PERFORMANCE STUDY OF PHOTOVOLTAIC SOLAR CELL

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Abstract

Energy is the driving force for any kind of economic and scientific development, automation, and innovation. Due to high excursion rate of conventional energy sources, availability of conventional fuels is reducing day by day. Consequently their prices are increasing very rapidly. Along with these they pollute atmosphere due to combustion and chemical process associated with them. Considering all these it is needed to find nonconventional sources to meet up energy requirements. Worldwide 'Solar Energy' is one of the most effective and popular nonconventional energy sources. Solar energy does not produce any pollutants and is one of the cleanest energy sources. This can be used to produce electricity from sunlight, named solar power. Solar power can be directly generated from PV cell or indirectly from concentrated solar power (CSP).
This paper focuses on the performance of photovoltaic (PV) solar cell for solar power. Therefore simulation is done to observe efficiency for different changing conditions and parameters of solar cell electrical model and observe better efficiency for InGaAs alloy.

***Key Words**: Solar power; Solar cell; PV; PV operation; Electricity generation; Electrical model; Solar cell materials; Efficiency; Different parameters; Silicon; Indium Gallium Arsenide alloy.*

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1. INTRODUCTION

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy [1]. Passive solar techniques include orienting a building to the sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

PV cell is an electrical device that has a light absorption property that absorbs photon and produces free electrons through its PV effect which is a physical and chemical phenomenon [2]. This effect converts energy of light directly into electricity.

Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms [3].

The electrical efficiency depends on the length and intensity of sunlight falling on the system and the type and quality of PV cells and cell materials and components used within the solar module. PV cell is usually made of monocrystaline or polycrystalline silicon. InGaAs can be a better option having higher efficiency of solar cell.

By simulated observation, this paper focuses on efficiency with respect to different parameters of PV solar cell.

2. PHOTOVOLTAIC SOLAR CELL

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.
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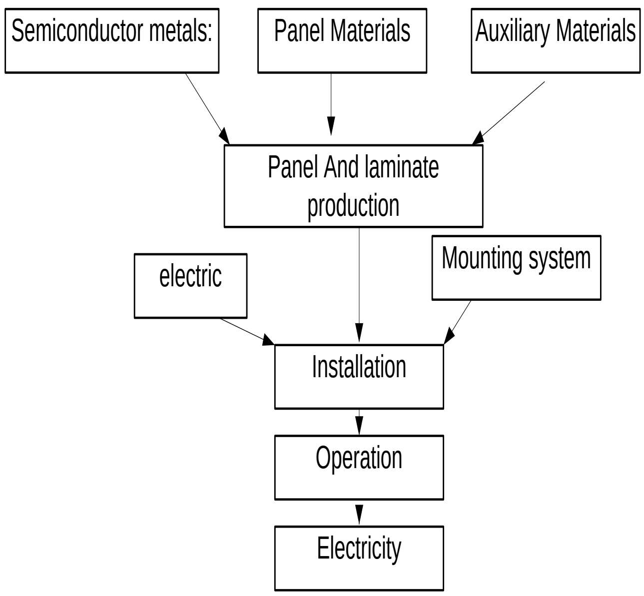

Fig -1: Steps for electricity generation by PV module[2]

2.1 Solar Cell Materials

Solar cells can be classified into first, second and third generation cells[3].

- The first generation cells—also called conventional, traditional or wafer-based cells—are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polycrystalline silicon and monocrystalline silicon.
- Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small stand-alone power system.
- The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaic's—most of them have not yet been commercially applied and are still in the research or development phase.

A high-band gap cell absorbs the "blue" portion of the spectrum and the remaining light is transmitted and then absorbed by lower cells with decreasing band gap[4]. In this paper we study about Silicon and $In_{(x)}\ Ga_{(1-x)}\ As$.

❖ Silicon :

Silicon is a chemical element with symbol Si and atomic number 14

❖ Indium gallium arsenide :

Indium gallium arsenide (InGaAs) (alternatively gallium indium arsenide) is a ternary alloy (chemical compound) of indium, gallium and arsenic. Indium and gallium are both from boron group (group III) of elements while arsenic is a pnictogen (group V) element. Thus alloys made of these chemical groups are referred to as "III-V" compounds. Because they are from the same group, indium and gallium have similar roles in chemical bonding. InGaAs is regarded as an alloy of gallium arsenide and indium arsenide with properties intermediate between the two depending on the proportion of gallium to indium.

2.2 Electrical Model Of Solar Panel

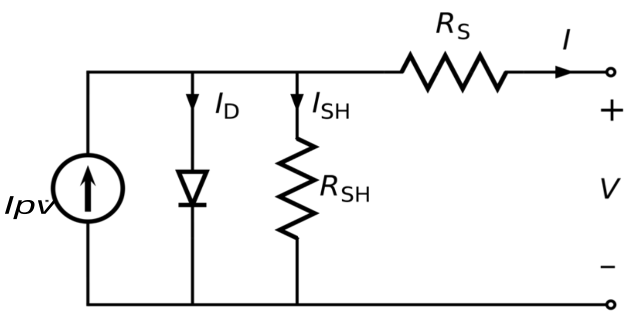

Fig -3: Electric model of solar cell[5-7]

$$I = I_{pv} - I_o\left[exp\left(\frac{V + IR_s}{aV_T}\right) - 1\right] - \frac{V + IR_s}{R_{sh}}$$

$$V_T = \frac{N_s kT}{q}$$

$$I_{pv} = \frac{G}{G_n}[I_{pvn} + K_i(T - T_n)]$$

$$I_o = I_{on}\left(\frac{T}{T_n}\right)^3 exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right]$$

$$I_{on} = \frac{I_{scn}}{exp(V_{0cn}/aV_{Tn}) - 1}$$

$$P_{max} = V_{oc}I_{sc}FF$$

$$\eta = \frac{V_{oc}I_{sc}FF}{P_{in}}$$

- I_{pv} is the current generated by PV effect
- I_D is the current through the diode
- I_{SH} is current through shunt resistor
- R_{SH} is shunt resistor
- R_S is series resistor
- I is the PV output current
- V is the PV output voltage
- I_O is saturation current of the diode
- Q is elementary charge $1.6x10^{-19}$
- K is constant value $1.38x10^{-23}$J/K
- E_g is material band gap
- N_s is series connected cells
- T_n is the nominal cell temperature in Kelvin
- G_n is nominal irradiance in w/m^2
- n is diode ideality factor (typically between 1 and 2)
- V_{oc} open circuit voltage
- I_{sc} short circuit current
- FF is fill factor
- η is efficiency

3. SIMULATION AND OBSERVATION OF PV CELL

Table -1: Electrical data used for simulating solar panel

Electrical Data of solar panel	
Input power	260W
Open Circuit Voltage (V_{oc})	37.92 V
Short Circuit Current (I_{sc})	8.67 A
Cell Orientation	60 Cells
Temperature Coefficient of Voc	-0.33% / °C0
Temperature Coefficient of Isc	0.06% / °C
Reference temperature	(25°C) in Kelvin

3.1 Comparison between (Si) & $In_xGa_{1-x}As$ Alloy Regarding Energy Gap (Eg)

➢ For Silicon (Si)

Energy gap, Eg=1.12eV for Si

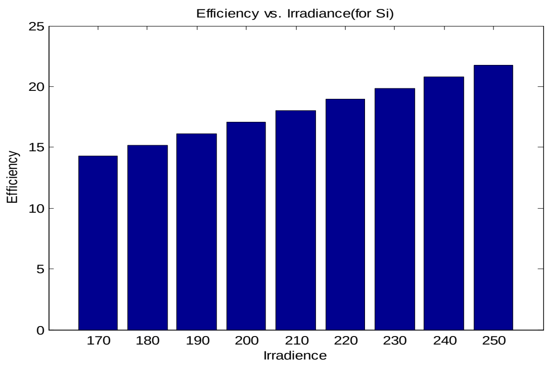

***Fig-4**: Efficiency vs. Irradiance (Si)*

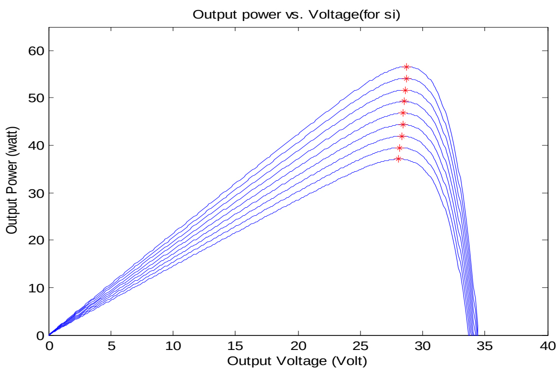

Fig-5: Output Power vs. Voltage (Si)

Table-2: Efficiency & Pmax for different irradiance(Si)

Irradiance(watt/m^2)	P_{max}(watt)	Efficiency (%)
250	56.5935	21.7667
240	54.1407	20.8233
230	51.6936	19.8822
220	49.2498	18.9422
210	46.8100	18.0038
200	44.3366	17.0679
190	41.9485	16.1340
180	39.5261	15.2023
170	37.1101	14.2731

➢ **For Indium Gallium Arsenaid ($In_xGa_{1-x}As$)**

Instead of silicon, ($In_xGa_{1-x}As$) alloy's efficiency for solar cell is observed.

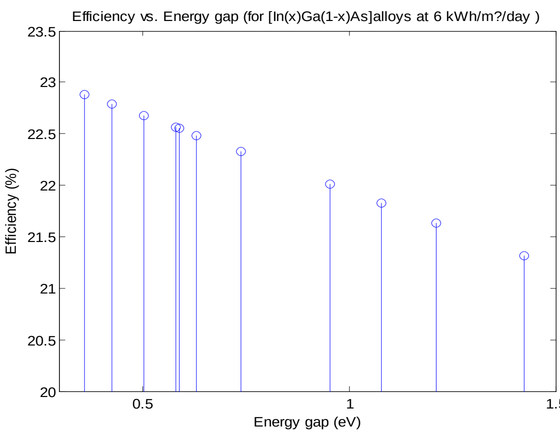

Fig-6: Efficiency vs. Energy Gap for $In_xGa_{1-x}As$ alloy

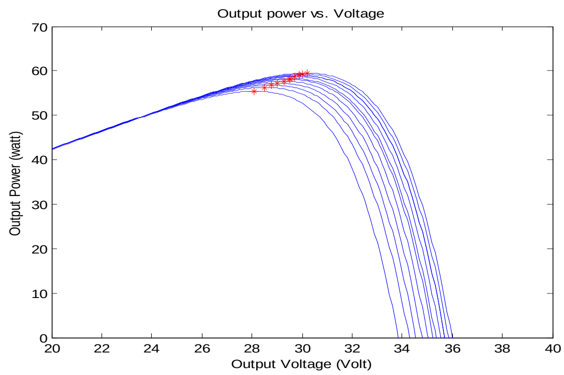

Fig-7: Output Power vs. Voltage ($In_xGa_{1-x}As$)

Table-3: Efficiency, P_{max} & Energy Gap for irradiance 6 kWh/m²/day

(x) for ($In_xGa_{1-x}As$) alloys	Energy gap, E_g (eV)	Efficiency (%)	P_{max}(watt)
1	0.360	22.8859	59.5032
0.9	0.427	22.7875	59.2475
0.8	0.503	22.6756	58.9567
0.7	0.588	22.5504	58.6310
0.6	0.681	22.5605	58.2739
0.55	0.731	22.4868	58.0824
0.45	0.838	22.3292	57.6725
0.35	0.953	22.0126	57.2327
0.25	1.077	21.8301	56.7584
0.15	1.210	21.6337	56.2476
0	1.425	21.3170	55.4205

3.2 Study of Efficiency By Varying Irradiance(G)

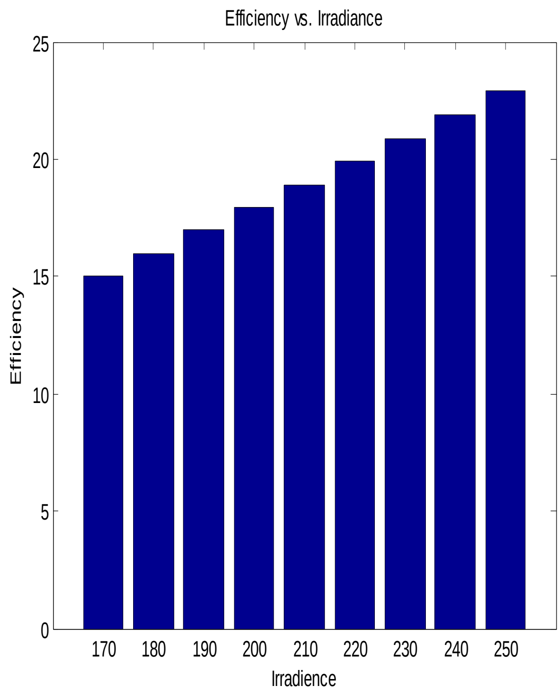

Fig-8: Efficiency vs. Irradiance curve for varying irradiance from 4.2kwh/m^2/day to 6.22kwh/m^2/day

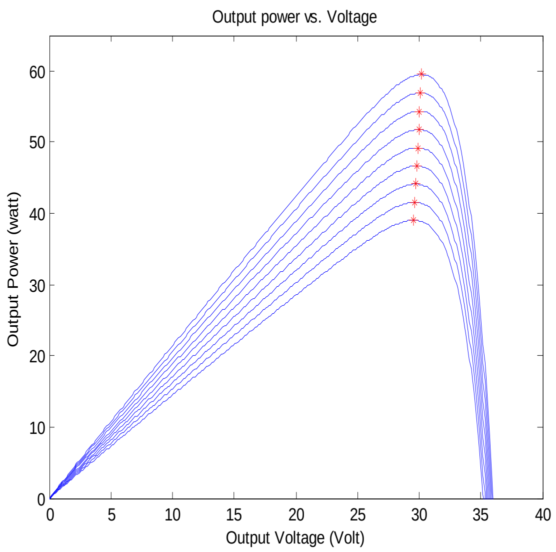

Fig-9: Output power vs. output voltage curve for varying irradiance from 4.2kwh/m^2/day to 6.22kwh/m^2/day

Table-4: Efficiency & P_{max} for different irradiances

Irradiance (w/m^2)	P_{max}	Efficiency
250	59.5032	22.8859
240	56.9280	21.8954
230	54.3554	20.9059
220	51.7837	19.9180
210	49.2242	18.9324
200	46.6662	17.9485
190	44.1134	16.9667
180	41.5665	15.9871
170	39.0264	15.0102

3.3 Study of Efficiency By Varying Number of Series Connected Cells(Ns)

For Energy band gap E_g=0.36 of ($In_xGa_{1-x}As$) alloy, where x=1 and Irradiance =6 kWh/m²/day

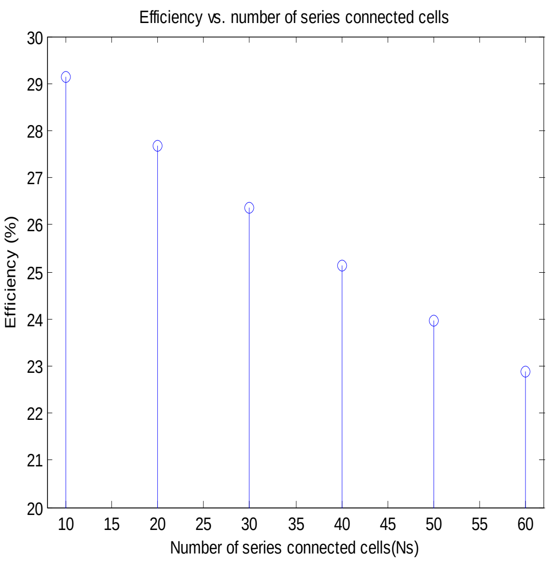

Fig-10: Efficiency vs. Number of series cells(Ns) (G=250 w/m^2)

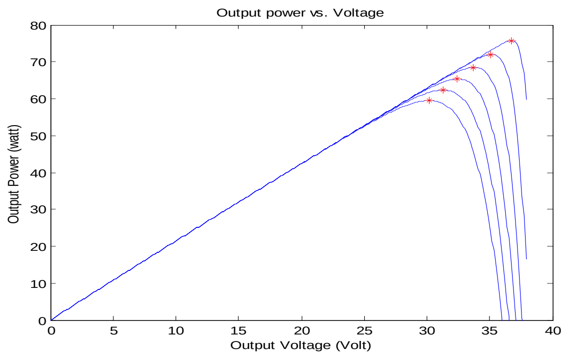

Fig-11: Output Power vs. Output voltage for different values of Number of series cells (Ns) (G=250 w/m^2)

Table-5: Efficiency & P_{max} for different values of Number of series cells (Ns)

Number of series cells	Efficiency	P_{max} (watt)
10	29.1450	75.7771
20	27.6767	71.9594
40	25.1235	65.3211
50	23.9730	62.3297
60	22.8859	59.5032

3.4Study of Efficiency By Varying Ideality Factor(a)

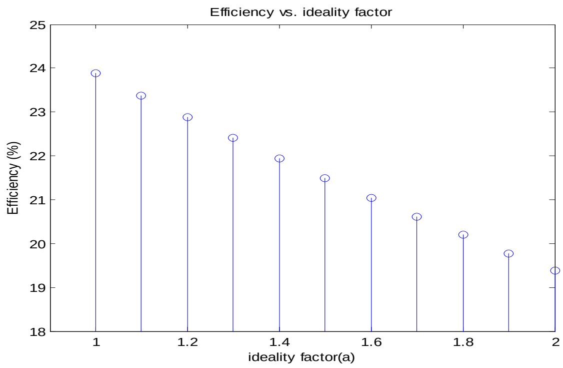

Fig-12: Efficiency vs. Ideality Factor (a) (G=250 w/m^2)

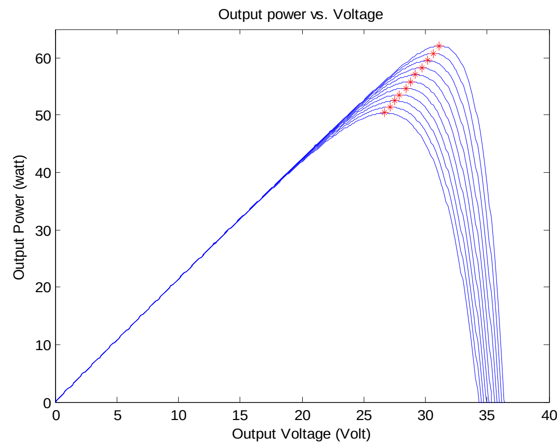

Fig-13: Output Power vs. Output voltage for different values of ideality factor (a) (G=250 w/m^2)

Table-6: Efficiency & P_{max} for different values of Ideality factor (vary from 1 to 2)

Ideality factor	Efficiency (%)	P_{max} (watt)
1	23.8836	62.0973
1.1	23.3776	60.7819
1.2	22.8859	59.5032
1.3	22.4079	58.2606
1.4	21.9421	57.0494
1.5	21.4882	55.8693
1.6	21.0451	54.7172
1.7	20.6132	53.5944
1.8	20.1914	52.4975
1.9	19.7791	51.4257
2.0	19.3762	50.3781

3.5Study of Efficiency By Varying series resistance (Rs)

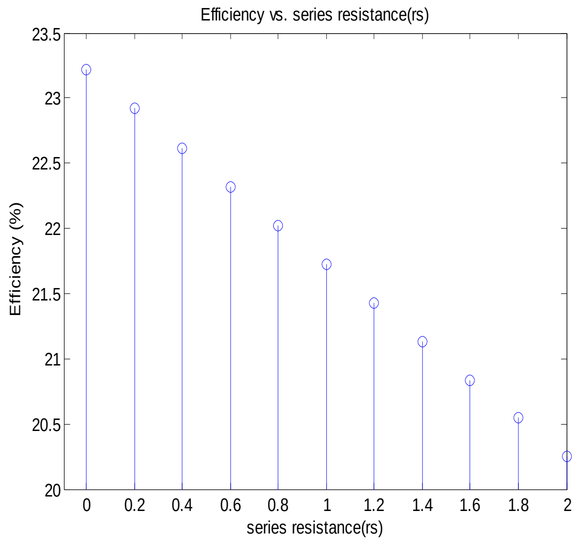

Fig-14: Efficiency vs. series resistance (Rs) (G=250 w/m^2)

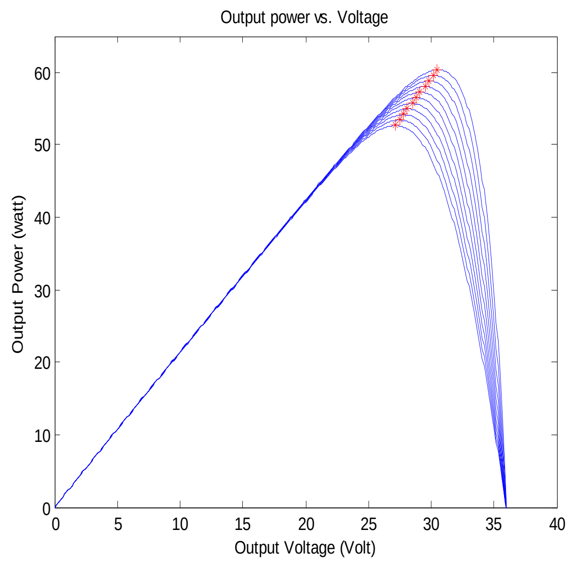

Fig-15: Output Power vs. Output voltage for different values of series resistance (Rs) (G=250 w/m^2)

Table-7: Efficiency & P_{max} for different values of Series resistance (Rs)

Series resistance	Efficiency(%)	Pmax (watt)
0	23.2186	60.3683
.2	22.9179	59.5864
.4	22.6174	58.8052
.6	22.3185	58.0282
.8	22.0199	57.2516
1	21.7232	56.4802
1.2	21.4269	55.7099
1.4	21.1319	54.9431
1.6	20.8383	54.1797
1.8	20.5456	53.4185
2.0	20.2543	52.6611

3.6 Study of Efficiency By Varying shunt resistance (Rsh)

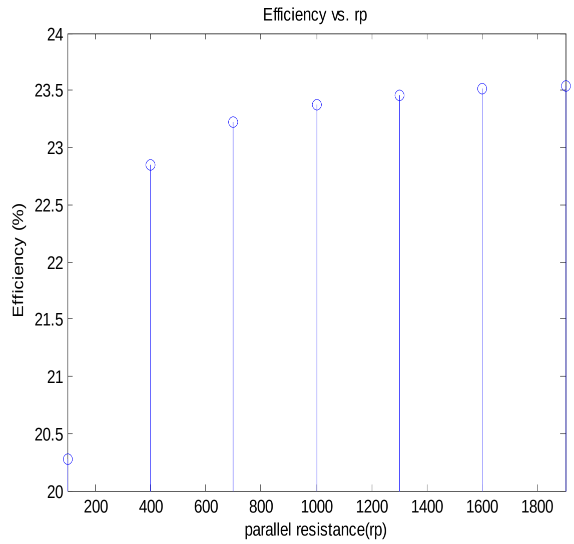

Fig-16: Efficiency vs. Shunt resistance (Rsh) (G=250w/m^2)

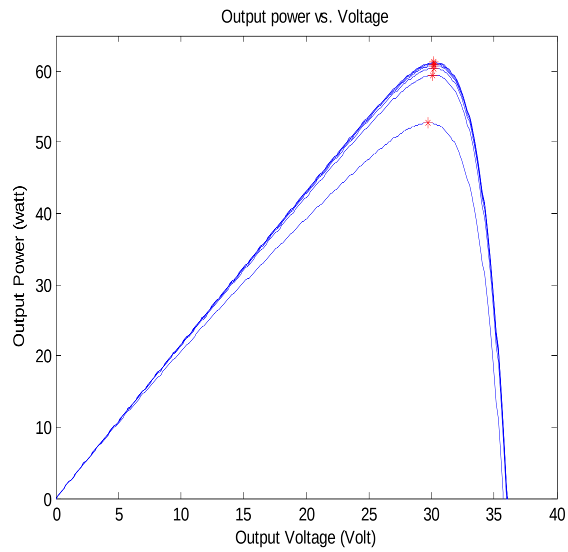

Fig-17: Output Power vs. Output voltage for different values of series resistance (Rs) (G=250 w/m^2)

Table-8: Efficiency & P_{max} for different values of Shunt resistance (Rsh)

Shunt resistance	Efficiency(%)	Pmax (watt)
100	20.2744	52.7134
400	22.8535	59.4191
700	23.2280	60.3927
1000	23.3778	60.7823
1300	23.4585	60.9921
1600	23.5089	61.1232
1900	23.5434	61.2129

3.7 Study Of Efficiency By Varying Temperature (T)

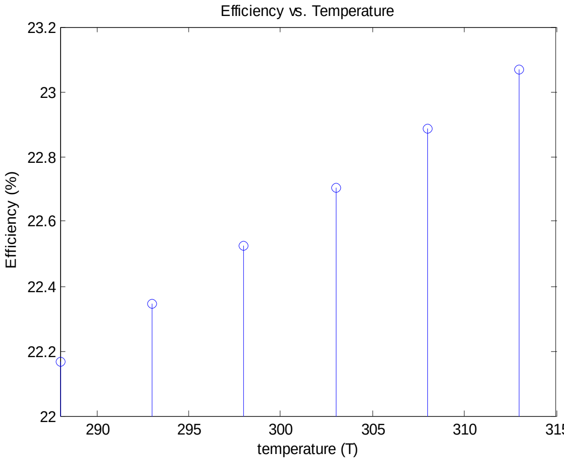

Fig-18: Efficiency vs. Temperature (T) (G=250w/m^2)

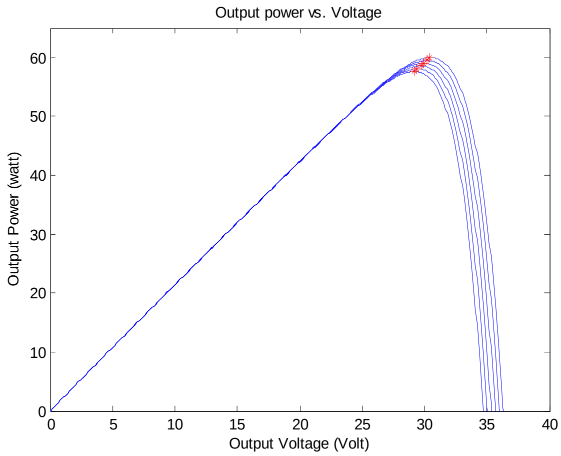

Fig -19: Output Power vs. Output voltage for different values of Temperature (T) (G=250 w/m^2)

Table-9: Efficiency & P_{max} for different values of Temperature (T)

Temperature (Kelvin)	Efficiency (%)	P_{max} (watt)
288	22.1670	57.6341
293	22.3451	58.0974
298	22.5238	58.5619
303	22.7047	59.0322
308	22.8859	59.5032
313	23.0692	59.9798

4. CONCLUTION

- For different values of x (from 0.25 to 1), ($In_xGa_{1-x}As$) alloy has better efficiency than silicon for same irradiance.
- Efficiency increases with
- Increasing irradiance
- Decreasing number of series cells
- Decreasing ideality factor
- Decreasing series resistance
- Increasing Shunt resistance
- Increasing temperature.
- Solar cell can be designed to have maximum efficiency by combining different parameters.
- Future work can be done by combining solar, biogas and hydro based hybrid renewable energy system to overcame problems regarding energy resources.

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BIOGRAPHIES

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