MODELLING AND SIMULATION OF A PHOTOVOLTAIC SYSTEM WITH MPPT CONTROLLER

Subhashis Mohanty (111EE0141)

Ganta Suresh (111EE0158)

Rabisankar Jena (111EE0245)

Department of Electrical Engineering,

National Institute of Technology, Rourkela

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A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelors of Technology in "Electrical Engineering"

By

Subhashis Mohanty (111EE0141)

Ganta Suresh (111EE0158)

Rabisankar Jena (111EE0245)

Under the Supervision of

Prof. Monalisa Pattnaik

Department of Electrical Engineering

National Institute of Technology, Rourkela

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the thesis entitled **"MODELLING AND SIMULATION OF A PHOTOVOLTAIC SYSTEM WITH MPPT CONTROLLER"** submitted by Subhashis Mohanty (111EE0141), Ganta Suresh (111EE0158) and Rabisankar Jena (111EE0245) in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge the content of this thesis has not been submitted to any other university/Institute for the award of any Degree.

DATE: (Dr. Monalisa Pattnaik)

PLACE: Rourkela Department of Electrical Engineering

NIT Rourkela

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DEDICATED TO

Our beloved family, friends & the almighty

ABSTRACT

Today with the growing demand for the Renewable energy, the demand for the PV power has been increased more due to its plenty of availability and easy controllability. The most important thing in the PV system designing is efficient conversion of solar energy into electrical energy and cost reduction.

This work proposes modelling and simulation of a photovoltaic system. In this work the utilization of a three-diode model of a PV solar cell using voltage controlled resistors is highlighted. This model also calculates the series and shunt resistance by efficient iterative method and simulates the effects of various parameters such as temperature, irradiance. To reduce simulation time, the input parameters are limited to few. Based on the available information from the PV module datasheet the developed model allows the user to predict PV cell's current-voltage and power-voltage characteristics curve by varying sunlight, cell temperature and series resistance value. To operate the panel at its maximum power point, Perturb and Observe algorithm is applied to generate the controlled gate pulse for the Boost converter. The characteristics curves obtained by the simulation of different models are matched with the data provided by manufacturers with respect to the changing values of above mentioned internal parameters.

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ABBREVIATIONS AND ACRONYMS

PV	Photovoltaic
DC	Direct Current
MOSFET	Metal Oxide Semiconductor Field Effect transistor
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
STP	Standard temperature and pressure
N-R	Newton Raphson

CHAPTER – 1

1.1 INTRODUCTION

Solar photovoltaic system is a source of renewable energy. It is an emerging alternative that can play a vital role in supplying electricity for long-term sustainability. Nowadays a major problem in the power sector to deal with is the rise in the power demand on daily basis but the failure of conventional energy sources to meet the demand alone. PV cells offer great potential as solar energy is abundant and cell operation is noiseless, and free from harmful emissions.

The major and traditional sources of electric power generation in India includes coal, petroleum, natural gas, and other fossil fuels etc. But in recent years non-conventional/ renewable sources like solar energy in electric power generation is gaining interest due to many reasons. In solar power generation, the PV modules used are very costly hence optimal use of solar power is essential. This mandates an accurate and appropriate design of PV systems prior to installation.

1.2 MOTIVATION OF PROJECT WORK

The amount of conventional resources is so limited that they are on the verge of end. More over the growing population of world necessitates huge amount of power to sustain on daily basis. The need of the hour is to search for alternative which can which can fulfil the requirements. Solar energy is one of the major available source of renewable energy but is underutilized till date. Optimal utilization of solar energy can contribute to meet the power demand and will be vital in avoiding energy crisis in future. So power generation through PV cell is highly encouraged but since the installation is costly it is necessary to ensure the optimum use of the energy. For this purpose PV cell modeling is done and optimization techniques are used to extract maximum power. Estimation of the non-linear I-V and P-V characteristics affects the accuracy of a simulation in the PV cell modeling. Design of PV cell along with DC-DC boost converter leads to practical implementation of the PV cell and the Maximum Power Point Tracking (MPPT) leads to an optimal utilization of the PV Power.

1.3 OBJECTIVE

- Mathematical modelling of a photovoltaic (PV) module using piece wise linear model whose design consists of 3 diodes connected in parallel with voltage controlled resistor R_1, R_2 , R_3 for their better performance over a small change over of voltage.
- Estimation the series (R_s) and shunt resistance (R_{sh}) by Newton Raphson iteration method for matching of maximum power and to observe the I-V characteristics during the variation of temperature and irradiation.
- Comparison of the results (Power vs Voltage) obtained at different temperature and irradiation level with other two models (Classical model & R_{sh} model).
- Design of DC-DC boost converter along with MPPT to ensure the optimal utilization of the PV module.

1.4 LITERATURE SURVEY

The research work over solar energy system is done by many researchers all around the globe. As the solar cell operate at very low efficiency and due to high cost of solar cell, so there is requirement of advanced control mechanism for increasing the efficiency and control over the output power from the solar cell. This research over advanced control mechanism is known as MPPT (Maximum power point tracking)

A comparative analysis of PV cells operation with the change of solar irradiation and temperature is done [1].

A basic mathematical modelling and simulation of a PV system in MATLAB/Simulink is done and its current vs voltage and power vs voltage characteristics is discussed [2].

To assess the effect of temperature and irradiation variation over PV cell's characteristic curve and effect of partial shading over the PV cell an approach is made for an accurate analytical modelling of a 2 diode PV cell [3].

Simulation of different PV cells and their comparison with the manufacturing datasheet is done for analysis of error [4].

Generalized photovoltaic modelling using MATLAB/Simulink is done and effect of partial shading over different MPPT techniques used for extracting maximum power from the system and optimized algorithms is studied [5].

The variation of peak points in power vs voltage characteristics in case of partial shading is shown in [6].

The theoretical and mathematical analysis of a single PV cell with the variation of temperature from STP is discussed in [7].

A comparative analysis of different maximum power point tracking (MPPT) at different solar irradiation to make the output power almost constant in all the cases is done [8].

The design of the boost converter in the area of photovoltaic power control with a tracking algorithm is given for maximum power extraction from the PV system [9].

Voltage regulation of photovoltaic array is studied and its small signal analysis and control design is done [10].

Simulation of different PV cells are done and their comparative and error analysis with the manufacturing datasheets is discussed [11].

The theory of operation of boost converter is discussed in [12].

1.5 ORGANIZATION OF THESIS

The thesis is organized as follows:

Chapter 1 makes a brief introduction about the requirement and growing demand of PV power generation and advantage of PV power generation over conventional power generation.

Chapter 2 gives a basic overview of solar cell modelling. This chapter includes the modelling of PV cells with 3 different models such as: Classical model, R_{sh} model, Proposed piecewise linear model.

Chapter 3 gives an introduction to Maximum Power Point Tracking (MPPT). Different MPPT methods used in PV power generation, implementation of Perturb and Observe (P&O) algorithm in this project work to operate PV cell at MPP are discussed.

In chapter 4, design and simulation of boost converter power circuit along with the PV cell and MPPT controller is discussed.

In chapter 5 the brief conclusion of the thesis is drawn and future scope of work are discussed.

CHAPTER – 2

2.1 Introduction to Photovoltaic system

The smallest block of PV system is termed as a PV cell. As a PV cell is capable of generating very small amount of current (around 30mA) and voltage (around 0.6V). So a PV module is designed with a number of series (for increasing voltage) and parallel (for increasing the current level) combination of PV cells and a PV panel with a series and parallel combination of PV arrays. This PV panel converts solar energy into electrical energy by using material having semiconductor properties. The arrangement is such that photo current is generated when light falls on the semiconductor crystal. Upon solar insolation electrons are emitted and when connected with load constitutes electric current.

Materials used for PV Cell: Mostly the solar cells are made of a thin layer of silicon which forms an electric field when light energy strikes the cell. The kind of silicon are used for PV cell are

1. Single crystalline silicon
2. Polycrystalline silicon

Now a days other kind of materials are used for PV cell which are

1. Gallium Arsenide (*GaAs*)
2. Cadmium Telluride (*CdTe*)
3. Copper Indium Diselenide ($CuInSe_2$)

2.2 PV CELL MODELLING

When a solar cell exposed to sun light then a current which is proportional to solar irradiation is generated. A simple ideal solar cell can be modelled in a circuit as a current source connected to a diode in parallel. As no cell is ideal so for accurate modeling there are shunt and series resistance connected as shown in fig 2.1. In this project work some of the existing model (classical model and R_{sh} and R_s model) with proposed model is designed in MATLAB/Simulink.

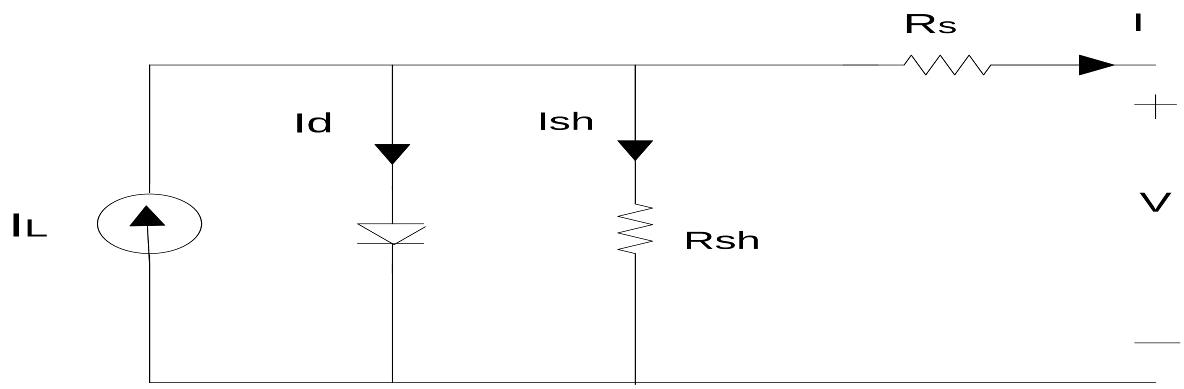

Fig. 2.1 Classical model of single PV cell

Then the mathematical equation for this model can be given as

$$I = I_L - I_d - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (2.2.1)$$

$$I_d = I_0\left[exp\left(\frac{q\times V}{A\times k\times T}\right) - 1\right] \quad (2.2.2)$$

Where

I_L- light emitted photo current

I_d - current through diode

I_o - reverse saturation current of the diode

V - Diode voltage (V)

T - Temperature (K)

k - 1.380658×10^{23} (Boltzmann constant [J/K])

q - 1.6×10^{-19} Charge of electron

A- Diode ideality factor

2.3 R_{sh} Model

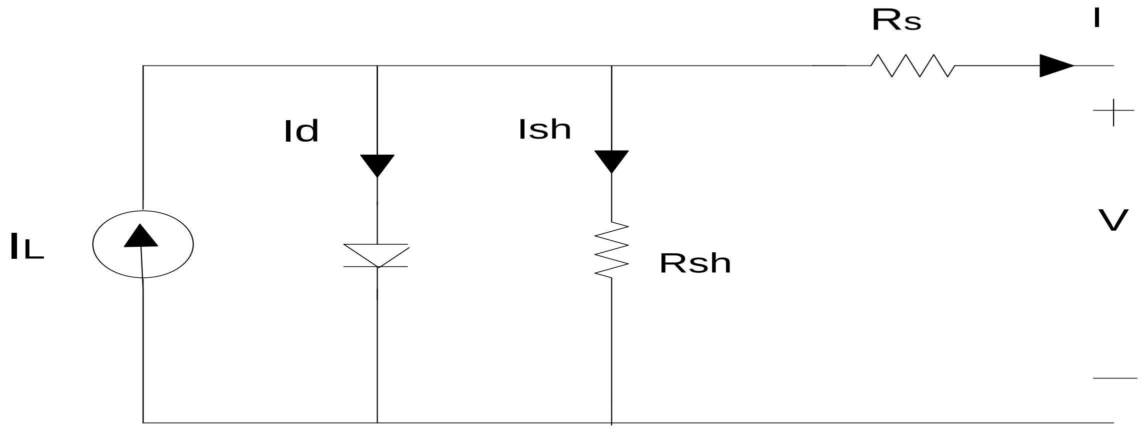

Fig. 2.2 R_{sh} Model of PV cell

Same method of finding load current and diode current as in classical model but however R_{sh} & R_s are determined by the Newton Raphson method.

$$R_{sh} = \frac{V_{max}(V_{max}+I_{max}R_s)}{[V_{mp}\{I_L-I_d\}-P_{max}]} \quad (2.3.1)$$

With initial condition

$$R_{sh} = (\frac{V_{max}}{I_{sc}-I_{max}})-(\frac{V_{oc}-V_{max}}{I_{max}}) \quad (2.3.2)$$

And $R_s=0$ (2.3.3)

Where

V_{max} - Voltage at maximum power

I_{max} - Current at maximum power

I_{sc} - Short circuit current

V_{oc} - Open circuit voltage

The advantages of R_{sh} and R_s model over classical model is matching of R_{sh} and R_s for maximum power output by iterative method. So, to have a more accurate model, those parameters can be calculated at a time, using the datasheet information which is open circuit voltage, maximum power, and short circuit current. Newton-Raphson algorithm is used to calculate these parameters and they are computed, from equation (2.3.1). Newton-Raphson algorithm has the better and a quick convergence with initial values near the root, as given in equation (2.3.2). So, within a few iteration steps a good solution of R_{sh} in function of R_s in equation (2.3.1) is computed until the maximum experimental power and voltage values coincides with the (P_{max}, V_{max}) datasheet values of different module.

2.4 Proposed PV Modelling

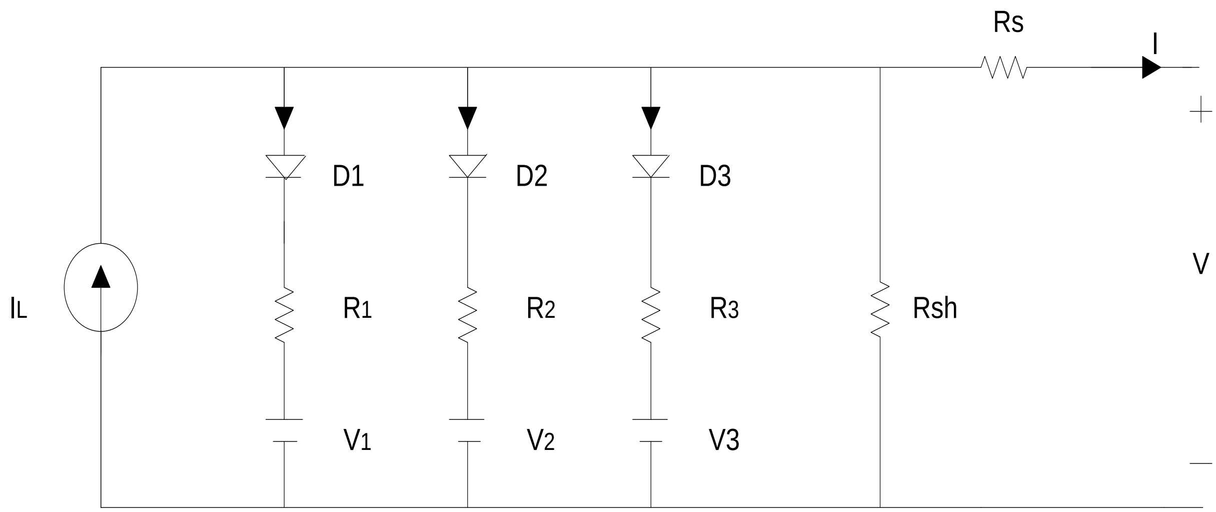

Fig. 2.3 Proposed model of PV cell

So from the above circuit the mathematical equation for this becomes

$$I = I_L - I_{d1} - I_{d2} - I_{d3} - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (2.4.1)$$

Where

I_{d1} - current through diode1

I_{d2} - current through diode2

I_{d3} - current through diode 3

Voltage controlled resister are used in series with diodes gives control over power (To keep power constant) near at the maximum power point voltage (V_{max}) even if there is little change in voltage near at Vmax (here it is done between .9V_{max} to 1.1 V_{max} with 0.1 V_{max} interval) by suitable switching ON and OFF of the diodes connected in parallel rather than switching of all the diodes at the same time. The detailed analysis of switching ON and OFF of the diodes connected in parallel and determination of the value of the voltage controlled register are given below. The switching voltages are taken at V1= 0.9V_{max}, V2= V_{max}, V3=1.1V_{max}.

Interval 1*:* (V_D < V_1)

(V_1 = 0.9 V_{max}). When the generated voltage from the PV panel is less than V_1, then all the diodes are in OFF state, and there will be no flow of current through those diodes, So all the light generated current from the PV panel will flow through the load and a very small portion of the I_L will pass through the shunt resistance R_{sh}, that's why the current is almost remains constant in this interval

Interval 2*:* (V_1 < V_D < V_2)

In this case diode D_1 will be ON and the value of PV current fails from I_L to I_L-I_{d1}

R_1 is given in the following equation (2.4.2):

$$R_{1} = \frac{V_{max}-0.9V_{max}}{I_{d1}} \tag{2.4.2}$$

Interval 3*:* (V_2 < V_D < V_3)

Diodes D_1 and D_2 are ON.

The current passing through diode D_1 is given by the equation (2.4.3):

$$I_{d1} = \frac{1.1V_{max}-.9V_{max}}{R_1} \tag{2.4.3}$$

The current passing through the diode D2 becomes:

$$I_{d2} = I_d - I_{d1} - I \tag{2.4.4}$$

R_2 is computed as follows

$$R_2 = \frac{1.1V_{max}-V_{max}}{I_{d2}} \tag{2.4.5}$$

Interval 4*:* (V_3 < V_D < V_{OC})

In this case all the three diodes will be turned ON and the current passing through the load will be zero at V_{oc}. The current passing through the diode D_1 is given in the equation (2.4.6)

$$I_{d1} = \frac{V_{oc} - 1.1\, V_{max}}{R_1} \tag{2.4.6}$$

Similarly the current passing through the diode D_2 is given as:

$$I_{d2} = \frac{V_{oc} - 1.1 V_{max}}{R_2} \tag{2.4.7}$$

In the same way current passing diode D3 is given by:

$$I_{D3} = I_L - I_{d1} - I_{d2} - I \tag{2.4.8}$$

In this proposed model both R_{sh} and R_s are calculated simultaneously by Newton – Raphson iteration method similar to the procedure proposed given in equation [2.3-1, 2, 3].

2.5 SIMULATION RESULT

The Classical model, R_{sh} model, proposed piece wise linear model are designed in MATLAB/Simulink for different model and their comparative study is given below.

2.5.1 At different temperatures

I-V and P-V characteristics are shown in Fig 2.4 and Fig 2.5 for various models at temperature 25^0c and 50^0c and the variation is observed.

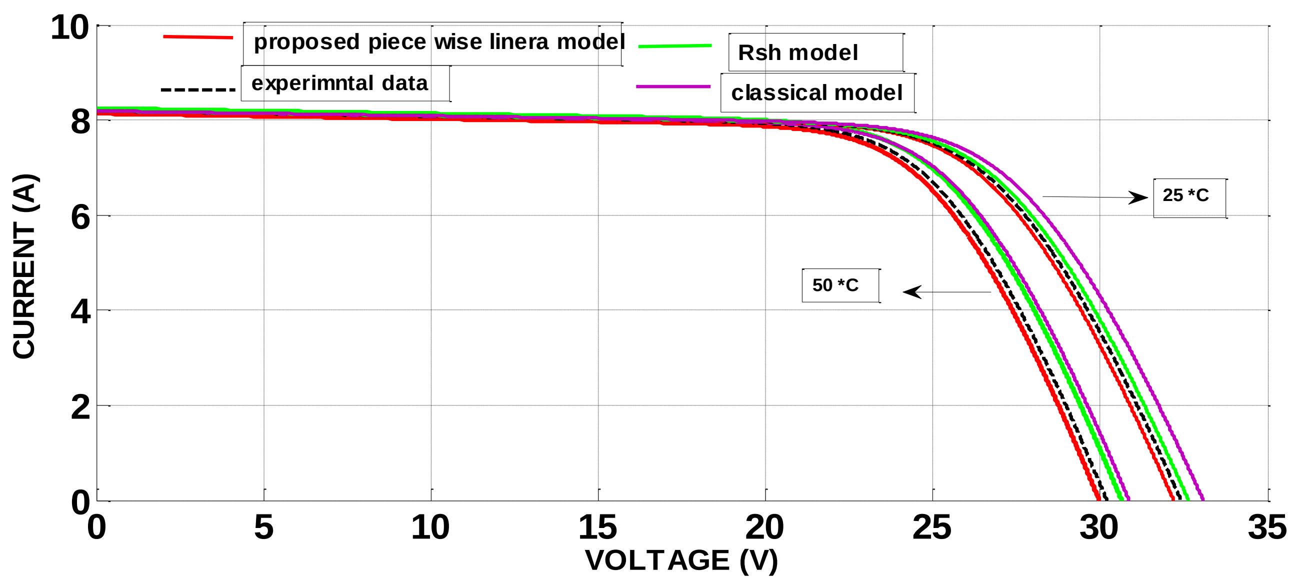

Fig. 2.4 Current-Voltage characteristics of PV module at different temperature

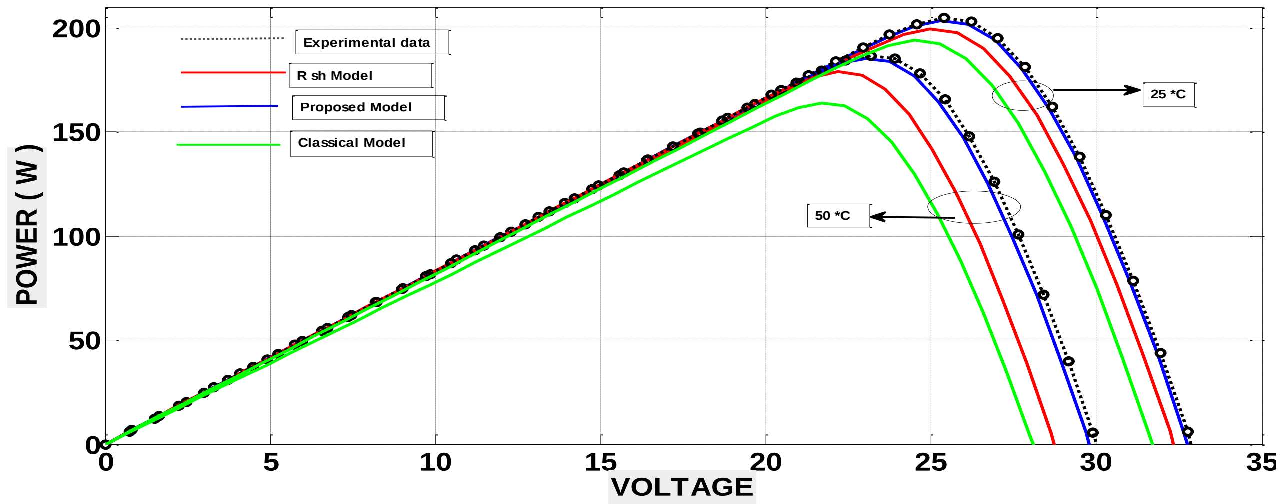

Fig. 2.5 Power-Voltage characteristics of PV module at different temperature

From the above I-V and P-V characteristics of different models (classical, R_{sh} and proposed model) at different temperature, the proposed model has its characteristics very much close to the plot obtained from the manufacturing datasheet.

2.5.2 At different irradiation

I-V and P-V characteristics are shown in Fig 2.6 and Fig 2.7 for various models at irradiation 800W/m^2 and 1000W/m^2 and the variation is observed. The legends used in above figure is also applicable here.

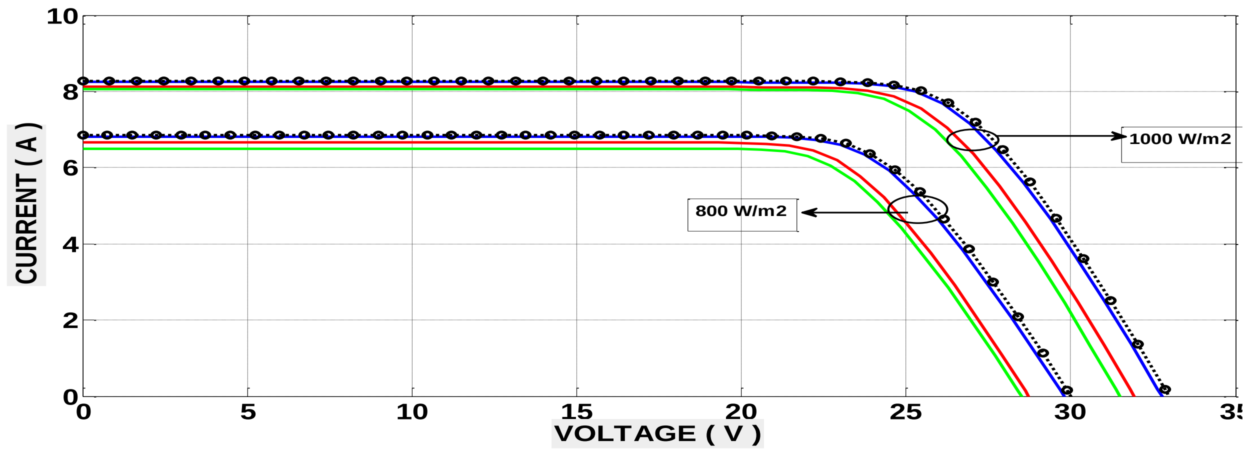

Fig. 2.6 Current vs Voltage Characterstics of PV module at different irradiation

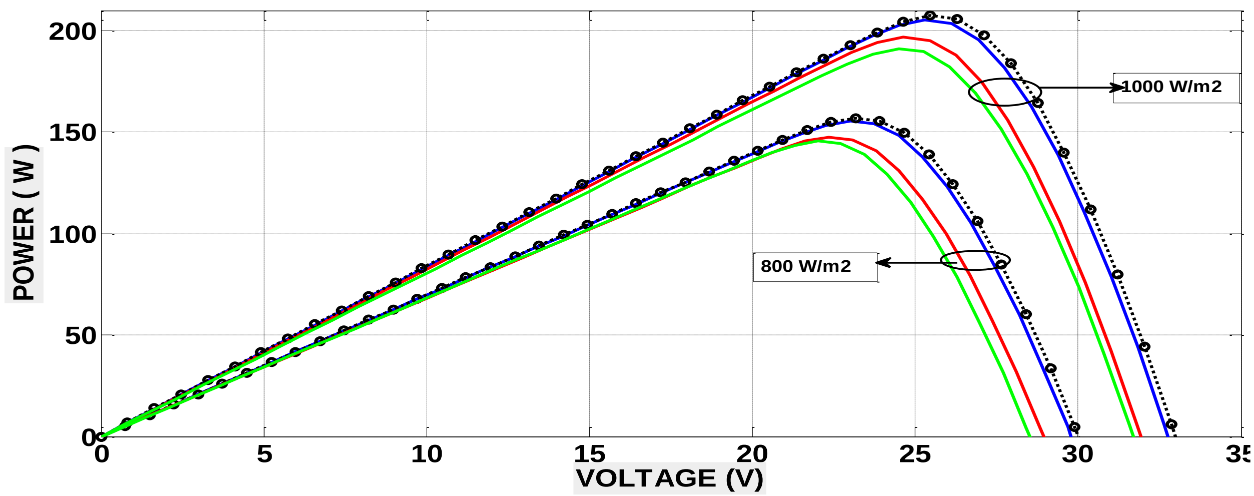

Fig. 2.7 Power vs Voltage Characteristics of PV module at different irradiation

From the above I-V and P-V characteristics of different models (classical, R_{sh} and proposed model) at different irradiation, the proposed model has its characteristics very much close to the plot obtained from the manufacturing datasheet.

- At low temperature the classical model furnishes desired results but considerable amount of error is introduced as temperature and insolation increases.
- The shunt resistance model provides better results than the classical model as approximation is done by Newton Raphson method but it is also not satisfactory for higher temperature and insolation period.
- The three diode model furnishes efficient results with considerable accuracy overcoming the limitations of first two models.
- As insolation increases current, voltage and corresponding power output increases.
- As temperature increases current increases a bit but voltage decreases significantly resulting in decrease in power output.

2.5.3 Relative error in power w.r.t. temperature

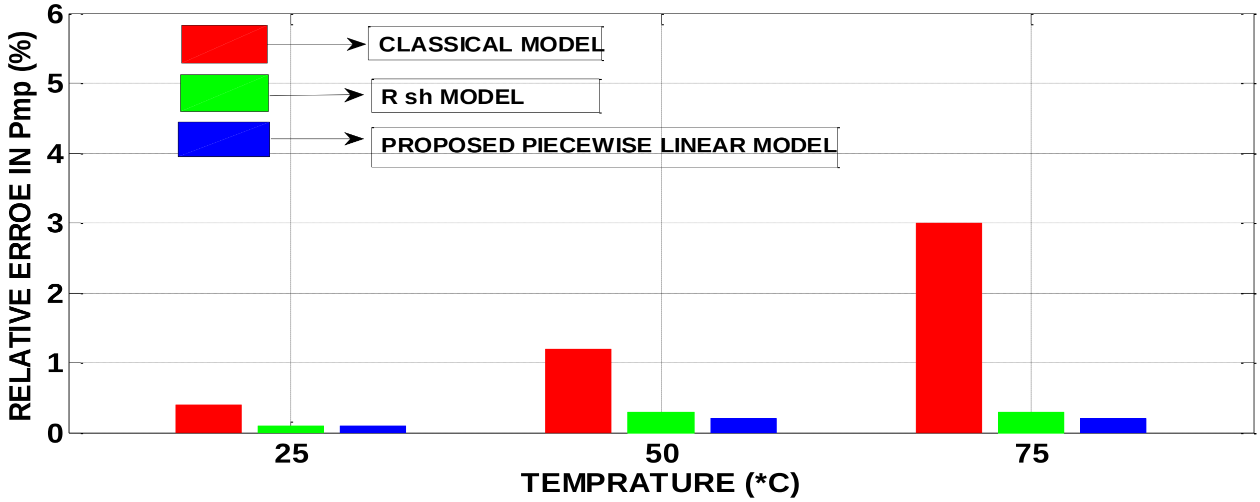

Fig. 2.8 Relative error in power w.r.t. temperature

The relative error in power output of the three models with respect to temperature are plotted in Fig 2.8 and it is observed that the proposed three diode model shows less deviation from datasheet values at higher temperature.

2.5.4 Relative error in V_{oc} w.r.t. temperature

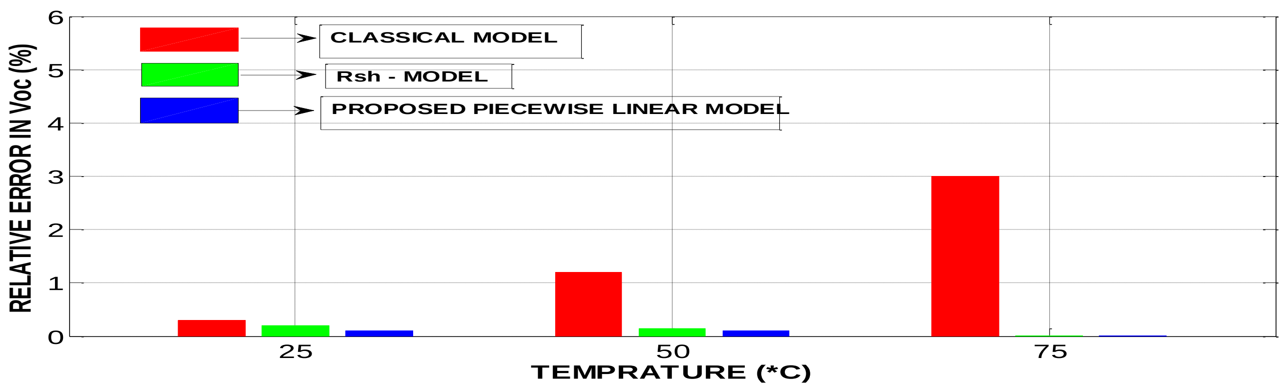

Fig. 2.9 Relative error in V_{oc} w.r.t. temperature

The relative error in open circuit voltage of the three models with respect to temperature are plotted in Fig 2.9 and it is observed that the proposed three diode model shows less deviation from datasheet values at higher temperature.

CHAPTER – 3

3.1 Introduction to Maximum Power Point Tracking

PV installations are costly. So it is desired to extract maximum power for optimal utilization of panel. Solar insolation and temperature vary at every instant of a day. The objective is to find out the voltage that corresponds to maximum power output for different irradiation and temperature. When solar panel is installed without any optimization technique it leads to wastage of power. The solar irradiation varies frequently which restricts optimum use of solar panel. So Maximum Power Point Tracking (MPPT) technique is implemented to extract maximum power from the panel at all instants. The objective of this technique is to find out the panel operating voltage that corresponds to extraction of maximum power at the load. MPPT, is an electronic arrangement to track the voltage (VMPP) or current (IMPP) routinely for operation of PV panel should in order to achieve the maximum power output (PMPP) when environmental condition changes rapidly.

Some desired features of MPPT are mentioned below.

`• Low cost.

• Easy implementation.

• For dynamic analysis, tracking there must be rapid tracking response.

• Correctness and no oscillation around the MPP are needed for steady state analysis.

• For solar radiation and temperature varying over wide range, the MPPT must be capable of tracking the MPP.

3.2 Types of MPPT Techniques:

Nowadays, several methods are used to track maximum power point. They can be distinguished on the basis of complexity, efficiency and cost. Some algorithms are listed below:

i. Perturb and Observe (P &O)
ii. Incremental conductance
iii. Fractional open circuit voltage
iv. Fractional short circuit current
v. Current sweep

vi. Maximum power point current and voltage computation

vii. Fuzzy logic control

viii. Neural networks

ix. State based MPP tracking technique

Out of all the above techniques, Perturb and observe (P & O) algorithm is used for simplicity.

3.3 Perturb and Observe Algorithm

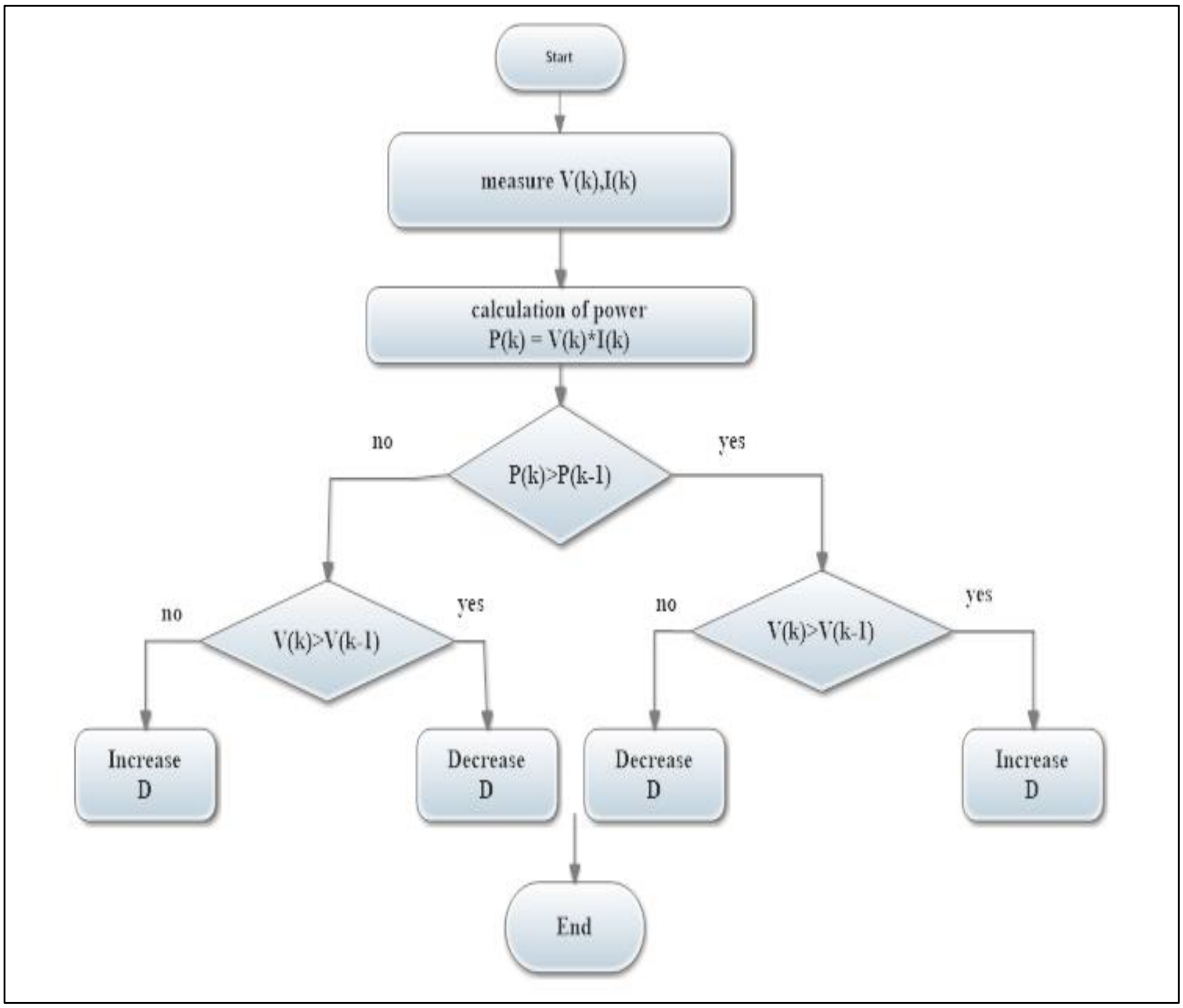

Fig. 3.1 P&O Flowchart

Table 3.1 Result of Different Models at 25°C and 1000 W/m²

Parameters	***PWL Model***	***R_{sh} Model***	***Classical Model***	***Manufacturer datasheet value***
P_{max} (W)	200.01	198.14	196.340	200.143
V_{max} (V)	26.28	26.27	26.24	26.3
I_{max} (A)	7.58	7.54	7.52	7.61
R_{sh} (Ω)	414.89	414.8	415.40	--
R_s (Ω)	0.245	0.245	0.221	--
R_1, R_2,,R_3(Ω)	7.12 ,3.13, 2.345	--	--	--

Table 3.2 Manufacturer datasheet values

Maximum Power (P_{max})	200.143W
Voltage at maximum Power (V_{max})	26.3V
Current at max Power (I_{max})	7.61A
Short circuit Current (I_{sc})	8.21A
Open circuit Voltage (V_{oc})	32.9V
Light emmitted Current (I_L)	8.23A

Chapter 4

4.1 DC-DC Converter

The output of PV module is low but in order to fulfil the load requirements converter is used. Since the output of PV cell is DC so DC-DC converter is used for this purpose. These converters are used to change the level of input voltage. The desired voltage is obtained at the output. The circuit uses capacitor, inductor and switch. The interface of converter with PV module is very essential so a good converter is required for that purpose. They serve as a charge controller in connecting MPP tracker and PV module with the load. Buck and boost converter are generally used in this field because of their structural simplicity. For our requirement boost converter is implemented in the project.

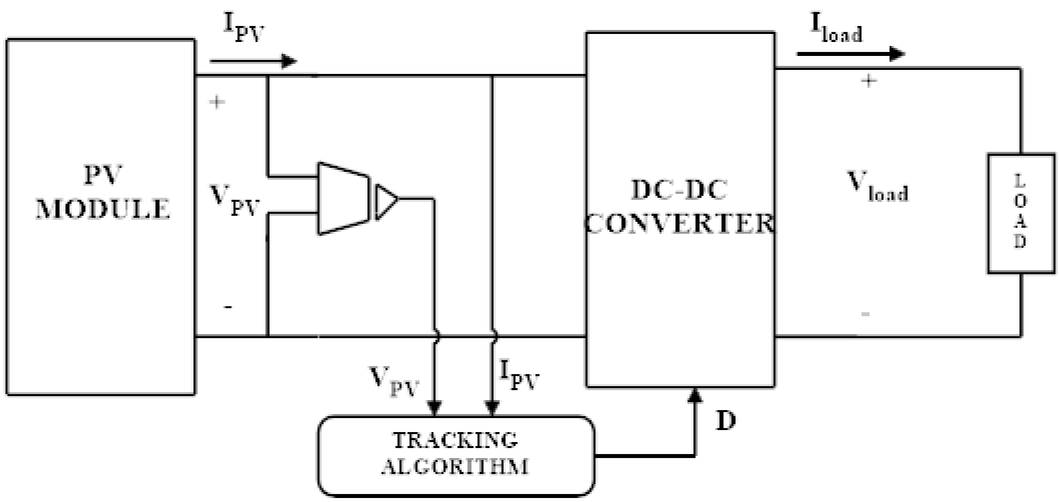

Fig. 4.1 Experimental setup of PV panel

4.2 Boost Converter

The boost converter is used to step up the voltage from lower level to higher level. It can be considered as a dc equivalent of transformer. The step up level is determined by the duty cycle of the converter. The MPP tracker controls the duty cycle of the converter and the duty cycle is varied using PWM generator through the controller. The converter consists of a switch, inductor, diode and capacitor. Besides a battery is used for DC supply and a suitable resistance is considered as load. The battery supplies dc power and the inductors stores the energy during on period. During off period it discharges and the voltage of inductor along with the source voltage appears across the load thus satisfying the step up operation. During on period the diode blocks the current but allows to flow through the load during off period. The output capacitor maintains the load current through discharging when the source current is short circuited through the switch. The output of the converter can be obtained across the load can be utilized as per requirement. The output voltage is given by:

$$V_o = V_{in}/(1 - D)$$

Where $V_{in}$the input voltage and D is the duty cycle.

4.3 Boost Converter Operation

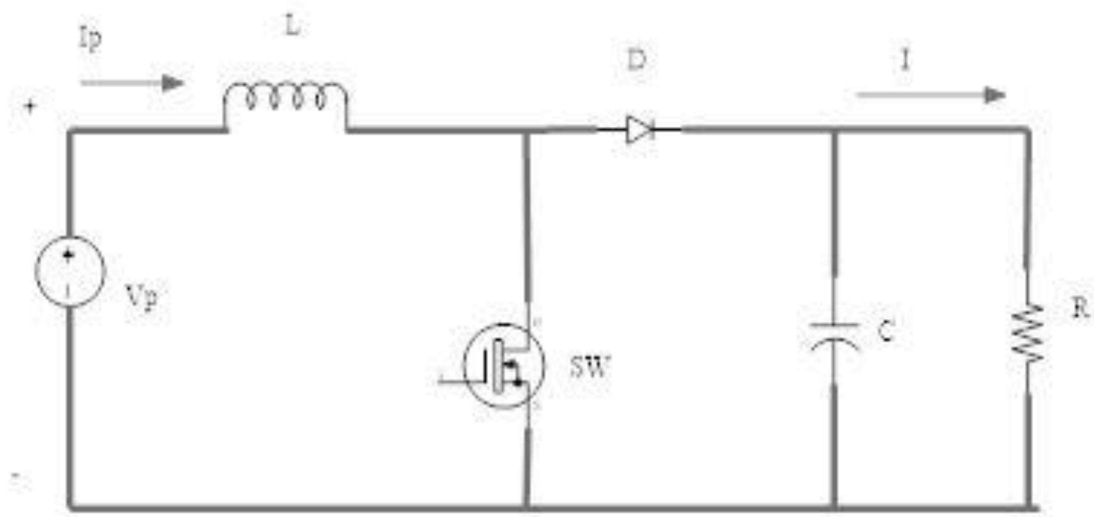

Fig. 4.2 Boost Converter

Thus depending upon the value of D the voltage will be stepped up. Here the boost converter is controlled by Time ratio control. Though the time ratio control can of constant as well as variable frequency for this purpose constant frequency operation is assumed. Again considering the on and off period there will be two modes of operation of the converter namely mode 1 operation and mode 2 operation.

4.3.1 Mode 1 Operation:

During on period i.e. when the switch in on the inductor gets charged and stores energy. The current does not pass through the diode to the load instead gets short circuited through the switch. During this time the capacitor gets discharged and maintains the load current. The current through the inductor rises exponentially. The circuit corresponding to mode 1 operation is shown below:

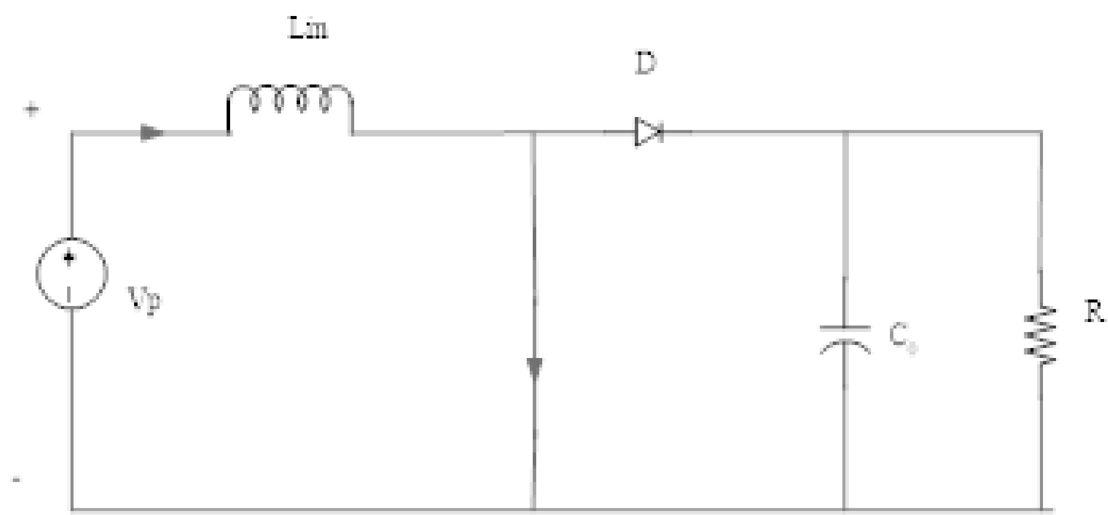

Fig. 4.3 Mode 1 Operation

4.3.2 Mode 2 Operation:

In this mode the switch is turned off and the polarity across the inductor reverses. The inductor starts discharging and current flows across the load though the diode. The voltage across the output will be the summation of input voltage and the voltage across the inductor. Thus stepped up voltage is obtained across the load. More over the capacitor is charged by the discharging of inductor and the load current remains constant throughout the entire process. The circuit corresponding to mode 2 operation is shown below:

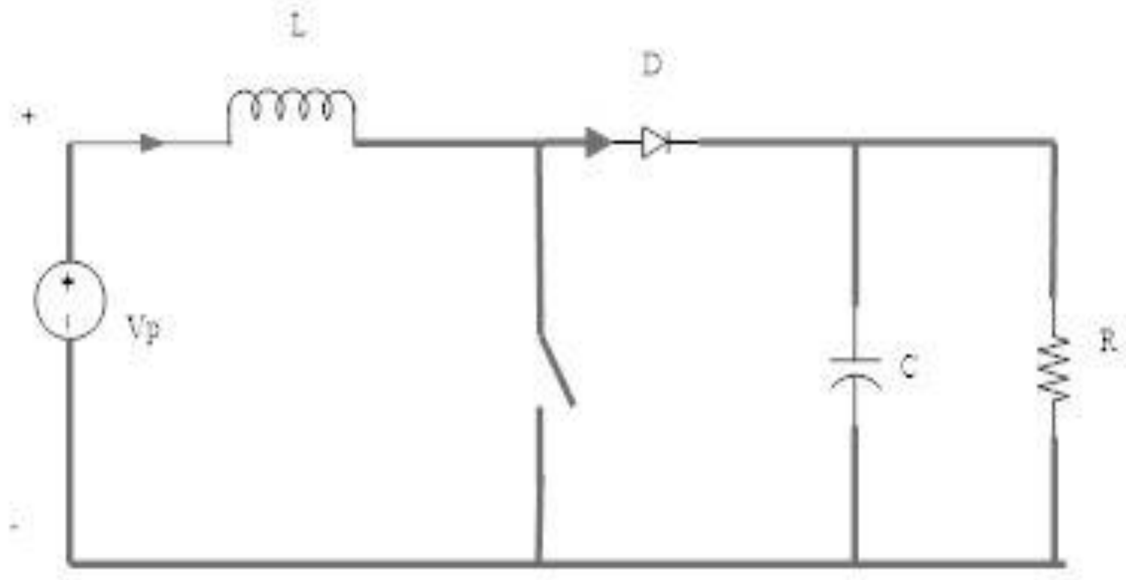

Fig. 4.4 Mode 2 Operation

4.4 Design of Boost Converter

The power circuit consists of the following components.

i) main switch
ii) diode
iii) inductor
iv) capacitor

Necessary calculations for each circuit element is given below:

Table 4.4.1 Boost Converter parameters

Sl.no	Parameter	Specification	Value
1	Input voltage	V_s	24 - 28V
2	Output voltage	V_o	50V
3	Output Power	P	200W
4	Output voltage ripple	V_r	1%
5	Input current peak ripple	ΔI_r	20%
6	Switching frequency	F_s	100 KHz

4.4.1 Inductor L:

The value of the inductor *L*, decides the peak input current which corresponds to withstanding capacity of the converter switches. More over this current determines the rating of other equipment's used in power circuit. Hence its value must be calculated first. The maximum current without ripple is

$$I_{in\_pk} = \frac{\sqrt{2}\frac{P}{\eta}}{V_s} = \frac{\sqrt{2}\,.\frac{200}{.95}}{26} = 11.45\text{A}$$

The maximum peak-peak ripple current is

$$\Delta I_r = I_{pk\_max}.\Delta\text{I} = 11.45 \times .2 = 2.29\text{A}$$

Hence the maximum peak input current with ripple is

$$I_{rpk\_max} = I_{pk\_max} + \frac{\Delta\text{I}_r}{2} = 11.45 + \frac{2.29}{2} = 12.59\text{A}$$

The duty cycle of the converter corresponding to maximum current is

$$D_p = 1 - \frac{\sqrt{2}V_{s\_min}}{V_o} = 1 - \frac{\sqrt{2}}{50} \times 26.3 = 0.25$$

The inductor value is calculated as follows

$$L = \frac{\sqrt{2}V_{s\_min}D_p}{\Delta\text{I}_r F_s} = \frac{\sqrt{2}\times 26.3\times 0.25}{2.29\times 100\times 10^3} = 40.6\mu\text{H}$$

4.4.2 Capacitor C:

The capacitor serves as an energy storage device. Energy is stored in the capacitor near the peak values of input voltage and current and it gets discharged in order to maintain the load current constant irrespective of the circuit conditions. The factor that plays vital role in capacitor selection is the ripple in the output voltage. The peak charging current of the capacitor is

$I_{chg\_pk} = \frac{P}{V_o} = \frac{250}{50} = 5\text{A}$

The voltage ripple across C is

$$V_{chg\_pk} = \frac{I_{chg\_pk}}{2.\pi.f_r.C}$$

$$C = \frac{I_{chg\_pk}}{2.\pi.f_r.V_{chg\_pk}} = \frac{5}{2 \times 3.14 \times 120 \times 0.01 \times 50} = .0132F$$

4.4.3 Diode:

The maximum voltage across the diode corresponds to the output voltage V_0=50V that appears across the diode when the main switch is conducting. The peak with ripple of the current flowing through inductor is also the peak current that flows through the diode.

The value is given by: $I_{rpk\_max} = 12.59\text{A}$

The average current flowing through the diode is:

$$I_{DI\_avg} = \frac{P}{V_o} = \frac{200}{50} = 4A$$

Chapter 5

5.1 Conclusion

This project presents simplified piecewise linear model for a PV solar panels suitable for power electronics simulation studies. In this thesis we have described how to estimate the parameters of KC-200GT and designed to operate at maximum power transfer by the MPPT controller. The obtained results prove the validity of the proposed model to simulate the PV with considerable accuracy under different operating conditions. Major conclusions are listed below.

- The MPPT technique uses P & O algorithm which is quite simple but fails under rapidly changing conditions of temperature and irradiation.
- For partial shading the proposed MPPT method is not sufficient and requires implementation of advanced MPPT techniques.
- In the open loop control of boost converter there is fluctuation in the output voltage.
- The switching loss of the converter depends on the switching frequency.

5.2 Future Work

- Implementation of advanced MPPT technique during partial shading.
- Design and implementation of hardware setup using Arduino DUE controller for the above project work.
- Use of PI controller for improvement in obtained results.

5.3 Reference

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