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Linear Programming for Solving Solar Cell Parameters

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Abstract: In this paper, the major physical parameters of a commercial silicon solar cell such as maximum current, maximum voltage, fill factor, and efficiency have been investigated. The important parameters of a silicon cell are examined using Linear Programming Problem (LPB) and the obtained results are compared with those of experimental values. The experimental results of the solar cell show excellent agreement as compared with those obtained by LPB.

Keywords: Linear programming, solar cell, temperature, physical parameters

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1. Introduction

The world is currently facing economic and environmental challenges due to the use of conventional fuels. Therefore, alternative energy has been directed to where sunlight is the only source of abundance and safety. Solar cell supplies the energy for long time for satellites and space vehicles, which have been utilized in universal applications, space fields: used in charging operating platforms for satellite vehicles. Kepler and Barker equations with a three-body problem are used in the celestial mechanicsto solve the problems with the orbit satellite[1-8]. Thin film technology has always been cheaper but less efficient than conventional other technologies. However, it has improved markedly over the years[9-10]. Many light materials are manufactured in different ways on a different substrates. Solar cells based thin films are always categorized according to the light materials utilized[11-25]. In the ideal model of solar cells, the cell is appeared using a source of electric current by a dual diode, while; practically there isn't ideal solar cell for that put on the resistance in parallel shunt resistance and other resistance series resistance respectively as a simulation of reality is shown in Figure 1.

In this research, a linear programming problem has been utilized to presage maximum and minimum values of output parameters of a photovoltaic cell and compare the obtained results with the experimental values. This method is used for several applications.

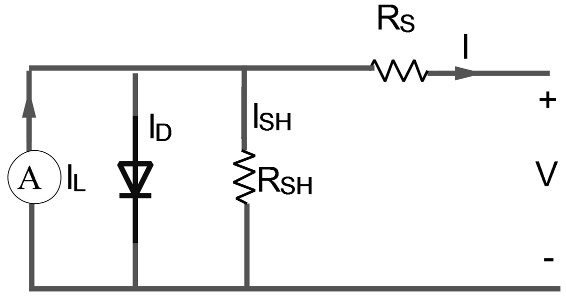

Figure 1. Solar cell equivalent circuit.

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1.1 Solar Cell Physical Parameters

From **Figure 1** current output of the solar cell = current output from the source I_L - current in the uniform diode I_D - current in the resistance located on the parallel R_{SH}, voltage on both ends of the resistor diode = voltage on the sides V + current × resistance (IR).

Investigation current-voltage plot, many factors should be calculated such as fill Factor, the maximum output energy P_m that is based on V_{oc} and I_{sc}[26].

$$\mathrm{FF} = \frac{P_m}{V_{oc}I_{sc}} = \frac{V_m I_m}{V_{oc}I_{sc}} \quad (1)$$

where P_m : power at maximum point, V_{oc} : open circuit voltage, I_{sc} : short circuit current. When FF increases, Increases P_m increase too; thus the output power increase. Then, it is possible to study the energy conversion efficiency η of the solar cell, which is, characterized the ratio of output photons to the incident photons[27].

$$\eta = \frac{P_m}{E \times A} \times 100\% \quad (2)$$

where E is the optical radiation in (mW/cm^2) and A is the surface area of the cell in (cm^2) and P_m is the largest obtained capacity in (mW/cm^2), substituting Eq. 1 in Eq. 2 yields[28,29].

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{E \times A} \times 100\% \quad (3)$$

The Eq. 3 obtains the efficiency, which is the expression of the amount of light transformed into electricity.

1.2 Linear Programming[30-31]

Linear programming is one of the most important methods to solve administrative problems by relying on a mathematical formula called linear model that includes the deletion of the object and the associated constraints. In this research, the components of the linear model and its main determinants will be discussed. Linear programming models are usually constructed according to a formulation that expresses the nature of the problem to be determined mathematically. This formulation contains three main parts: objective function, Structural constraints, and non-negativity conditions. A general formula can be developed for the linear programming model, which includes the target function (Z) in the maximization (Maximize) and reduction (Minimize) cases, and on n from decision variables (X_i), (m) from the constraints that can be taken as mathematical signs (≥ , = , ≤). The general formula of the mathematical model of linear programming can be expressed as follows

$Max\ or\ Min\ Z = C_1X_1 + C_2X_2 + \dots + C_nX_n$ (Target Function)

Subject to: (Constraints)

$$A_{11}X_1 + A_{12}X_2 + \dots + A_{1n}X_n \ (\le\ ,\ =\ ,\ \ge) b_1$$

$$A_{21}X_1 + A_{22}X_2 + \dots + A_{2n}X_n \ (\le\ ,\ =\ ,\ \ge) b_2$$

.....

$$A_{m1}X_1 + A_{m2}X_2 + \dots + A_{mn}X_n \ (\le\ ,\ =\ ,\ \ge) b_m$$

The non-negativity conditions

$$X_1 + X_2 + \dots + X_n \ \ge 0$$

The general formulation of the previous linear programming model can be expressed more succinctly using the sum, as follows

$Max.\ or\ Min.\ Z = \sum_{j=1}^{n} C_jX_j$ (Target Function)

Subject to: (Constraints)

$$\sum_{j=1}^{n} a_{ij}X_j \ (\le\ ,\ =\ ,\ \ge), (i = 1, 2, \dots, n)$$

The non-negativity conditions

$$X_j \ge 0, (j = 1, 2, \dots, n)$$

2. Experimental Method

A 210 cm^2 Area of commercial silicon solar cell is used to calculate the physical factors experimentally. The method including Linear programming method has been utilizrd to determine PV physical parameters and conversion efficiency of the cell.

3. Results and Discussion

Under conditions AM1.5 The experimental data of the silicon solar cell acquired when the cell loaded by decade box resistors is shown in **Figures 1, 2, 3** and **4** was performed using a commercial silicon solar cell with an active area of 210 cm^2 under illumination power density of 69 mW/cm^2 [21].

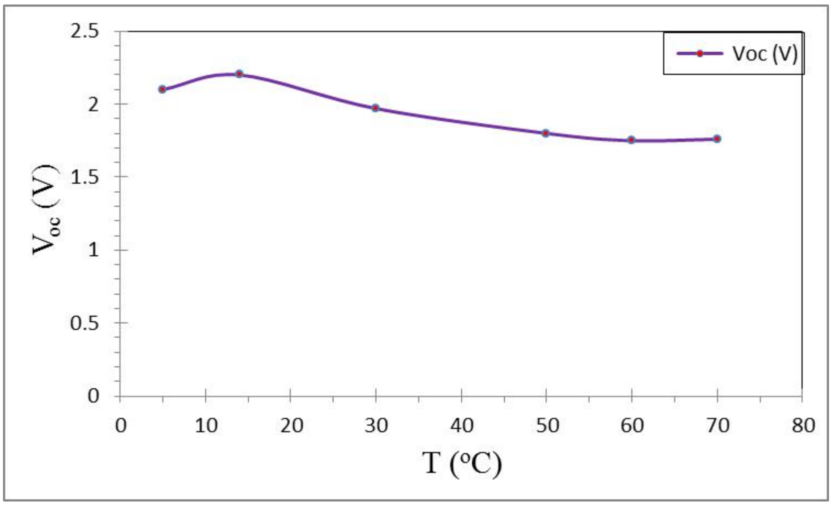

Figure 1. Open-circuit voltage against temperature

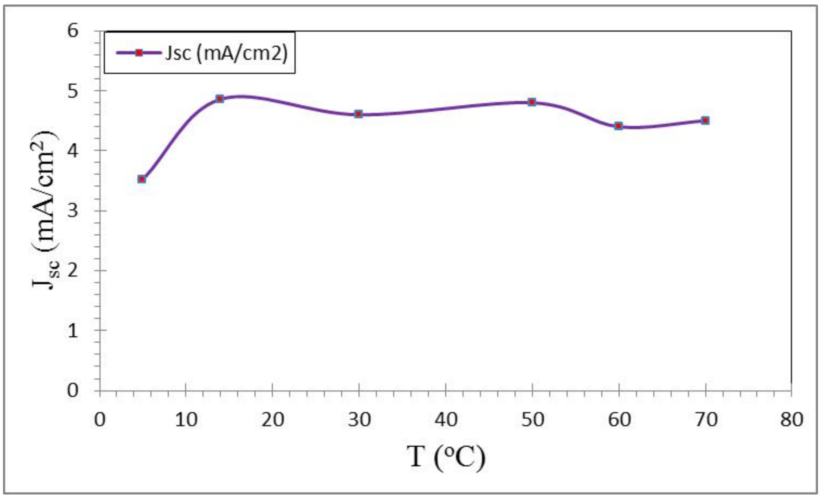

Figure 2. Short-circuit current density against temperature.

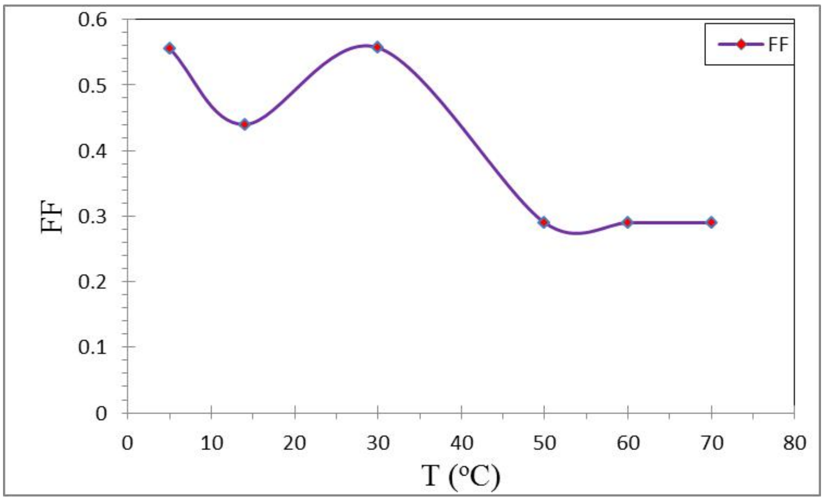

Figure 3. Fill factor against temperature.

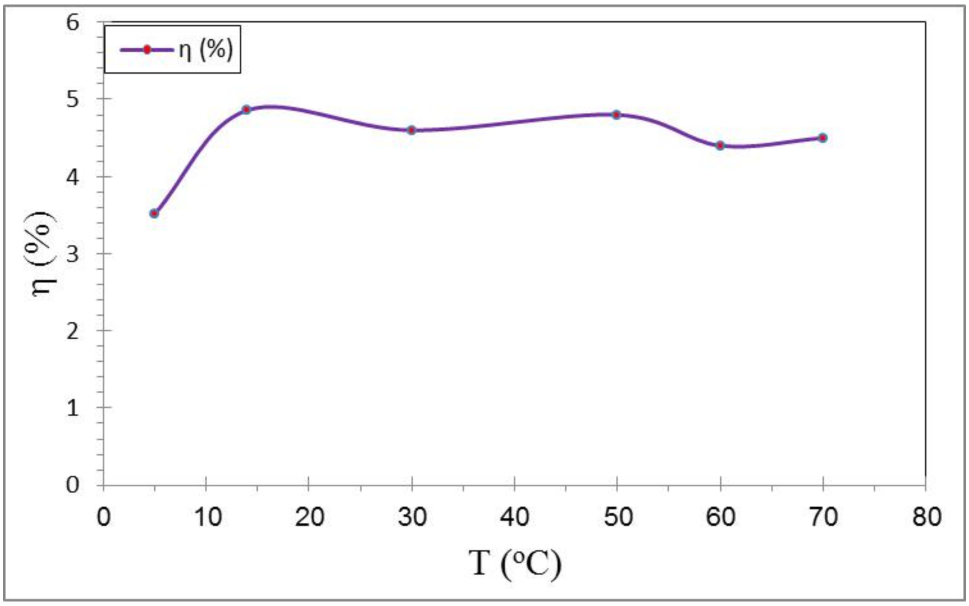

Figure 4. The efficiency against temperature

The above Figures show that open-circuit voltage of the cell decrease with the increasing of temperature (T). Short-circuit current density increase with the increasing of T, Fill factor of the cell decrease with the increasing of T . In addition the efficiency of the silicon solar cell increase with the increasing of temperature because the temperature

Now, linear programming method has been applied to predict the values of the physical parameters of the solar cell and to see the effect of each parameters on the energy conversion efficiency of the cell. The obtained results are shown in the examples below

EXAMPLE 1

$Max\ Z = 0.9341\ \mu_1 + 0.6254\ \mu_2$
$Subject\ to$

$0.556\, ff \le 0.9$
$4.1100\ pm \le 100$
$\mu_1 , \mu_2 , ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 1.6181$, $\mu_2 = 24.3309$, $Max\ Z = 16.7286$.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where (c_{ij} - Δ_1 , c_{ij} , $c_{ij} + \Delta_2$) and $i = 1,2$, $j = 1,2$.

$$Max\ Z = (0.7341,0.9341,1.7341)\ \mu_1 + (0.4254,0.6254,1.4254)\ \mu_2$$

$Subject\ to$

$0.556\, ff \le (0.7,0.9,1.7)$
$4.1100\ pm \le (99.8,100,100.8)$
$\mu_1 , \mu_2 , ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.

$Max\ Z = 0.9941\ \mu_1 + 0.6854\ \mu_2$
$Subject\ to$

$0.556\, ff \le 0.96$
$4.1100\ pm \le 100.06$
$\mu_1 , \mu_2 , ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 1.7266$, $\mu_2 = 24.3455$, $Max\ Z = 18.4028$.

EXAMPLE 2

$Max\ Z = 1.0692\ \mu_1 + 0.4444\ \mu_2$
$Subject\ to$

$0.44\, ff \le 0.9$
$4.7045\ pm \le 100$
$\mu_1 , \mu_2 , ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 2.0455$, $\mu_2 = 21.2562$, $Max\ Z = 11.6333$.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where (c_{ij} - Δ_1 , c_{ij} , $c_{ij} + \Delta_2$) and $i = 1,2$, $j = 1,2$.

$$Max\,Z = (0.8692,1.0692,1.8692)\ \mu_1 + (0.2444,0.4444,1.2444)\ \mu_2$$
Subject to

$0.44\,ff \le (0.7,0.9,1.7)$
$4.7045\ pm \le (99.8,100,100.8)$
$\mu_1,\ \mu_2, ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.

$Max\,Z = 1.1292\ \mu_1 + 0.5044\ \mu_2$
Subject to

$0.44\,ff \le 0.96$
$4.7045\ pm \le 100.06$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 2.1818$, $\mu_2 = 21.2690$, $Max\,Z = 13.1918$.

EXAMPLE 3

$Max\,Z = 1.1472\ \mu_1 + 0.5049\ \mu_2$
Subject to

$0.555\,ff \le 0.9$
$5.0475\ pm \le 100$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 1.6158$, $\mu_2 = 19.8118$

, $Max\,Z = 11.8566$.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where $(c_{ij} - \Delta_1,\ c_{ij},\ c_{ij} + \Delta_2)$ and $i = 1,2$, $j = 1,2$.

$$Max\,Z = (0.9472,1.1472,1.9472)\ \mu_1 + (0.3049,0.5049,1.3049)\ \mu_2$$
Subject to

$0.557\,ff \le (0.7,0.9,1.7)$
$5.0475\ pm \le (99.8,100,100.8)$
$\mu_1,\ \mu_2, ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.
$Max\,Z = 1.2072\ \mu_1 + 0.5649\ \mu_2$
Subject to

$0.557\,ff \le 0.96$
$5.0475\ pm \le 100.06$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 1..7235$, $\mu_2 = 19.8237$, $Max\,Z = 13.2790$.

EXAMPLE 4

$Max\,Z = 0.5695\ \mu_1 + 0.5295\ \mu_2$
Subject to

$0.29\,ff \le 0.9$
$2.5056\ pm \le 100$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 3.1034$, $\mu_2 = 39.9106$, $Max\,Z = 22.9001$.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where $(c_{ij} - \Delta_1,\ c_{ij},\ c_{ij} + \Delta_2)$ and $i = 1,2$, $j = 1,2$.

$$Max\,Z = (0.3695,0.5695,1.3695)\ \mu_1 + (0.3295,0.5295,1.3295)\ \mu_2$$
Subject to

$0.29\,ff \le (0.7,0.9,1.7)$
$2.5056\ pm \le (99.8,100,100.8)$
$\mu_1,\ \mu_2, ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.

$Max\,Z = 0.6295\ \mu_1 + 0.5895\ \mu_2$
Subject to

$0.29\,ff \le 0.96$
$2.5056\ pm \le 100.06$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 3.3103$, $\mu_2 = 39.9345$, $Max\,Z = 25.6253$.

EXAMPLE 5

$Max\,Z = 0.5075\ \mu_1 + 0.5942\ \mu_2$
Subject to

$0.29\,ff \le 0.9$
$2.2330\ pm \le 100$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 3.1034$, $\mu_2 = 44.7828$, $Max\,Z = 28.1849$.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where $(c_{ij} - \Delta_1,\ c_{ij},\ c_{ij} + \Delta_2)$ and $i = 1,2$, $j = 1,2$.

$$Max\,Z = (0.3075,0.5075,1.3075)\ \mu_1 + (0.3942,0.5942,1.3942)\ \mu_2$$
Subject to

$0.29\,ff \le (0.7,0.9,1.7)$
$2.2330\ pm \le (99.8,100,100.8)$
$\mu_1,\ \mu_2, ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.

$Max\,Z = 0.5675\ \mu_1 + 0.6542\,\mu_2$
$Subject\ to$

$0.29\,ff \le 0.96$
$2.2330\ pm \le 100.06$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 3.3103$, $\mu_2 = 44.8097$, $Max\,Z = 31.1931$.

EXAMPLE 6

$Max\,Z = 0.5220\ \mu_1 + 0.6057\,\mu_2$
$Subject\ to$

$0.29\,ff \le 0.9$
$2.2968\ pm \le 100$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method): $\mu_1 = 3.1034$, $\mu_2 = 43.5388$,

Max Z = 27.9915.

The formulated LPP is converted into FLPP:
Let $\Delta_1 = 0.2$ and $\Delta_2 = 0.8$ where $(c_{ij} - \Delta_1,\ c_{ij},\ c_{ij} + \Delta_2)$ and $i = 1,2$, $j = 1,2$.

$$Max\,Z = (0.3220, 0.5220, 1.3220)\ \mu_1 + (0.4057, 0.6057, 1.4057)\,\mu_2$$
$Subject\ to$

$0.29\,ff \le (0.7, 0.9, 1.7)$
$2.2968\ pm \le (99.8, 100, 100.8)$
$\mu_1,\ \mu_2, ff, pm \ge 0$

Using the proposed ranking function, the FLPP is converted into a crisp linear programming problem.

$Max\,Z = 0.5820\ \mu_1 + 0.6657\,\mu_2$
$Subject\ to$

$0.29\,ff \le 0.96$
$2.2968\ pm \le 100.06$
$\mu_1,\ \mu_2, ff, pm \ge 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is: $\mu_1 = 3.3103$, $\mu_2 = 43.5650$,

Max Z = 30.9278.

5. Conclusion

The physical parameters (V_{oc}, I_{sc}, FF, η) of a solar cell have been demonstrated experimentally using an area of about 210 cm^2 a commercial silicon solar cell in outdoor measurements under AM1.5 condition. A linear programming method has been used to predict and compare the values of the physical parameters of a solar cell. The obtained results are with an excellent agreement with those obtained experimentally.

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