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An Investigation of Temperature Effects on Solar Photovoltaic Cells and Modules

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ABSTRACT

The solar photovoltaic (PV) systems are facing serious problems due to unavoidable losses in their system, leads to more deviation of output power from the input power level. This effect is known as a mismatch effect and is available in PV systems. Many losses are encountered in PV system and it is difficult to minimize such losses. In this paper, the influence of thermal effect on the solar PV system is considered and its influence on the performance of the operation, fill factor, open circuit voltage, and short circuit current, band gap level of various semiconductor materials, output power and efficiency are analyzed. The temperature effect of a solar PV cell, while connecting in a 36 cells in a module is analyzed for the various connection configurations like Simple Series configuration (SS), Series-Parallel configuration (SP), Total-Cross Tied configuration (TCT), Bridge-Linked configuration (BL), and Honey Comb configuration (HC) using MATLAB software. An increase in the level of temperature for various connection configurations, correspondingly decreases their open circuit voltage and series resistance. Shunt resistance and current are may not fully affected due to temperature. Finally, this problem creates a heating effect in the solar PV cell, so the life span of the photovoltaic panel is decreased gradually. While the temperature level increases, soldering points are affected and cell encapsulation is affects. Solar cell materials are changed their performance of operation, while there is a change in the band gap due to the effect of temperature.

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NOMENCLATURE

A_{pv}	Area of the photovoltaic cell/module	T_0	Atmosphere temperature (K)
C_{Tc}	Temperature co-efficient = 1 to 3	T_s	Solar temperature (K)
$E_g(T)$	Band gap level at specified temperature (K)	T_c, T_{stc}, T_{cell}	Cell temperature(K)
$E_g(0)$	Band gap level at atmospheric temperature (K)	T_{min}	Expected minimum-daily cell temperature (K)
E_{G0}	Band gap level at 0 K	T_{NOCT}	Nominal operating cell temperature (K)
E_{g0}	Band gap level at atmosphere temperature (eV)	V_m	Voltage at maximum level (V)
FF	Fill factor	V_{oc}	Open circuit voltage (V)
G	Solar irradiation (Wm^{-2})	v_{oc}	Open circuit voltage normalized to the thermal voltage (V)
G_0	Solar irradiation at atmospheric conditions (Wm^{-2})	$V_{oc}(T)$	Open circuit voltage at operating temperature (V)
G_{inc}	Incident Solar Irradiance (Wm^{-2})	$V_{oc}(T_0)$	Open circuit voltage at atmosphere conditions (V)
G_T	Solar irradiation (Wm^{-2})	V_{max_oc}	Open circuit voltage at minimum cell temperature (V)
$h(w)$	Heat transfer coefficient under the account of Wind velocity	V_{oc_stc}	Open circuit voltage at STC (V)
$h(1)$	Heat transfer coefficient under air flow level is $1\ m/s$	V_c	Output voltage (V)
I	PV module output current at (G, T) conditions.	***Greek Symbols***	
I_L	Light generated current (A)	ΔT	Temperature Difference (K)
I_m	Electric current at maximum level (A)	γ_v	Voltage temperature co-efficient
I_{ph}	Photo current (A)	λ	Solar irradiation intensity (kW/m^2)

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I_s	Diode saturation current (A)	α_1, β_1	Co-efficient of photovoltaic cell materials
I_0	PV module output current at (G_0, T_0) conditions	α, β, δ	Temperature and Solar irradiance correction factor
$I_0(T)$	Reverse saturation current dependent on temperature(A)	η	Efficiency of a photovoltaic cell
I_c	Output current (A)	**Subscripts**	
I_{sc}	Short circuit current (A)	oc	Open circuit
k	Boltzmann constant	oc_stc	Open circuit under standard test conditions
k_1	Constant with respect to temperature	max_oc	Maximum under open circuit
$NOCT$	Normal Operating Cell Temperature (K)	stc	Standard test conditions
n	Ideality factor	sh	Shunt
N_{cp}	Number of PV cells in parallel connection	s	Series
N_{cs}	Number of PV cells in series connection	ir	irradiance
P	Output power (W)	λ	conductive resistance
P_{elect}	Electrical power output (W)	T	temperature
P_0	Output power at reference conditions (W)	o	output
P_T	Output power at temperature dependent(W)	elect	electrical
q	Charge of an electron (C)	inc	incident
R_λ	Conductive Resistance (kW^{-1})	g_0	Band gap at atmosphere temperature
R_s	Series resistance (Ω)	G_0	Band gap at 0 K
R_{sh}	Shunt Resistance (Ω)	Tc	Temperature co-efficient
S	Module area (m^2)	t	total
S_{ir}	Solar irradiance (Wm^{-2})	pv	photovoltaic
T	Operating Temperature (K)		
T_a	Ambient temperature (K)		

1. INTRODUCTION

In recent years, a handful of studies have conducted on PV cell with effect of temperature. Previously, the investigation on the different connection configurations of PV cell for the effect of temperature is diminutive. The maturity of thin-film technologies, width of the PV cell as minimum in construction. So, additional current can flow in the PV cell circuit, this current itself acts as a barrier in improving the PV cell performance and overall efficiency. The temperature available in PV cell as a result of electrical current sources flow in the circuit (internal effect), and solar irradiation sources will fall on surface layer (external effect) in a PV cell. It was used only 0.04% of total solar energy available on earth for human being, because of lagging in the energy conversion process of solar energy into PV energy/thermal processes and cost/Watt is high [1]. The calculation of current in a solar cell was depends on solar irradiation, cell temperature and temperature co-efficient. The dividable loads (load connected in series and parallel combinations) under changing of solar irradiance may possibly reduce the power loss in PV cell output. So, reducing the power loss and temperature effects on PV cell might be reduced [2].

The series resistance has incrased its value under high temperature level, with the variation in voltage. The shunt resistance value was high in the lower temperature range, i.e., vice versa of series resistance [3]. The problem of mismatch for joining in cell structure with the soldering effect, the excess of current flow, may be occurrs in the form of heat. Excess amount of heat formation have decreases the voltage and fill factor. At the lower range of temperature, PV cell may produce more amount of electrical power, a higher level of temperature inside a PV cell or module, part of the temperature used to convert the solar irradiation into electrical power and remaining will be removed in the form of excess heat. At higher temperature, two types of problems occurs either solar cell structure gets vibrate or the PV cell junction begins to break down its structure [4].

A simple non-destructive model was developed to measure the junction temperature, which gives the maximum error of $1.3^\circ C$ under estimation as compared with the general average surface temperature method of $4.3^\circ C$ [5]. The temperature variation in PV cell changes the value of performance characteristics like open circuit voltage (V_{oc}), fillfactor (FF), short circuit current (I_{sc}), efficiency (ή), reverse saturation current density (I_0) and semiconductor materials (Ge, Si, GaAs, InP, CdTe and CdS) are changes its function and performance. The increases in temperature level, the band gap of semiconductor material shrinks in that V_{oc}, FF and ή were decreases [6]. The prediction of uncertainity problem in long-term PV system estimated for solar radiation is 3% and temperature level in a PV cell also changes[7].

In general, it is difficult to reduce heat content or loss from the solar PV cell or module and to improve the electrical efficiency. Sometimes, absorbing the thermal heat into the solar PV module mainly depends on the type of load connecting to the power generating units. The thermal load particularly lower enthalpy load, connected to the photovoltaic module, needs more heat, so extract heat from the atmosphere or heat sink with the help of a heat pump. In the above, method loses the significance of electrical parameters [8].

The thermal resistance of silicon solar cell and junction temperature was calculated using Current Driving Method (CDM), and Light Illumination Method (LIM). The efficiency will drop from 14.6% to 10.1% when the junction temperature increases from $32.7^{\circ}C$ to $35.5^{\circ}C$[9]. The fixing of glass cover increases the thermal efficiency, where as unglassed cover system are higher in electrical and over all exergy efficiency. Thus, the temperature increases in a PVcell/module, which in turn decrease the electrical power generation [10].

Different PV cell interconnection configurations (SS, SP, TCT, BL and HC) have evaluated in comparision of the maximum power and fill factors of these connections configurations are carried out. Here, TCT produces the maximum power under partial shading conditions [11]. The effects of partial shading on energy output of different connection configurations of solar PV cell and reduction of this effect with the help of bypass diode are analyzed. MATLAB (M-code) and a generalized algorithm have developed for all the connection schemes [12]. The electrical characteristics of array interconnection schemes (SP, TCT and BL) are investigated through comparision of fresh cells and aged cells. The fresh cells had less redundancy and current, voltage and fill factor are higher [13].

In this paper, a detailed analysis has been carried out for SS, SP, TCT, BL and HC connection schemes under the influence of thermal effect. Based on the variation of the temperature on solar PV cell, the effect of series resistance, shunt resistance, fill factor, variation in voltage for the change of temperature, current values are identified. From this analysis, it is found that certain features of the connection configurations have remarkably affected, and other connections schemes are not affected with the temperature.

2. BASIC IDEAS AND GENERAL EQUATIONS

2. 1. Temperature Effects on Short Circuit Current When the temperature increases on PV cell, the I_{sc} also increases simultaneously. In this case, the band gap of PV cell shrinks (4 to 5.6x10^{-4} eV/deg [14]), so that more number of electrons could move easily from the valence band to the conduction band. Similar effects observed with increases in solar irradiation. The PV module output current (I) and voltage (V) can be predicted from the stnadard values of I-V curve and correction factors ($\alpha = -0.009^{\circ}C^{-1}$, δ= --0.0039, β = - 0.0028$^{\circ}C^{-1}$). The relationship expression is given by [15, 16]:

$$I(G,T) = I_0(G_0,T_0).\frac{G}{G_0}.[1+\alpha(T-T_0)] \quad (1)$$

$$V(G,T) = V_0(G_0,T_0)[1+\beta(T-T_0)]\left[1+\delta.\ln\left(\frac{G}{G_0}\right)\right] \quad (2)$$

The effect of temperature on PV cell under mismatched problem, the reverse saturation current increases logarithmically and changing of band gap level also, is given by the equation [17],:

$$I_0(T) = k_1.T^3 e^{\left(\frac{-E_{G0}}{kT}\right)} \quad (3)$$

2. 2. Temperature Effects on Open Circuit Voltage As the temperature increases the V_{oc} value decreases, because PV cell p-n junction voltage affects of changing the operating temperature and correspondingly the FF is decreased.The hotness of the PV cell, modify the V_{oc}, is given by [18],:

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_{ph}}{Is}+1\right) \quad (4)$$

The V_{oc} variation with related to the band gap level of a semiconductor material is given by [19],:

$$V_{oc}(T) = V_{oc}(T_0) - \left[\frac{E_{g0}}{q} - V_{oc}(T_0)\right]\left[\frac{T}{T_0}-1\right] - \frac{3kT}{q}\ln\frac{T}{T_0} \quad (5)$$

2. 3. Effect of Temperature on Output Power The effect of temperature on the efficiency of a PV cell may be varied due to changes in operating parameters, PV cell/module maximum voltage, maximum current, V_{oc}, I_{sc} and FF [8].

$$P_{elect} = I_m V_m = (FF) I_{sc} V_{oc} \quad (6)$$

The output power of a photovoltaic cell is related to the temperature of a solar cell, temperature co-efficient, and calibration constant is given by the relations [20-22] as shown in below,:

$$P = P_0[1+(\alpha-\beta)\Delta T] \quad (7)$$

where, $\alpha = 0.5mu$ per $^{\circ}C$ is temperature co-efficient and $\beta = 5mu$ per $^{\circ}C$ is calibration constant.

Simplifying the above equation,:

$$P = P_0[1-0.0045\Delta T] \quad (8)$$

Similarly,

$$P = (\alpha T_C + \beta)G_T \quad (9)$$

and

$$P_T = -8.6415 + 0.076128 G_T + 1.02318 x G_T^2 + 0.20178 T - 4.9886 x 10^{-3} T^2 \quad (10)$$

where, T is the panel temperature (K).

2. 4. Temperature Effect on PV Conversion Efficiency The accumulation of temperature in PV cell depends on various atmospheric conditions. The flow of current in the PV cell under different resistance of each cell may create temperature deviations within the module [23]**.** The temperature level reaches beyond the maximum point in solar cell, energy production efficiency was reduced in 1.1% of the peak. The dissipated heat energy may change the performance of the operation of a PV, decreases the V_{oc} and FF value. The heat developed inside the PV cell, reduces the band gap. The photocurrent in PV cell was increased, whenever an electron hole pair combination increases in the PV cell junction. Sometimes, the absorbed unwanted irradiation may diminish the PV cell encapsulation coating. The effects on temperature of PV cell will vary due to changes in a PV cell material. For crystalline silicon module-0.4% K^{-1}, a-Si module – 0.1% K^{-1} ranges the power output decreases [24].

2. 5. Temperature Related Equations for PV Cell In general, the influence of wind speed with the PV cell temperature will not be considered, up to the level of 100kW PV module capacity, either in free-mounted PV module or in rigid PV module, but it is a key parameter for estimating the cell temperature. The relationship of cell temperature with wind-speed impact on PV module is given by [14]:

$$T_{cell} = T_a + (NOCT - 20) \times \left[\frac{G_{inc}}{800}\right] \times \left[\frac{R_\lambda S + \frac{1}{h(w)}}{R_\lambda S + \frac{1}{h(1)}}\right] \quad (11)$$

The effect of cell temperature (T_c), due to change in solar irradiation intensity with ambient temperature can be considered as constant. The relationship is given by [25],:

$$T_c = T_a + \left(\frac{T_{NOCT} - 20}{0.8}\right)\lambda \quad (12)$$

2. 6. Temperature Effect on the Band Gap Level In direct band gap semiconductor material, the electrons fall off and to occupy an empty state of valence band, which releases the energy in terms of photons of light. However, in indirect band gap semiconductor, the electrons fall off and occupy an empty state of valence band which releases the thermal heat in the band gap of semiconductor material. The influence of thermal effects of the various PV cell material bandgap level changes due to variation in operating temperature level. For Ge, Si, InP, GaAs materials band gap level value with the effect of temperature is given in Table 1.

The variation of band gap with absolute temperature (T) is expressed by Thurmond C.D [26]

$$E_g(T) = E_g(0) - \frac{\alpha_1 \times T^2}{T + \beta_1} \quad (13)$$

The electrical conductivity of semiconductor materials mainly depends on the gap between valence band and conduction band. These band level may change with in the external or internal effect of temperature development. The single junction semiconductor materials, having GaAs is the maximum band gap level. Its band gap decreases from 1.3680eV to 1.3469eV when the temperature incrases from 325K to 400K (Table.1), and same problem will also arise on other semiconductor materials.

2. 7. Performance of the Cell as the Function of Temperature The part of solar radiation is available in the form of useful electrical energy, which depends on the properties of solar cell material, the remaining energy goes as heat. The influence of temperature and irradiance on series and parallel resistance are obtained using the iterative method [29]. The inside temperature of a solar cell is higher than the atmospheric temperature, under non- rejection of heat to the sink or the atmosphere. Based on the above process, performance of solar cell parameter changes dramatically. The reverse saturation current also raises for increasing manner of heating effect inside a solar cell. Besides the change of above parameters, the overall efficiency of a solar cell decreases its value. According to Landsberg, the efficiency limit of a solar cell is given by [37]:

$$\eta = 1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 \quad (14)$$

This gives the maximum limit of theoretical efficiency of solar PV devices, so increasing in temperature value, simultaneously efficiency of PV cell device decreases.

The efficiency of a PV cell is the ratio of the electrical power output of the solar irradiance input and area of PV cell, and is denoted by:

$$\eta = \frac{P_{elect}}{S_{ir} A_{pv}} \quad (15)$$

$$\eta = \frac{V_{oc} I_{sc} (FF)}{S_{ir} A_{pv}} \quad (16)$$

The electrical efficiency has been decreased , when the solar cell temperature increases on the PV module with change in time for both unglazed and glazed cover PV panel [29].

TABLE 1. Effect of temperature on semiconductor

Temperature (K)	Material/Band gap level Eg (ev)			
	Ge	Si	InP	GaAs
325	0.6080	1.0680	1.2980	1.3680
350	0.6012	1.0612	1.2912	1.3612
375	0.5942	1.0542	1.2842	1.3542
400	0.5869	1.0469	1.2792	1.3469

2. 8. Temperature Effect on Fill Factor The general expression, for determining the fill factor value, is given by [38]:

$$FF = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \quad (17)$$

The fill factor varies due to series resistance(R_s) and V_{oc}. The two parasitic resistance are offer to change their performance with the effect of temperature. The various electrical parameters are identified either in increases or decreases in their values. The influence of temperature for various electrical parameters are given in Table 2. When by increasing in temperature, the I_{sc}, R_s, maximum power current (I_{mp}) and diode saturation current (I_0) are increased and V_{oc}, FF, R_{sh}, maximum power voltage (V_{mp}), maximum power (P_m), , energy band gap (E_g) level of PV cell material, efficiency(η) are decreased.

3. INTERCONNECTION SCHEMES of SOLAR CELLS

3. 1. Different Interconnection Schemes The PV cells are interconnected to each other to form a new connection configurations. Each configurations is a combination of 36 cells. The current and voltage parameter are differs from normal series connections of PV cells. The effect of temperature on PV cell affects the performance of operation, when connecting SS and SP connection configurations.

However, in TCT, BL and HC interconnection configurations schemes decrease the impact of temperature on PV cell. These methods are most suitable for abnormal conditions like shadow effect, mismatch effect, environmental effects and internal temperature effect.

A simple series (SS) connection scheme current will be the same and voltage as boost up, as to be seen in Figure 1(a). Figure 1(b) shows a series-parallel (SP) connection scheme, voltage will be maintained constant and current value can be increased in additive manner of branch currents. Figure 1(c) shows a TCT connection scheme, it is a derived version of series-parallel combination. In this scheme, build up voltage may be low as compared with current value. The main advantage of this method is that it may eliminate the problems due to shadowing, manufacturing tolerances of solar cell inter connections and it is a high reliability scheme. Figure 1(d) shows the BL connection scheme and it is making of connection with alterations of TCT scheme.

TABLE 2. Temperature effects on PV cell performance

T (K)	Photovoltaic cell parameters										
	V_{oc} (V)	$V_{mp}(V)$	I_{sc} (A)	$I_{mp}(A)$	$P_m(W)$	FF	R_{sh} (Ω)	R_s (Ω)	$I_0(A)$	$E_g(V)$	η(%)
Increases	Decreases (0.38%/°C)	Decreases (0.49%/°C)	Almost Remains constant	Increases	Decreases 0.4-0.6% °C	Decreases	Decreases	Increases	Increases	Decreases	Decreases (0.53%/°C)
References	[27, 29, 32, 33, 36]	[29]	[28, 29, 32]	[17, 29]	,34 ,29] [35	[29, 32, 33]	[31]	[31]	[17]	[28]	[27-30]

TABLE 3. Effect of temperature on different connection configurations parameters

Connection configurations	R_{sh}(Ω)		R_s(Ω)		Rate of change of voltage per unit temperature change (%V/K)	Open circuit voltage $V_{oc}(V)$	Short circuit current $I_{sc}(A)$	Fill factor	Efficiency (%)
	298K	318K	298K	318K					
Simple Series	0.5	0.7	∞	∞	0.010	21.6	2.5	0.8183	15.62
Series-Parallel	0.2	0.5	∞	∞	0.045	5.4	10	0.5606	10.17
Total Cross Tied	0.1	0.5	∞	∞	0.050	4.5	72	0.5177	59.35
Bridge Linked	0.3	0.5	∞	∞	0.030	14.4	15	0.7587	57.98
Honey Comb	0.2	0.4	∞	∞	0.025	9.5	24	0.6833	54.54

Here, voltage will be increased and current will be decreased in manner as compared with TCT scheme. Figure 1(e) shows Honey comb scheme, it is a derived version of BL connection scheme. The current and voltage value nearer to SP connection scheme and reliability is less. In this scheme, the V_{oc} is taken as 0.6V and I_{sc} is taken as 2.5A [39] for a single PV cell having a size of 10cm diameter in thin circular wafer .

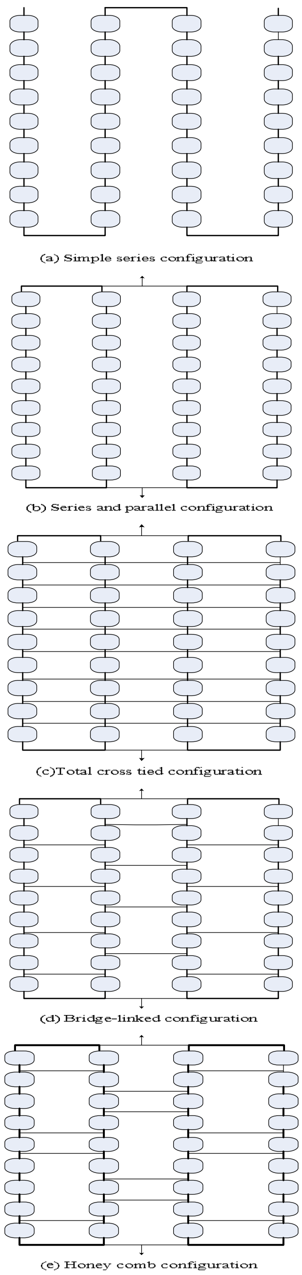

Figure 1. Interconnection configurations (9x4) schemes of solar cell (a) simple series configurations (b) series and parallel configurations (c) total cross tied configurations (d) bridge linked configurations (e) honey comb configurations.

The above mentioned detailes are consider as a reference, the V_{oc} and I_{sc} of all the interconnection schemes are calculated. The TCT and BL interconnection configurations schemes, which provides higher power rating as compared with other connection schemes. The details of connection schemes, open circuit voltage and short circuit current values are given in Table3. The SS interconnection scheme have produces maximum V_{oc} and FF are 21.6V, 0.8183 and TCT developes low level of V_{oc}, FF are 4.5V, 0.5177 respectively. These deviation are exhibits with the effectof PV cell interconnection behaviours. The I_{sc} and η values for interconnection schemes are vice-versa of V_{oc} and FF occurring effect. The I_{sc} can be obtained maximum for connecting of low band gap materials also. Similarly, V_{oc} and FF are obtained through high band gap materials.

3. 2. Flow Chart Figure 2 shows the procedure to draw I-V characterstic curve of a PV cell under various connection schemes. In that, predetermine the number of cell PV module and PV cell electrical parameters. This procedure can be apply to interconnection PV cell schemes for finding the performance parameters. The current and voltage equation are related with number of PV cells in series (N_{cs}) and parallel (N_{cp}) connection given below [40], to find the power and draw the I-V performance curve of a solar PV cell with various interconnection schemes.

$$I_{sc,t} = N_{cp,t} * I_{sc} \tag{18}$$

$$V_{oc,t} = N_{cs,t} * V_{oc} \tag{19}$$

$$V_1 = (0 : 0.0001 : V_{oc1}) \tag{20}$$

$$I_t = I_{sc,t} *(1-\exp(((V_t - V_{oc,t} / N_{cs,t} + (I_t * R_s) / N_{cp,t}) / (V_{th,t}) \tag{21}$$

4. RESULTS AND DISCUSSION

4. 1. Effects of Temperature on Solar Cell Band Gap Level Figure 3 shows temperatures have impacts on solar PV cell material. GaAs exhibits the higher band gap level at all levels of temperature compared to other semiconductor material. It can absorb long wave length operating at higher and lower temperature, but other material like Ge Si will absorb longer wave lengths at a higher junction temperature of the cell and absorb lower wave lengths at atmospheric temperature values. Ge is having lower band gap value, it can absorb long wavelength of radiation and its release in the form of heat in the solar cell material easily, because it is an indirect band gap material. GaAs is a direct bandgap material, having band gap level is 1.42eV and electron-hole recombination is creates photons of light.

4. 2. Effect of Temperature on Performance Parameters of Various Connection of PV Cell Figures 4 to 8 show the effect of temperature on simple series, series and parallel, total cross tied, bridge-linked, and honey comb configurations using Matlab. Operating cell temperature is 298K to 318K. .

The change in voltage per change in temperature for the SS, SP, TCT, BL and HC connection schemes are 0.01% V/K, 0.045% V/K, 0.05% V/K, 0.03 % V/K and 0.025% V/K, respectively. The R_s value for the SS, SP, TCT, BL and HC configurations are (0.7Ω,0.5Ω), (0.5Ω,0.2Ω), (0.5Ω,0.1Ω), (0.5Ω,0.3Ω) and (0.4Ω, 0.2Ω) at (318K, 298K), respectively. The above mentioned values are given in Table 3. The current and shunt resistance are having no effect with change of temperature and it maintains almost constant value.

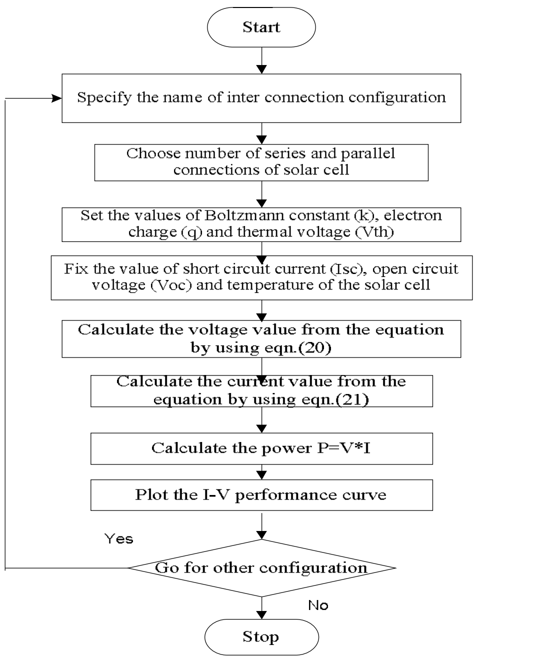

Figure 2. Flow chart of a I-V performance curve programming sequence

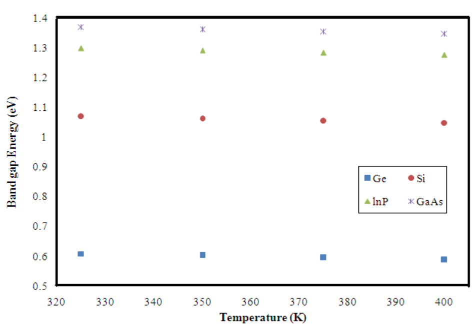

Figure 3. Solar cell materials having effects with temperature

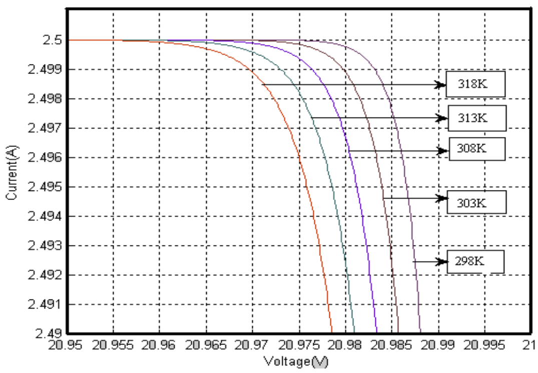

Figure 4. Effect of temperature on SS configurations

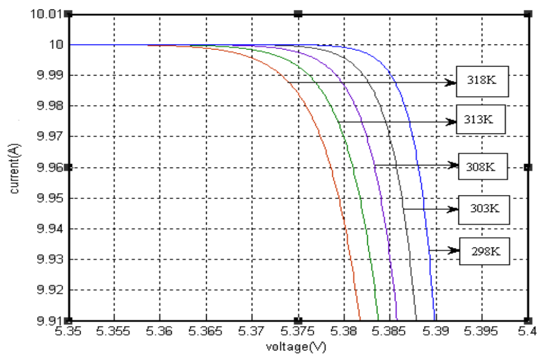

Figure 5. Effect of temperature on S-P configurations

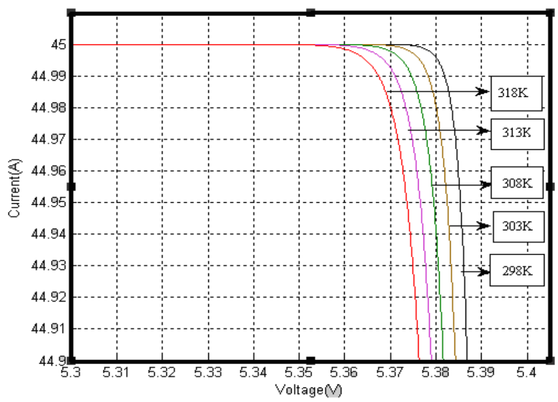

Figure 6. Effect of temperature on TCT configurations.

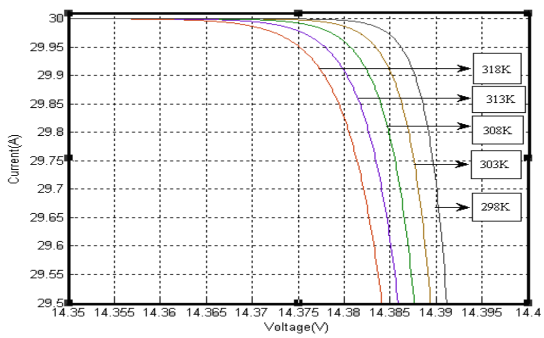

Figure 7. Effect of temperature on BL configurations

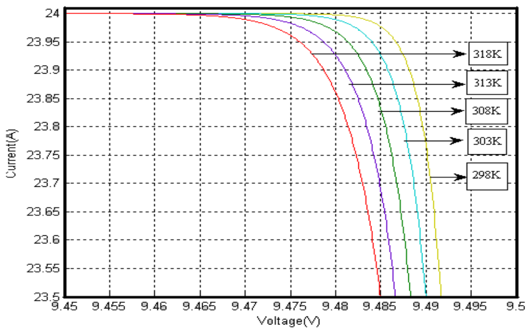

Figure 8. Effect of temperature on HC configurations

5. CONCLUSION

This work explains the effect of temperature on the performance of the solar cell and module. The heat generated, on the PV cell, due to internal resistance, affects the performance characteristics of the solar cell. The various configuration affected on temperature parameter and parasitic resistance changing their value. The open circuit voltage and series resistance were mainly affected due to the variation in temperature and these changes also depend on connection schemes of solar PV cells in a PV module. The current-voltage performance curves of various connection configuration were plotted to study the effect of temperature with the help of MATLAB program. Mostly, shunt resistances are constant and current value also remains constant with the variation of the temperature. The variation of the temperature on solar PV cell series resistance, shunt resistance, fill factor, variation in voltage for the change of temperature, current values are tabulated and analyzed. The solar cell of various materials with different bandgaps are formed to attain different temperatures. Solar irradiation intensity found to affected internal temperature. The change in voltage per unit temperature are found maximum of 0.050 (%V/K) and minimum of 0.010 (%V/K) for TCT and SS connection configuration respectively and remaining schemes like SP, BL and HC were lies between them. Similarly, SS are produced high fill factor of 0.8183 and TCT have the higest efficiency of 59.35%. Thus, it can be concluded that the temperature plays a vital role in determining the performance and efficiency of any PV cell/module.

6. REFERENCES

1. Moule, A.J., "Power from plastic", ***Current Opinion in Solid State and Materials Science***, Vol. 14, No. 6, (2010), 123-130.
2. Jwo-Hwu, Y., Chou, W.-L., Lu, P.-L., Syu, S.-Y. and Ji, J.-A., "The effects of dividable loads on photovoltaic power systems", ***International Journal of Electrical Power & Energy Systems***, Vol. 38, No. 1, (2012), 46-53.
3. Pan, L., "Analysis of photovoltaic module resistance characteristics", ***International Journal of Engineering-Transactions B: Applications***, Vol. 26, No. 11, (2013), 1369-1376.
4. Wu, M.-J., Timpson, E.J. and Watkins, S.E., "Temperature considerations in solar arrays", in Region 5 Conference: Annual Technical and Leadership Workshop, IEEE., (2004), 1-9.
5. Huang, B., Yang, P., Lin, Y., Lin, B., Chen, H., Lai, R. and Cheng, J., "Solar cell junction temperature measurement of PV module", ***Solar Energy***, Vol. 85, No. 2, (2011), 388-392.
6. Singh, P. and Ravindra, N., "Temperature dependence of solar cell performance—an analysis", ***Solar Energy Materials and Solar Cells***, Vol. 101, (2012), 36-45.
7. Thevenard, D. and Pelland, S., "Estimating the uncertainty in long-term photovoltaic yield predictions", ***Solar Energy***, Vol. 91, (2013), 432-445.
8. Skoplaki, E. and Palyvos, J., "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations", ***Solar Energy***, Vol. 83, No. 5, (2009), 614-624.
9. Zhang, J., Gao, Y., Lu, Y., Zhu, L., Guo, Z., Chen, G. and Chen, Z., "Transient thermal resistance test of single-crystal-silicon solar cell", ***Electron Devices, IEEE Transactions on***, Vol. 59, No. 9, (2012), 2345-2349.
10. Kasaeian, A., Mobarakeh, M.D., Golzari, S. and Akhlaghi, M., "Energy and exergy analysis of air PV/T collector of forced convection with and without glass cover", ***International Journal of Engineering-Transactions B: Applications***, Vol. 26, No. 8, (2013), 913-926.
11. Wang, Y.-J. and Hsu, P.-C., "An investigation on partial shading of pv modules with different connection configurations of PV cells", ***Energy***, Vol. 36, No. 5, (2011), 3069-3078.
12. Ramaprabha, R. and Mathur, B., "A comprehensive review and analysis of solar photovoltaic array configurations under partial shaded conditions", ***International Journal of Photoenergy***, Vol. 2012, (2012).
13. Kaushika, N.D. and Gautam, N.K., "Energy yield simulations of interconnected solar pv arrays", ***Energy Conversion, IEEE Transactions on***, Vol. 18, No. 1, (2003), 127-134.
14. Romary, F., Caldeira, A., Jacques, S. and Schellmanns, A., "Thermal modelling to analyze the effect of cell temperature on PV modules energy efficiency", in Power Electronics and Applications, Proceedings of the 14th European Conference on, IEEE., (2011), 1-9.
15. Marion, B., "A method for modeling the current–voltage curve of a pv module for outdoor conditions", ***Progress in Photovoltaics: Research and Applications***, Vol. 10, No. 3, (2002), 205-214.
16. Picault, D., Raison, B., Bacha, S., De La Casa, J. and Aguilera, J., "Forecasting photovoltaic array power production subject to mismatch losses", ***Solar Energy***, Vol. 84, No. 7, (2010), 1301-1309.
17. Li, S., Haskew, T.A., Li, D. and Hu, F., "Integrating photovoltaic and power converter characteristics for energy extraction study of solar pv systems", ***Renewable Energy***, Vol. 36, No. 12, (2011), 3238-3245.
18. Green, M.A., "Solar cells: Operating principles, technology, and system applications", ***Englewood Cliffs, NJ, Prentice-Hall, Inc.,*** (1982)., 79-80
19. Ogden, J. and Williams, R., "Electrolytic hydrogen from thin-film solar cells", ***International Journal of Hydrogen Energy***, Vol. 15, No. 3, (1990), 155-169.

20. Patel, M.R., "Wind and solar power systems: Design, analysis, and operation, CRC press, (2012).

21. Yang, H., Burnett, J. and Ji, J., "Simple approach to cooling load component calculation through PV walls", ***Energy and Buildings***, Vol. 31, No. 3, (2000), 285-290.

22. Jie, J., Wei, H. and Lam, H., "The annual analysis of the power output and heat gain of a pv-wall with different integration mode in hong kong", ***Solar Energy Materials and Solar Cells***, Vol. 71, No. 4, (2002), 435-448.

23. Jiang, J.-A., Wang, J.-C., Kuo, K.-C., Su, Y.-L., Shieh, J.-C. and Chou, J.-J., "Analysis of the junction temperature and thermal characteristics of photovoltaic modules under various operation conditions", ***Energy***, Vol. 44, No. 1, (2012), 292-301.

24. Bucher, K., "Site dependence of the energy collection of pv modules", ***Solar Energy Materials and Solar Cells***, Vol. 47, No. 1, (1997), 85-94.

25. Tsai, H.-L., "Insolation-oriented model of photovoltaic module using matlab/simulink", ***Solar Energy***, Vol. 84, No. 7, (2010), 1318-1326.

26. Thurmond, C., "The standard thermodynamic functions for the formation of electrons and holes in ge, si, gaas, and gap", ***Journal of the Electrochemical Society***, Vol. 122, No. 8, (1975), 1133-1141.

27. Machacek, Z., Benda, V. and Barinka, R., "Parameters of photovoltaic cells in dependence on irradiance and temperature", (2007).

28. Meral, M.E. and Dinçer, F., "A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems", ***Renewable and Sustainable Energy Reviews***, Vol. 15, No. 5, (2011), 2176-2184.

29. Park, K., Kang, G., Kim, H., Yu, G. and Kim, J., "Analysis of thermal and electrical performance of semi-transparent photovoltaic (pv) module", ***Energy***, Vol. 35, No. 6, (2010), 2681-2687.

30. M.Ahmadzadehtalatapeh, "Performance study of a solar integrated central heating systm of residential building using trnsys - an hurly simulation model", ***International Journal of Engineering , Transactions C: Aspcts***, Vol. 27, No. 3, (2014), 457-466.

31. Carrero, C., Amador, J. and Arnaltes, S., "A single procedure for helping pv designers to select silicon pv modules and evaluate the loss resistances", ***Renewable Energy***, Vol. 32, No. 15, (2007), 2579-2589.

32. Mekhilef, S., Saidur, R. and Kamalisarvestani, M., "Effect of dust, humidity and air velocity on efficiency of photovoltaic cells", ***Renewable and Sustainable Energy Reviews***, Vol. 16, No. 5, (2012), 2920-2925.

33. Nagae, S., Toda, M., Minemoto, T., Takakura, H. and Hamakawa, Y., "Evaluation of the impact of solar spectrum and temperature variations on output power of silicon-based photovoltaic modules", ***Solar Energy Materials and Solar Cells***, Vol. 90, No. 20, (2006), 3568-3575.

34. Ikegami, T., Maezono, T., Nakanishi, F., Yamagata, Y. and Ebihara, K., "Estimation of equivalent circuit parameters of PV module and its application to optimal operation of PV system", ***Solar Energy Materials and Solar Cells***, Vol. 67, No. 1, (2001), 389-395.

35. Sanchez Reinoso, C., Milone, D. and Buitrago, R., "Efficiency study of different photovoltaic plant connection schemes under dynamic shading", ***International Journal of Hydrogen Energy***, Vol. 35, No. 11, (2010), 5838-5843.

36. Garcia-Belmonte, G., "Temperature dependence of open-circuit voltage in organic solar cells from generation–recombination kinetic balance", ***Solar Energy Materials and Solar Cells***, Vol. 94, No. 12, (2010), 2166-2169.

37. Luque, A. and Marti, A., "Theoretical limits of photovoltaic conversion", ***Handbook of Photovoltaic Science and Technology, Wiley, Chichester, UK***, (2003).

38. Green, M.A., "Solar cell fill factors: General graph and empirical expressions", ***Solid-State Electronics***, Vol. 24, No. 8, (1981), 788-789.

39. http:// www.calsolareng.com/ access on may 2013.

40. Pandiarajan, N. and Muthu, R., "Mathematical modeling of photovoltaic module with simulink", in Proceeding of International Conference on Electrical Energy System., (2011), 3-5.

An Investigation of Temperature Effects on Solar Photovoltaic Cells and Modules

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چکیده

سیستم های خورشیدی فتوولتائیک (PV) با مشکلات جدی در اثر ضرر و زیان های غیر قابل اجتناب در سیستم خود روبرو هستند که منجر به انحراف بیشتر از توان خروجی از سطح قدرت ورودی می شود. این اثر به عنوان یک اثر عدم تطابق شناخته شده و در سیستم های PV موجود است. سیستم PV با بسیاری از اتلافات مواجه می شود و به حداقل رساندن این اتلافات دشوار است. در این مقاله، تأثیر اثر حرارتی بر روی سیستم PV خورشیدی در نظر گرفته شده و اثر آن بر عملکرد عملیات، عامل پر، ولتاژ مدار باز و جریان اتصال کوتاه، سطح شکاف باند از مواد مختلف نیمه هادی، توان خروجی و بازده تجزیه و تحلیل شده است. اثر درجه حرارت یک سلول PV خورشیدی، در حال اتصال با ۳۶ سلول در یک ماژول برای پیکربندی اتصال های مختلف مانند پیکربندی سری ساده (SS)، پیکربندی سری موازی (SP)، پیکربندی گره خورده متقاطع کلی (TCT)، پیکربندی ارتباطی پلی (BL) و پیکربندی لانه زنبوری (HC) با استفاده از نرم افزار متلب تجزیه و تحلیل شده است. افزایش سطح درجه حرارت برای پیکربندی اتصال های مختلف، به همان نسبت ولتاژ مدار باز آنها و مقاومت سری را کاهش می دهد. جریان و مقاومت شنت ممکن است به علت درجه حرارت به طور کامل تحت تاثیر قرار نگیرد. در نهایت، این مشکل ایجاد یک اثر حرارت در سلول PVخورشیدی را می نماید، به طوری که طول عمر پانل های فتوولتائیک به تدریج کاهش می یابد. در حالی که درجه حرارت افزایش می یابد، نقاط لحیم کاری وانکپسولاسیون سلول تحت تاثیر قرار می گیرد. مواد سلول های خورشیدی عملکرد خود را تغییر می دهند، در حالی که به علت اثر دما در شکاف باند تغییر وجود دارد.

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