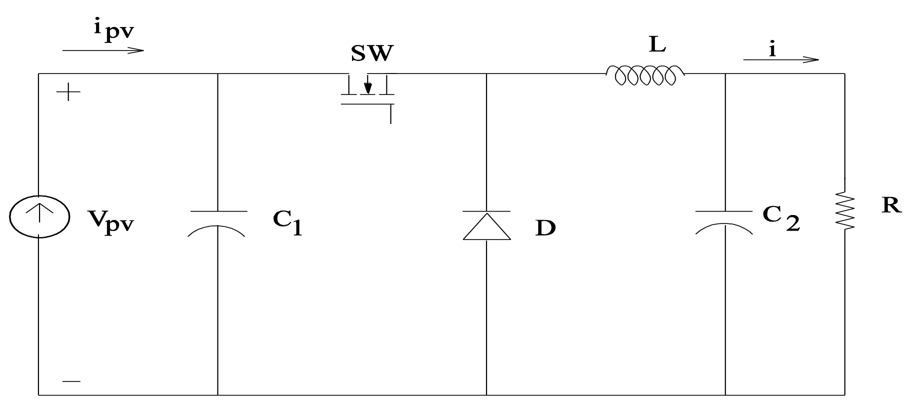

Figure 5.1: Buck converter interface with PV system

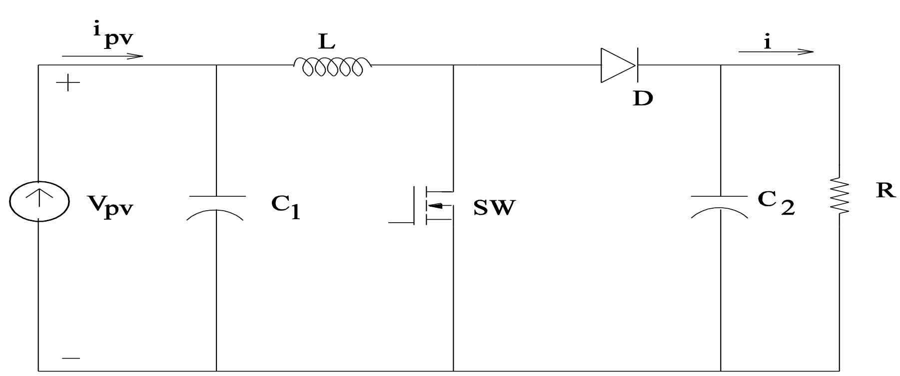

Figure 5.2: Boost converter interface with PV system

5.1Components comparison

Not very significant comparison between inductor of boost and buck converter ,boost converter require greater value inductor .As we compare the capacitor value buck converter requires a huge and bulky capacitor to remove ripple from the PV current, boost converter can handle ripple with less value capacitor.

MOSFET current rating of boost converter is less as compare to buck converter because in buck converter MOSFET connected with the source directly and heavy current flow through it, in boost converter less current flow through it.

A blocking diode is requiring to protect reverse current from load side at light load condition otherwise PV panel can burn or damage, in boost converter it has freewheeling diode but in buck converter it's require.

5.2Modeling of PV system with boost converter

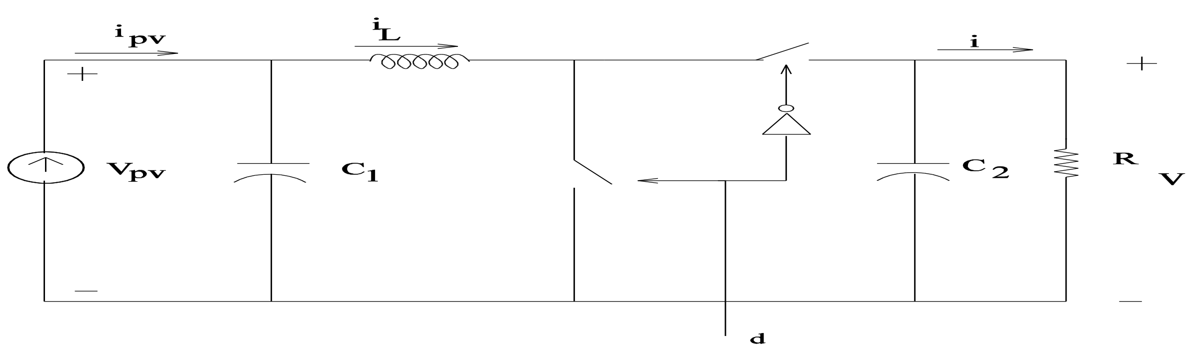

Figure 5.3: PV system

State space modelling is very useful in small signal and DC analysis.

Taking figure 5.3 system under consideration .Below equations describe the operation

$$\dot{x}(t) = A_j x(t) + B_j(t)u(t) \ldots\ldots\ldots\ldots (5.1)$$

$$y(t) = C_j x(t) + E_j(t)u(t) \ldots\ldots\ldots (5.2)$$

Where j=1, during dT and j=2 during d'T, where d is the duty ratio, defined as $d = \frac{T_{on}}{T}$, d' is it's compliment [16].

State vector $x(t)= \begin{bmatrix} i_L(t) \\ v(t) \\ v_{pv}(t) \end{bmatrix}$……………….(5.3)

Input vector $u(t)=[i_{pv}(t)]$……………………(5.4)

ON mode

$$L\frac{di_L(t)}{dt} = v_{pv}(t) \quad (5.5)$$

$$C_2\frac{dv(t)}{dt} = -\frac{v(t)}{R} \quad (5.6)$$

$$C_1\frac{dv_{pv}(t)}{dt} = i_{pv}(t) - i_L(t) \quad (5.7)$$

$$v_{in} = v_{pv}(t) \quad (5.8)$$

OFF mode

$$L\frac{di_L(t)}{dt} = v_{pv}(t) - v(t) \quad (5.9)$$

$$C_2\frac{dv(t)}{dt} = -\frac{v(t)}{R} + i_L(t) \quad (5.10)$$

$$C_1\frac{dv_{pv}(t)}{dt} = i_{pv}(t) - i_L(t) \quad (5.11)$$

$$v_{in} = v_{pv}(t) \quad (5.12)$$

$$A_1 = \begin{bmatrix} 0 & 0 & D \\ 0 & \frac{-D}{R} & 0 \\ -D & 0 & 0 \end{bmatrix}, \qquad B_1 = \begin{bmatrix} 0 \\ 0 \\ D \end{bmatrix}, C_1 = [0 \quad 0 \quad 1], E_1 = [0 \quad 0 \quad 0]$$

$$A_2 = \begin{bmatrix} 0 & D' & D' \\ D' & \frac{-D\prime}{R} & 0 \\ -D' & 0 & 0 \end{bmatrix}, \qquad B_2 = \begin{bmatrix} 0 \\ 0 \\ D' \end{bmatrix}, C_1 = [0 \quad 0 \quad 1], E_2 = [0 \quad 0 \quad 0]$$

Small signal AC state equation

$$L\frac{d\hat{i}_L(t)}{dt} = -D'\hat{v}(t) + V\hat{d}(t) + \hat{v}_{pv}(t) \ldots\ldots\ldots\ldots.. (5.13)$$

$$C_2\frac{d\hat{v}(t)}{dt} = D'\,\hat{i}_L(t) - \frac{1}{R}\hat{v}(t) - I_L\hat{d}(t) \ldots\ldots\ldots (5.14)$$

$$C_1\frac{d\hat{v}_{pv}(t)}{dt} = -\hat{i}_L(t) + \hat{i}_{pv}(t) \ldots\ldots\ldots\ldots.. (5.15)$$

$$\hat{y}(t) = \hat{v}_{in}(t) = \hat{v}_{pv}(t) \ldots\ldots\ldots\ldots\ldots (5.16)$$

5.3Control of DC-DC converters

The output of DC-DC converters controlled by switch ON-OFF the controllable switch with constant frequency $T_S=T_{ON}+T_{OFF}$. $d=T_{ON}/T_{OFF}$ is the duty cycle. MPPT will generate a signal which is compared with constant frequency ramp signal, a square wave is generated after it and its fed to DC-DC converter.

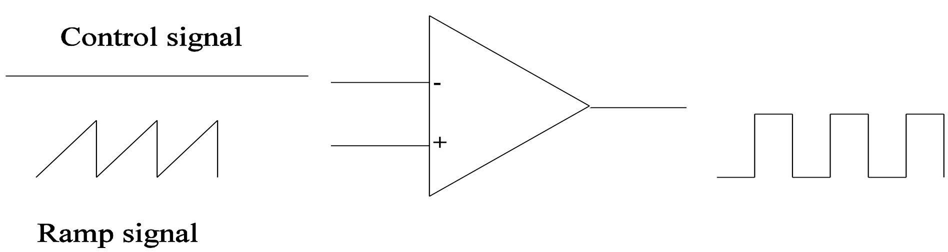

Figure 5.4 Duty cycle control of DC-DC converter

5.4Simulation results

PV module is simulated with MPPT with boost converter and out output voltage, output power curve is plotted and these are constant with some ripple in output. Figure 5.5 shows out-put power of boost converter and Figure 5.6 shows output voltage of boost converter.

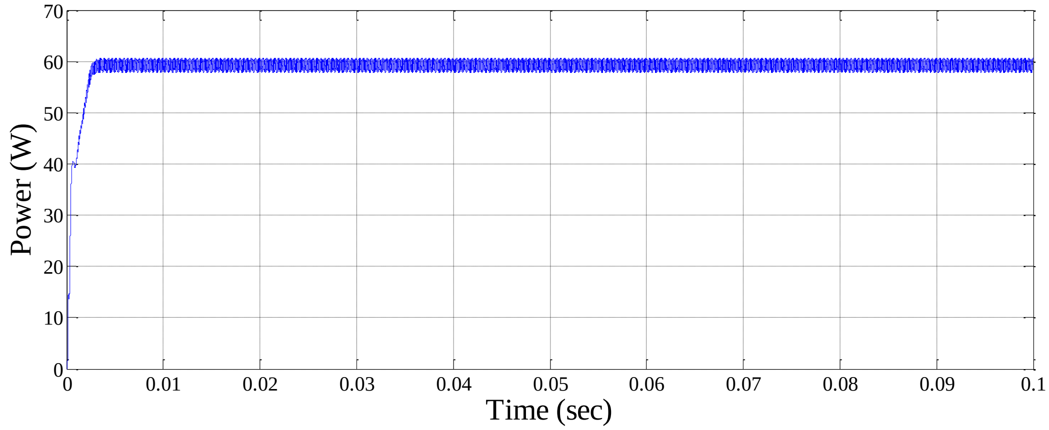

Figure 5.5: output power curve of boost converter

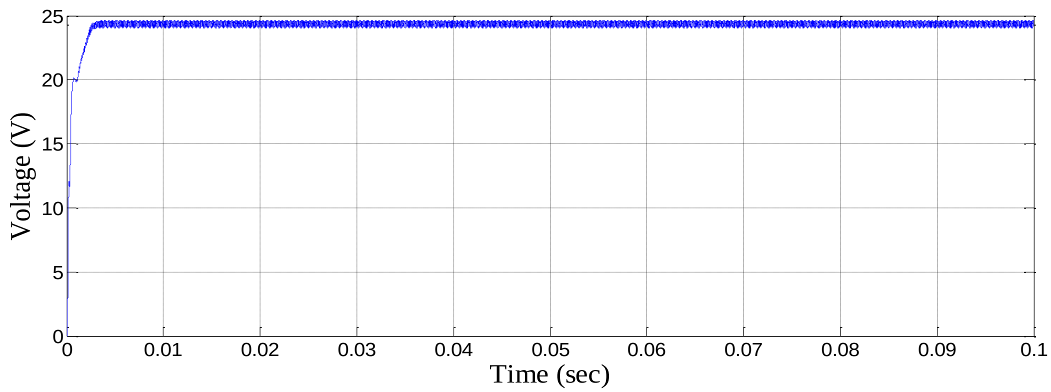

Figure 5.6: output voltage curve of boost converter

CHAPTER 6

Incremental conductance method

6.1 Mathematical description

Basic of INC method comes from P&O algorithm. In P-V curve as shown in figure 6.1, slope is positive, negative and zero in left, right and peak point respectively [11].

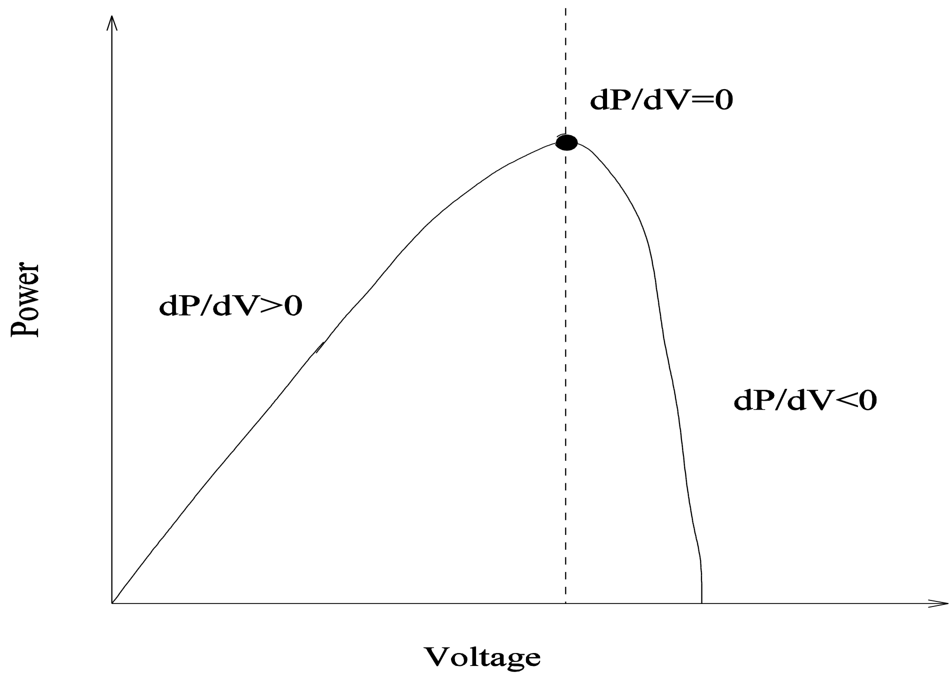

Figure 6.1: PV curve

At maximum power point $\frac{dP}{dV} = 0$…….. (6.1)

Since $P = VI$… (6.2)

So $\frac{dI}{dV} = -\frac{I}{V}$….. (6.4)

Because

$$\frac{dp}{dv} > 0 \quad \text{left side of the curve}$$

$$\frac{dp}{dv} < 0 \quad \text{right side of the curve}$$

$$\frac{dp}{dv} = 0 \quad \text{peak of the curve}$$

So

$$\frac{dI}{dv} > \frac{-I}{V} \quad \text{left side of the curve}$$

$$\frac{dI}{dv} < \frac{-I}{V} \quad \text{right side of the curve}$$

$$\frac{dI}{dv} = \frac{-I}{V} \quad \text{peak of the curve}$$

According to above expression algorithm is implemented for MPPT, instead of P-V curve, I-V curve is use in these. Figure 6.2 shows the algorithm of this method

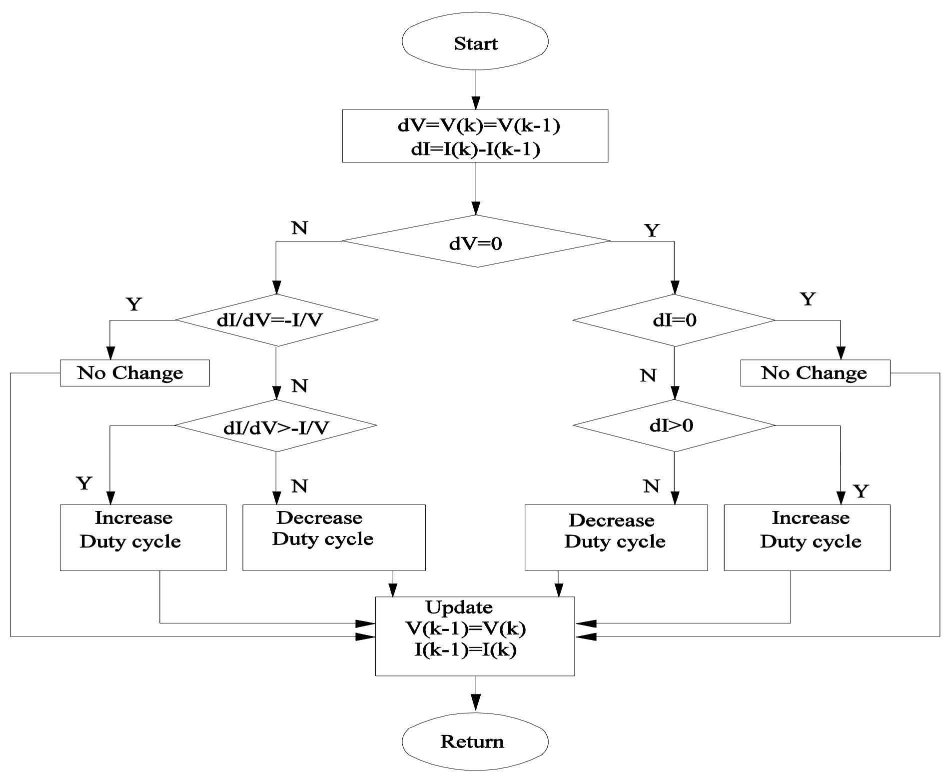

Figure 6.2: INC algorithm

Simulation has been done using INC method for various insolation and temperature change conditions and results has been plotted.

6.2 Varying insolation condition

Figure 6.3 shows the P-V curve in different insolation conditions, star point shows peak power of each curve, as insolation increases peak power shifted upwards.

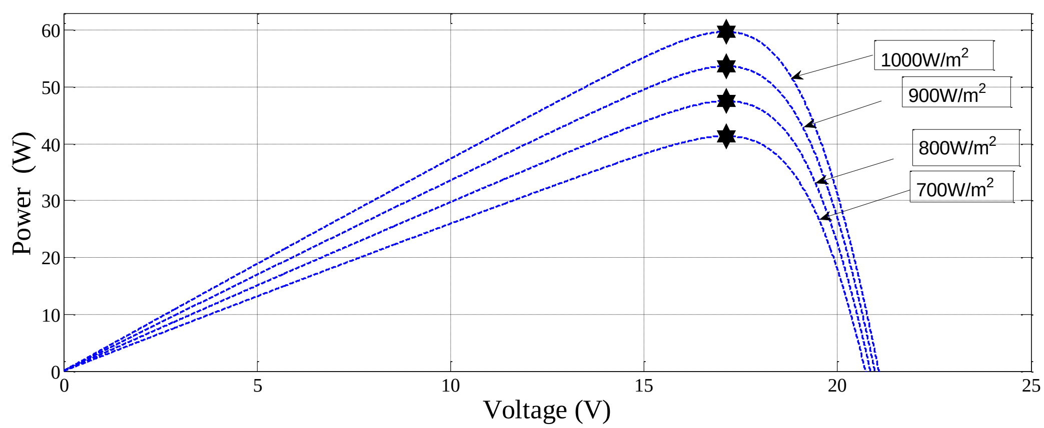

Figure 6.3: Irradiance effect on P-V characteristics at constant temperature (25°C)

Figure 6.4 shows output power of boost converter as the insolation increases power increases and INC method is properly tracking the MPP with change in insolation

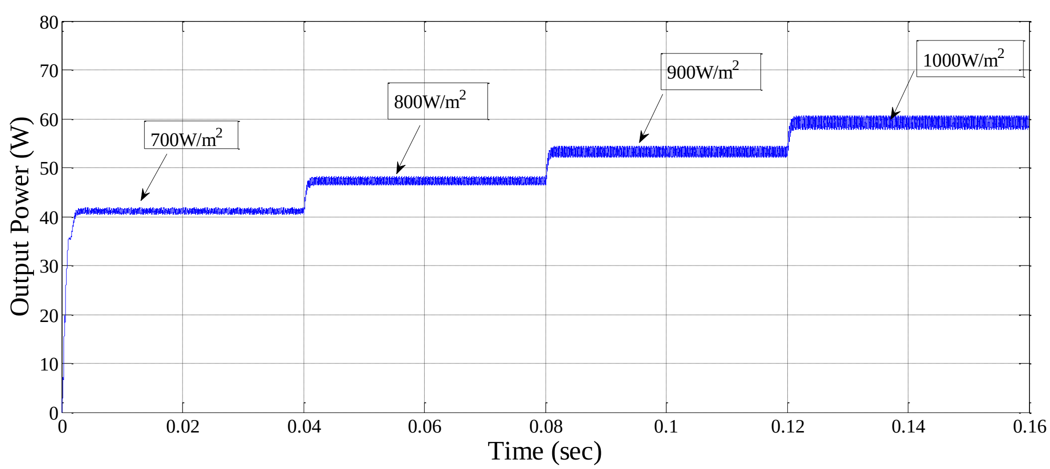

Figure 6.4: Irradiance effect on output power of boost converter at constant temperature (25°C)

Figure 6.5 is plotted to verify the results that out power are tracking exact the input power or not. Dashed line is P-V curve of panel output and continuous line is output power verses time and it is tracking exactly the input power.

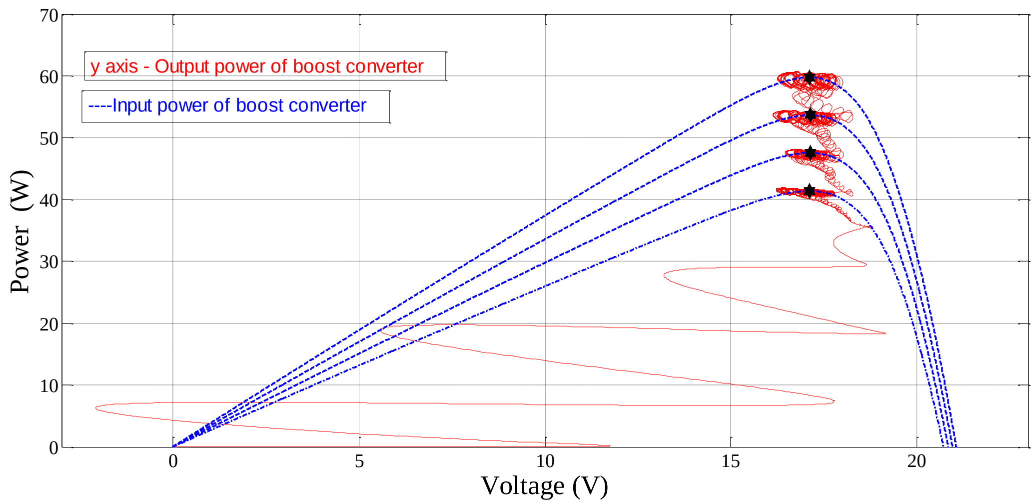

Figure 6.5: Different irradiance condition and constant temperature

6.3 Varying temperature condition

Figure 6.6 shows the P-V curve in different temperature conditions, star point shows peak power of each curve, as temperature increases peak power shifted downwards.

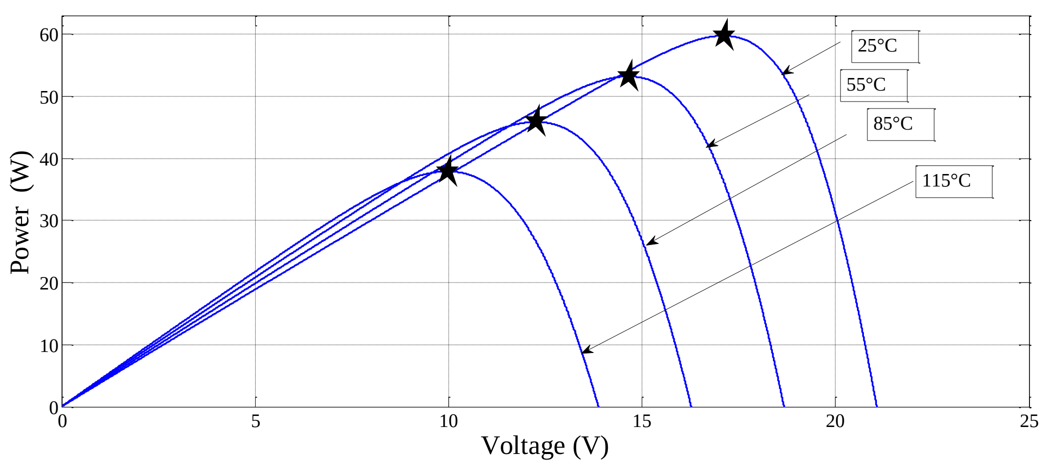

Figure 6.6: Temperature effect on P-V curve at constant irradiance (1000W/m^2)

Figure 6.7 shows output power of boost converter as the temperature increases power decreases and INC method is properly tracking the MPP with change in temperature.

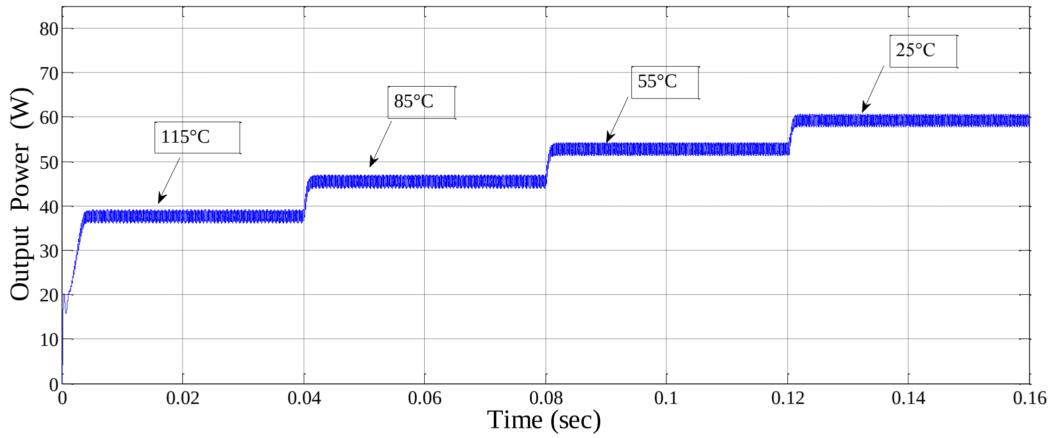

Figure 6.7: Temperature effect on output power of boost converter at constant irradiance ($1000W/m^2$)

Figure 6.8 is platted to verify the results that out power are tracking exact the input power or not. Dashed line is P-V curve of panel output and continuous line is output power verses time and it is tracking exactly the input power.

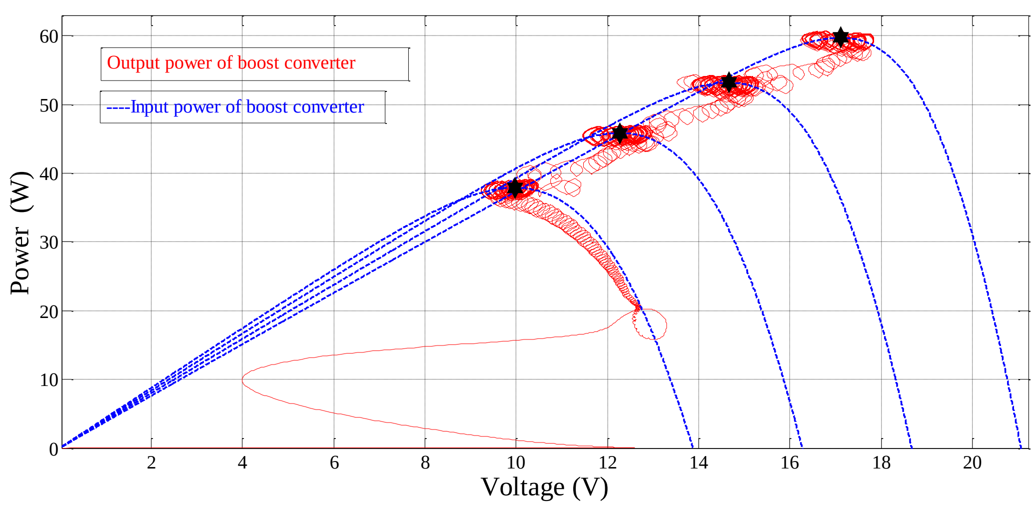

Figure 6.8: Different temperature condition and constant irradiance

CHAPTER 7

Partial shading

Partial shading occurs in PV system or cell because of dirt, neighbor building, aging effect of module etc. Shaded cell gives less power output and it's tough to consider the shading of each and every cell analysis will become tougher, so considering the effect of shading in module, we simulated.

We have considered two modules one is shaded and one is full illuminated, and check the how out P-V and I-V curve affected. Figure 1.2 shows partial shading phenomena. When one cell is shaded, cell become reverse bias, breakdown voltage can occur in this situation, which can cause serious damage in the cell, so anti parallel diode connected in series to bypass the current. Figure 7.2 and figure 7.4 shows how P-V and I-V curve will look like in this case.

Why we need to simulate PV array in partial shading condition because P-V curve had multiple local peak and a global peak, so MPPT should be good enough to track this global peak. So in partial shading condition I-V and P-V curve will give essential information for designing MPPT.

7.1 Modeling of partial shading phenomena in PV system

We can code or give a modeling approach to check partial shading effect in P-V and I-V curves, modeling is little bit easy. Modeling approach of PV system having following advantages

- Helps researchers to predict the effect of irradiation and temperature change in P-V and I-V curves.
- Different configuration can be check with its efficiency of PV system
- Different configuration can be check with different MPPT approach.

Two module output in shading condition

Two module is simulated in shading condition one is getting 1000 W/m^2 and other one is getting 100 W/m^2.Figure 7.2 and Figure 7.4 clearly shows how the I-V curve and P-V curve change respectively in partial shading condition.

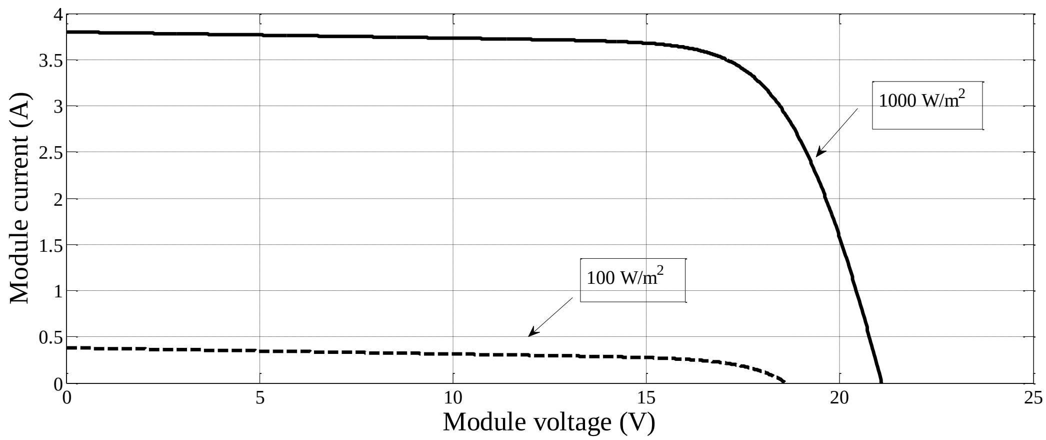

Figure 7.1 Module IV curves

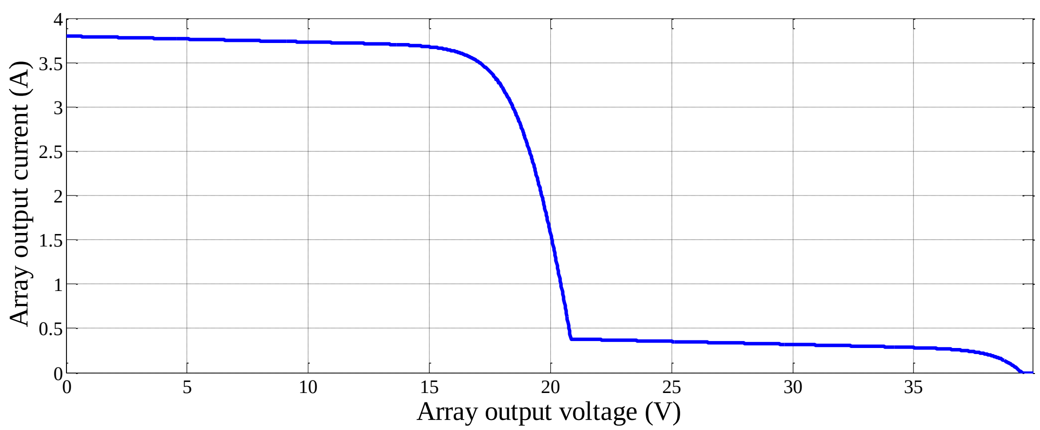

Figure 7.2:Array IV curve

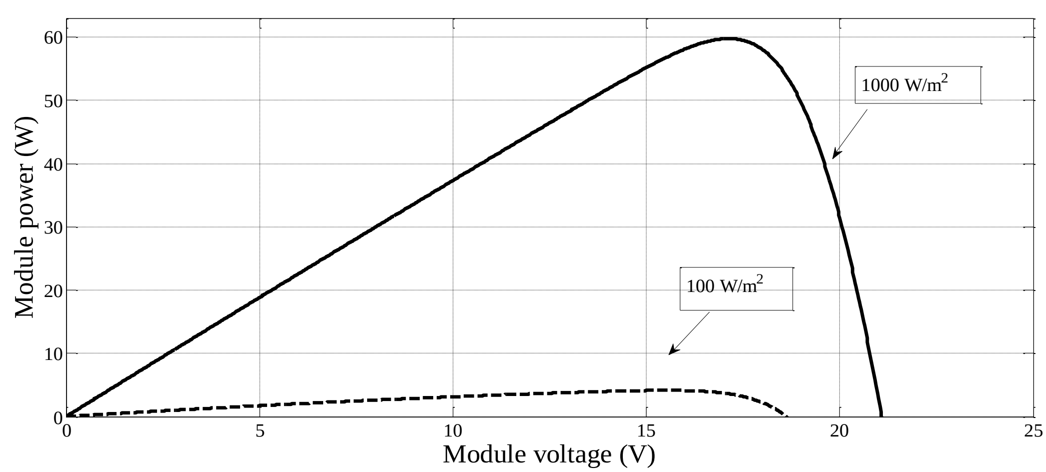

Figure 7.3: Module PV curves

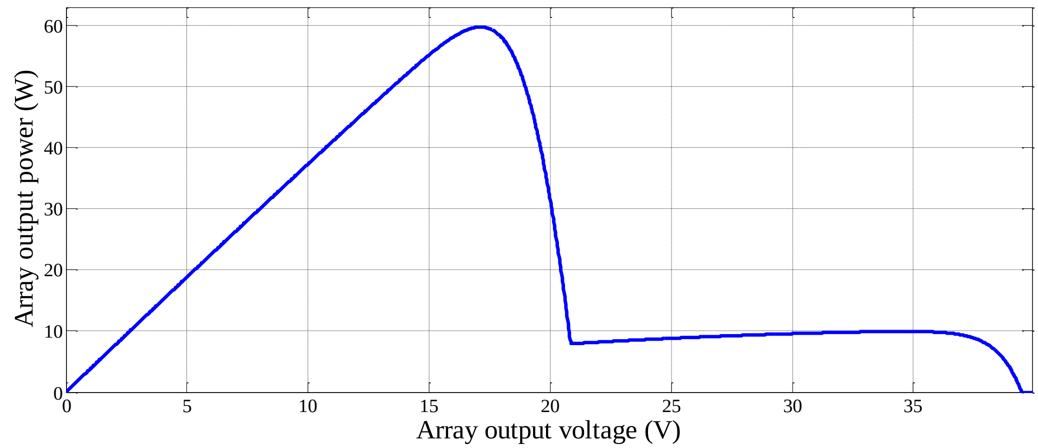

Figure 7.4: Array PV curve

Three modules in array in shading condition

Figure 7.5 shows three modules getting different irradiations, connected in series. How the output P-V and I-V curve affected by partial shading shown in figure 7.6.

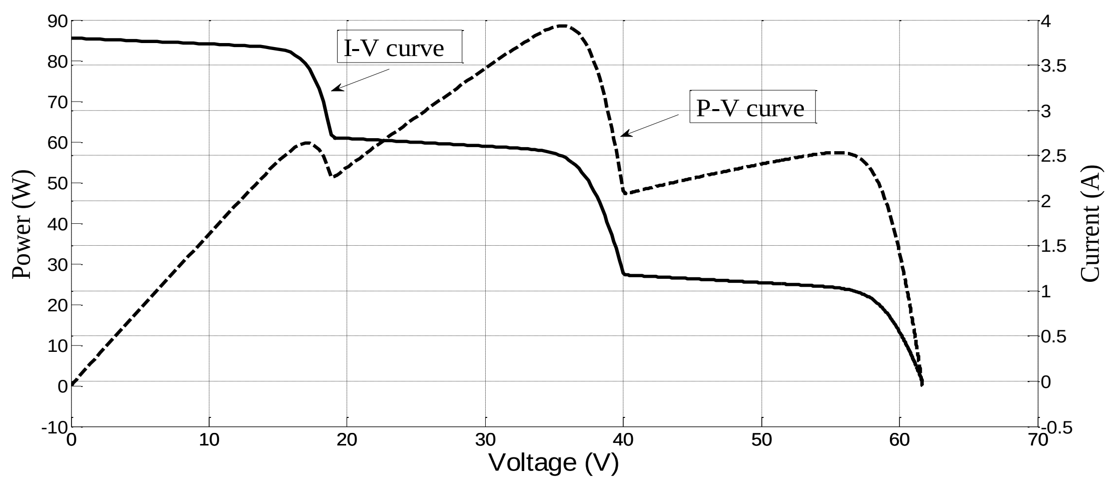

Figure 7.5: output P-V and I-V curve of PV array in shading condition for three modules

7.2 Analog implementation of MPPT

Control strategy

MPPT can perform in analog or digital both domains, analog domain is faster than digital domain because don't need I-V and P-V plot and cheaper also, partial shading occur instantaneous, so faster response of MPPT is require [18].

As MPP depends on temperature, noise, irradiation, aging and other factors, so we can write

$$\frac{dp}{dt} = \frac{\partial p}{\partial v}\frac{\partial v}{\partial t} + \frac{\partial p}{\partial \mu_1}\frac{\partial \mu_1}{\partial t} + \frac{\partial p}{\partial \mu_2}\frac{\partial \mu_2}{\partial t} + \cdots \text{.......... (7.1)}$$

Where μ_1, μ_2 are the noise terms. Neglecting the effect of noise In P-V curve for maximum power $\frac{\partial p}{\partial v} = 0$

Therefore

$$\frac{\partial p}{\partial v} = \begin{cases} > 0 & \text{if } v < V_{mpp} \\ = 0 & \text{if } v = V_{mpp} \\ < 0 & \text{if } v > V_{mpp} \end{cases} \text{......... (7.2)}$$

Where V_{mpp} is the voltage where power is maximum.

So when $\frac{\partial p}{\partial v} > 0$ and $v < V_{mpp}$ voltage should increase to achieve V_{mpp}, if $\frac{\partial p}{\partial v}$ =0 and $v = V_{mpp}$ voltage should operate in same point and $\frac{\partial p}{\partial v} < 0$ and $v > V_{mpp}$, decrease the voltage.

$$\frac{\partial v}{\partial t} = \begin{cases} > 0 & \text{if } v < V_{mpp} \\ = 0 & \text{if } v = V_{mpp} \\ < 0 & \text{if } v > V_{mpp} \end{cases} \text{............ (7.3)}$$

According to equation 7.3, obvious control strategy $\dot{v} = -k(v - V_{mpp})$ where k is a positive coefficient, associated with speed of controller. From equation 7.2 and 7.3 we can write $\dot{v} = -k\frac{\partial p}{\partial v}$, to implement this we need $\frac{\partial p}{\partial v}$,we have equation 7.1 after neglecting noise term $\frac{\partial p}{\partial v} = \frac{\partial p}{\partial v}\frac{\partial v}{\partial t} = \frac{\dot{p}}{\dot{v}}$ and $\dot{v} = k\frac{\dot{p}}{\dot{v}}$,but this is very though to implement because $\dot{v}$ appear in denominator and at $v = V_{mpp}$, $\dot{v} = 0$, singularity occur. If we make $\dot{v}^2$=0 we may lose vital information related to sign.

We can use signum function sgn x= -1 if x<0, 0 if x=0 and1 if x>0,sgn ($\dot{v}$)←sgn $\left(\frac{\dot{p}}{\dot{v}}\right)$ where ← denotes RHS of equation gives information to LHS but x=0 again creates problem and we can write if x≥0 so sgn x=1 and to avoid division we use sgn ($\dot{v}$) ← sgn ($\dot{p}$) sgn ($\dot{v}$)

Practical implementation

Power will get through simple multiplication of current and voltage p = v i and and $\dot{v}$, $\dot{p}$ will get through differentiator, after that comparator to compare the condition and Boolean expression use to execute by XOR gate. High frequency can damage the switch to control that D flip flop is used.

Table 7.1 Principle of operation of controller

			Comparator output				
Condition	$\dot{p}$	$\dot{v}$	X_p	X_v	S	Switch	v
$v \leq V_{mpp}$	> 0	> 0	1	1	0	Opens	Increase
$v \leq V_{mpp}$	≤ 0	≤ 0	0	0	0	Opens	Increase
$v > V_{mpp}$	> 0	>0	1	0	1	Closes	Decrease
$v > V_{mpp}$	≤ 0	≤ 0	0	1	1	Closes	Decrease

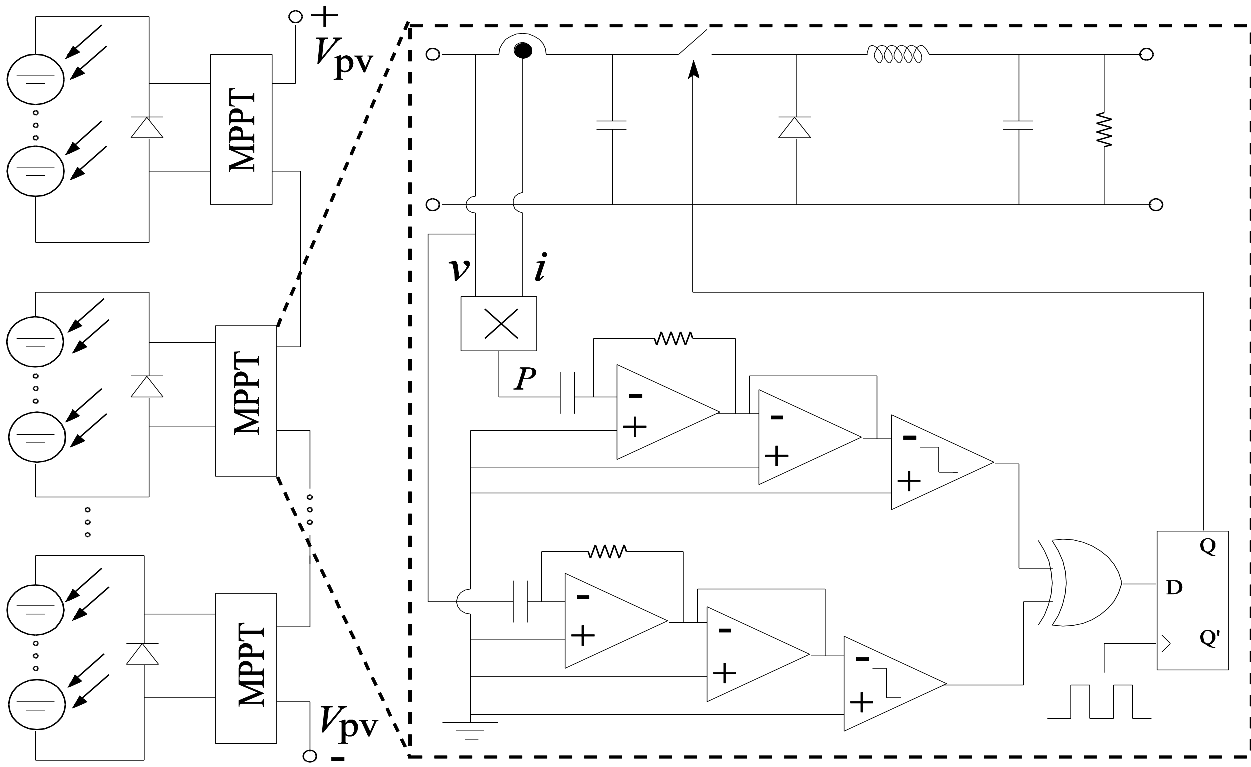

Figure 7.6: Analog implementation of MPPT

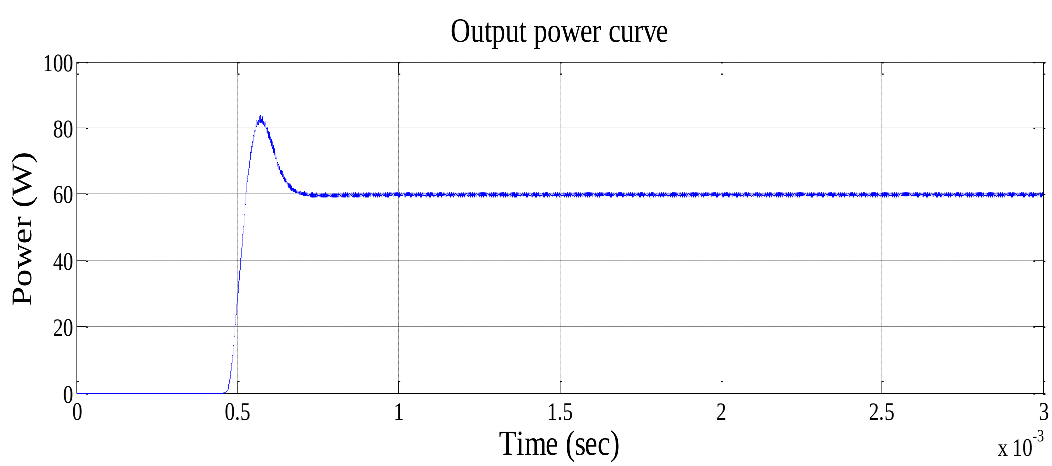

Figure 7.7: Power output curve in partial shading condition

CHAPTER 8

Conclusion

8.1. Summary

There are many MPPT techniques available in both digital and analog domains. Although the INC method reported earlier has proved it's important, still it is unable to track maximum power under partial shading condition.

In partial shading condition array output P-V and I-V curve are drastically changed and there exist multiple local minima and one global maxima power point. In such situations, it is difficult to track the global maximum point. It is therefore necessary one to look for an intelligent solution, which cannot be solved by available MPPT controllers for partial shading conditions.

With his views, in this thesis, we propose a module integrated converters structures. This is achieved by using the self-controlled (implemented in analog domain) dedicated modular dc-dc converter architecture. The analog implementation of MPPT is easy, faster and cheaper. Moreover, in order to show its tracking performance, system has also been evaluated for different loading conditions.

8.2Future research directions

Battery is very much requires in stand- alone systems so study based on battery and varying load condition can study.

State space modelling of PV system has been done, stability analysis can be done controller may design based on modeling.

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