

# CONTENTS

	Page No.
List of Figures	i-ii
List of Tables	iii
Nomenclature	iv-v
<b>Chapter 1</b>	
<b>Introduction</b>	<b>1-3</b>
1.1 Energy Scenario	1
1.2 Overview of Photovoltaic's in India	2
1.3 Cell mismatch and Hot Spot Effect	2
1.4 Research objective	3
<b>Chapter 2</b>	
<b>Physics of Photovoltaic devices</b>	<b>4-15</b>
2.1 Introduction	4
2.2 Physics of solar cell	4
2.2.1 Semiconductor properties	4
2.2.2 Mobility of carriers	5
2.2.3 Photon Absorption	6
2.2.4 Recombination	7
2.2.5 P-n junction	8
2.2.6 Solar cell module	11
2.2.6.1 One-Diode Model	11
2.2.6.2 Two-Diode Model	12
2.2.7 Breakdown Mechanism	13
2.3 Solar Cell materials	14
2.4 Module Construction	15
<b>Chapter 3</b>	
<b>Literature Review</b>	<b>16-18</b>
3.1 Literature Review on Hot Spot due to Cell Mismatch	16

## **Chapter 4**

<b>Methodology</b>	<b>19-49</b>
4.1 Introduction	19
4.2 Hotspot Theory	19
4.2.1 Electrical Analysis	21
4.2.2 Thermal Analysis	22
4.3 Experimental Setup	23
4.3.1 STC	23
4.3.2 NOCT	26
4.3.3 Spi Sun simulator	27
4.3.4 IR Analyser	29
4.4 Experimental Procedure	32
4.5 Experimental Data	34
4.5.1 Data from Spi sun Simulator	34
4.5.1 IR analyser images of various PV module	42

## **Chapter 5**

<b>Result and Discussion</b>	<b>50-55</b>
5.1 Temperature profile for Multi Crystalline silicon PV module	50
5.2 Temperature profile for Mono Crystalline silicon PV module	52

## **Chapter 6**

<b>Conclusion and Future work</b>	<b>56</b>
<b>References</b>	<b>57</b>

## List of Figures

Figure No.	Title	Page No.
Figure: 1.1	Renewable energy share for global final energy consumption	1
Figure: 2.1	Energy bands introduced	5
Figure: 2.2	The Energy- Crystal Momentum diagram of absorption	6
Figure: 2.3	The Energy- Crystal Momentum diagram of radiative recombination	7
Figure: 2.4	Isolated p- and n- materials with respective energy-band structure	8
Figure: 2.5	The p-n junction structure with energy band diagram at thermal equilibrium	9
Figure: 2.6	The equivalent circuit of an ideal solar cell.	10
Figure: 2.7	The structure of a p-n solar diode.	11
Figure: 2.8	The equivalent circuit of a solar cell in a) dark and b) illuminated conditions	12
Figure: 2.9	The equivalent circuit of the two-diode model in a) dark and b) illuminated	13
Figure: 2.10	The equivalent circuit of one-diode model with additional breakdown voltage term	13
Figure: 2.11	Typical construction of a silicon PV module.	15
Figure: 4.1	Illustration of power dissipation due to $R_{sh}$ operation in reverse mode	21
Figure: 4.2	Solder melt in mc-Si at hot-spot site.	21
Figure: 4.3	Measurement of $I_{leakage}$ .	23
Figure: 4.4	Outlook of STC quick sun software	25
Figure: 4.5	NOCT field setup.	27
Figure: 4.6	Visual of Spi sun simulator software	29
Figure: 4.7	$I_{sc}$ vs cell no plot of C1	34
Figure: 4.8	$I_{sc}$ vs cell no plot of C2	35
Figure: 4.9	$I_{sc}$ vs cell no plot of C9	36
Figure: 4.10	$I_{sc}$ vs cell no plot of C10	37
Figure: 4.11	$I_{sc}$ vs cell no plot of C11	38
Figure: 4.12	$I_{sc}$ vs cell no plot of C12	39
Figure: 4.13	$I_{sc}$ vs cell no plot of C13	40
Figure: 4.14	$I_{sc}$ vs cell no plot of C14	41
Figure: 4.15	Thermal image of module C9	42
Figure: 4.16	Thermal image of module C10	43
Figure: 4.17	Thermal image of module C12	44
Figure: 4.18	Thermal image of module C6	45
Figure: 4.19	Thermal image of module C7	46
Figure: 4.20	Thermal image of module C11	47
Figure: 4.21	Thermal image of module C13	48
Figure: 4.22	Thermal image of module C14	49
Figure: 5.1	Showing variation of $\Delta T$ vs $\Delta I_{sc}$ for Multi C-Si in No Load condition	50

Figure: 5.2	Showing variation of $\Delta T$ vs $\Delta I_{sc}$ for Multi C-Si in full Load condition	51
Figure: 5.3	Showing variation of $\Delta T$ vs $\Delta I_{sc}$ for Mono C-Si in No load Condition	52
Figure: 5.4	Showing variation of $\Delta T$ vs $\Delta I_{sc}$ for Mono C-Si in full load Condition	53
Figure: 5.5	The effect of temperature on the IV characteristics of a solar cell	54

## List of tables

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
Table: 4.1	Specification of quick sun simulator	24
Table: 4.2	Specification of spi sun simulator	28
Table: 4.3	Specification of IR analyzer	29
Table: 4.4	Physical data of module c1	34
Table: 4.5	Physical data of module c2	35
Table: 4.6	Physical data of module c9	36
Table: 4.7	Physical data of module c10	37
Table: 4.8	Physical data of module c11	38
Table: 4.9	Physical data of module c12	39
Table: 4.10	Physical data of module c13	40
Table: 4.11	Physical data of module c14	41
Table: 4.12	Specifications module c9	42
Table: 4.13	Specifications of module c10	43
Table: 4.14	Specifications of module c12	44
Table: 4.15	Specifications of module c6	45
Table: 4.16	Specifications of module c7	46
Table: 4.17	Specifications of module c11	47
Table: 4.18	Specifications of module c13	48
Table: 4.19	Specifications of module c14	49
Table: 5.1	Data collected from NOCT for Multi C-Si (open)	50
Table: 5.2	Data collected from NOCT for Multi C-Si (Load)	51
Table: 5.3	Data collected from NOCT for Mono C-Si (open)	52
Table: 5.4	Data collected from NOCT for Mono C-Si (load)	53

## Nomenclature Used

$E_g$	Energy gap
$N(E)$	Density of states function
$E_F$	Fermi energy level
$eV$	Electron Volt
$E_D$	Donor energy level
$E_A$	Acceptor level
$h$	Planck's constant
$F$	frequency of the light
$\lambda$	wavelength
$\alpha$	Absorption coefficient
$E_{Fp}$	Fermi energy level for P type material
$E_{Fn}$	Fermi energy level for n type material
$V_D$	Diode voltage
$K$	Boltzmann's constant
$I_{diff}$	Diffusion current
$I_D$	Diode Current
$I_0$	Dark saturation current
$R_S$	Series resistance
$n$	Ideality factor
$V_{Br}$	Breakdown voltage
$R_{sh}$	Shunt resistance
$I_{ph}$	Photo generated current
$J_{leakage}$	Leakage current density
$I_{leakage}$	Leakage Current
$A_{hotspot}$	Area of hotspot
$I_{sc}$	Short circuit current
$V_{oc}$	Open circuit voltage
$P_{mpp}$	Maximum output
$I_{mpp}$	Current at $P_{mpp}$
$V_{mpp}$	Voltage at $P_{mpp}$
$FF$	Fill factor
eta	Efficiency

$P_{\max}$	Maximum power
$\Delta I_{sc}$	$I_{sc}$ difference
$\Delta T$	Temperature difference
$R^2$	Correlation factor