

Effect of Silicon Solar Cell Physical Factors on Maximum Conversion Efficiency Theoretically and Experimentally

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Abstract: In this paper, ten major physical factors of a commercial silicon solar cell such as maximum current density, maximum voltage, maximum resistance, fill factor, energy conversion efficiency, lifetime τ , series and shunt resistances have been demonstrated. Integer linear programming (ILP) tests these factors of a commercial cell and the obtained results are compared with those of experimental values. The experimental results of the solar cell indicate excellent agreement as compared with those obtained by (ILP).

Keywords: Fuzzy set technique, commercial solar cell, physical parameters, outdoor measurement

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1. Introduction

Solar energy is one of the best types of energy because of its advantages that make it one of the preferred and widely used alternative energy sources clean and cheap but almost free to add to the low cost of manufacturing materials used in. Photovoltaic cells are the field of technology and research related to a practical application in the production of electricity from light, but it is often used specifically to refer to the generation of electricity from sunlight. Cells are described as photovoltaic cells, although the light source is not the sun (e.g. lamp light, artificial light ... etc.). Applications of solar cells are diverse, including low-power devices such as computers, electronic games, clocks. Second type is average power devices such as light-emitting devices, radio-visual equipment, traffic lights. The third type including high power devices such as pumping water, communication stations, satellite stations. Solar panels are used on spacecraft for two important purposes: First production of energy for measuring and exploration devices, providing heat for work or cooling, and for

communication. Second Generating power to operate the rocket engine or the electric motor of a spacecraft and is sometimes called solar-electric propulsion. Many researchers interesting to solve Kepler equation to overtake the problems in the orbital satellite^[1-8]. Researchers focused on the manufacture of solar cells using inexpensive, non-toxic, easy to prepare and uncomplicated materials. These materials are inorganic and organic and are prepared in different ways and are in the form of thin films passed on various bases that have been solid such as: silicon, ITO, FTO and glass substrates or to be flexible substrates such as plastic and the goal is to obtain a flexible solar cell^[9-23].

Practically, a solar cell, the value of short-circuit density based on some parameters, reflection losses, series and shunt resistance, front and back contact and recombination losses. The value of short circuit current is determined using Eq. 1 at different temperatures

$$I = I_D \times \left(\exp^{\frac{qV}{nKT}} - 1 \right) - I_L$$

1

The open circuit voltage is the maximum voltage

available from a solar cell. Eq.1 when $I = 0$ the

$$V_{oc} = \frac{qV}{nkT} \ln \left(\frac{I_{sc}}{I_o} + 1 \right)$$

2

where $I_{sc} = I_{ph}$, V_{oc} is corresponding to I_{sc} and I_o , For a high open circuit voltage is inversely proportional to I_o , thus increases V_{oc} leads to decreases I_o and Vice versa.

Fill factor is defined as the ratio of the maximum power output at the maximum power point to the product of the open circuit voltage and short circuit current expressed by the relation^[24,25]

$$FF = \frac{P_m}{V_{oc}I_{sc}} = \frac{V_m I_m}{V_{oc} I_{sc}}$$

3

The efficiency of a solar cell is the ratio of the power output corresponding to the maximum power point to the power input is expressed by the equation^[26-32]

$$\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{V_{oc} \times I_{sc} \times FF}{P_{in}} \times 100\%$$

4

where P_m : maximum power intensity, P_{in} : intensity of the incident radiation V_{oc} : open circuit voltage, I_{sc} : short circuit current. This equation indicates the efficiency of a solar cell at any temperature.

Integer Linear Programming^[33,34].

Optimization problems are those problems in which we look for the largest or smallest value of a function that depends on a variable or variables. This function is called the objective function. There are several components to any problem addressed by linear programming, for the requirements of a linear programming as follows: objective function, decision variables, constrain, and nonnegative. These elements can be expressed as follows: Objective function: One goal must be unequivocally defined in the form of a quantifiable criterion. The objective function of the linear programming problem is either maximization or minimization. For a linear relationship, that is, they are

expression of V_{oc} become

all raised to the same true. Achieving the goal is to implement multiple activities and functions called resources, of which specific quantities are available which constitute a constraint on the achievement of the objective. Decision variables: they fall within the function of the target to be maximized or reduced and are first-class variables, and these variables are either zero or positive. Constraint: are specific resources competing for exploitation and use of different areas, expressed in the problem of linear programming through the available resources, in the sense that we maximize or underestimate the variables within the target function under the constraints of limited resources. The constraints are expressed in the form of linear equations, as follows: equality ($=$), less than or equal to (\leq), and more than or equal to (\geq)

In this research, an integer linear programming method has been used to predict the (maximum and minimum values) of a main factors of a photovoltaic cell measurements, and compare all the input parameters with the output parameters using this method. Operations research is concerned with the improvement of specific processes and methods in order to arrive at an optimal solution to the problems.

2. Experimental Method

The method including integer linear programming method has been applied to describe solar cell parameters with respect to T . also these factors have been tested experimentally, then the acquired results are compared with each other theoretically and experimentally.

3. Results and Discussion

Figure 1- Figure 4 present the factors of the solar cell (R_m , J_m , V_m , FF , η_m , τ , R_s , R_{sh}) with respect to temperature (experimentally)^[17].

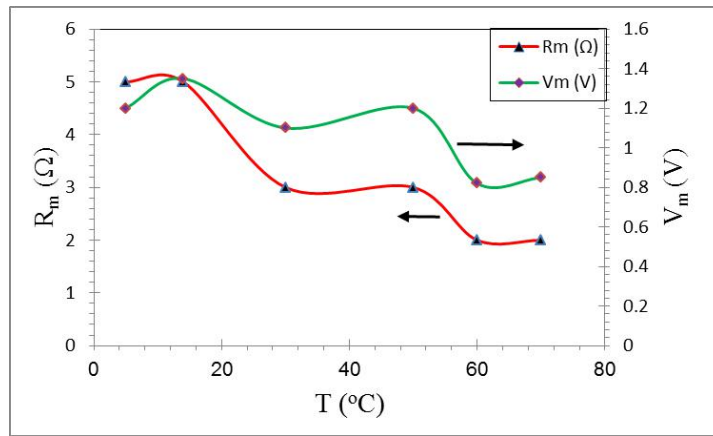


Figure 1. Maximum values of resistance and voltage vs. T.

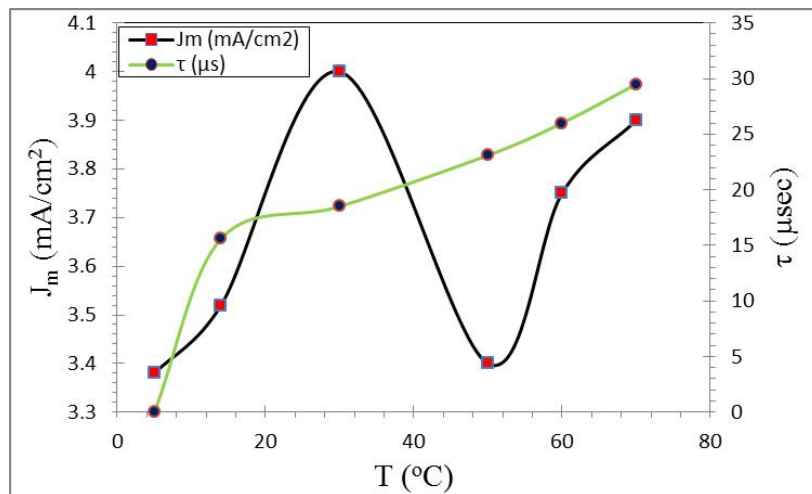


Figure 2. Maximum values of current density and minority carrier lifetime vs. T.

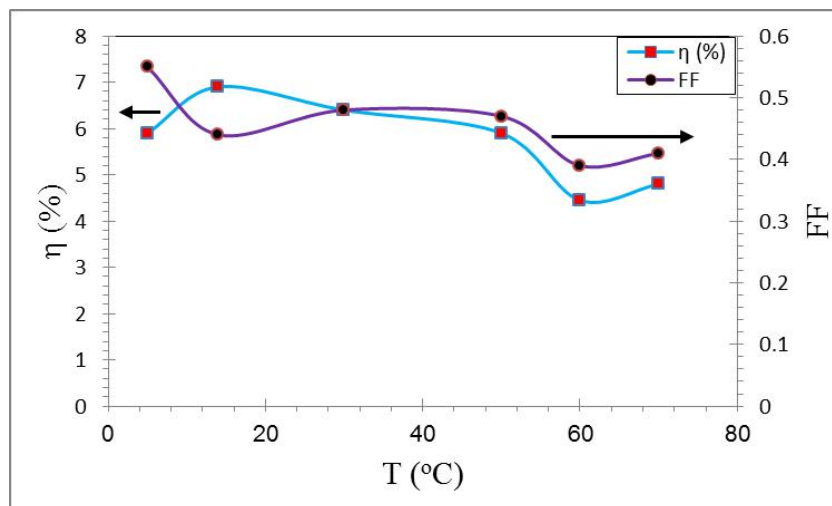


Figure 3. Conversion efficiency and fill factor vs. T

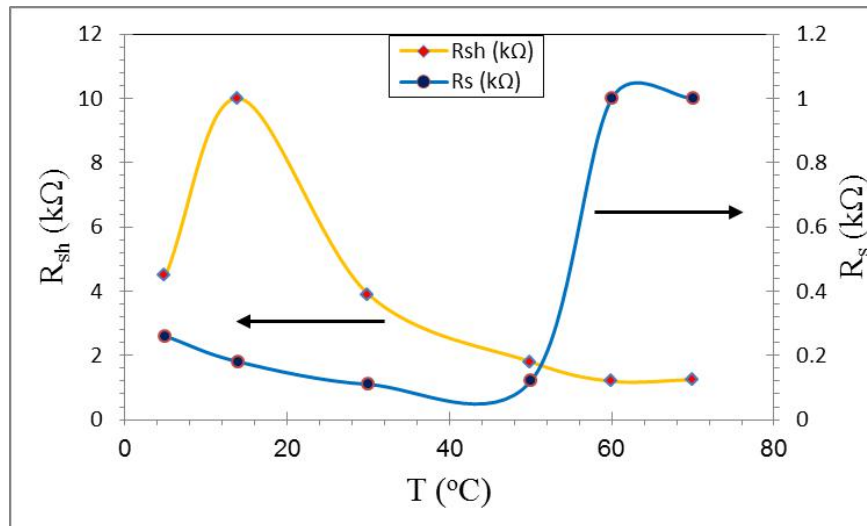


Figure 4. Series and shunt resistance values vs. T.

Using integer linear programming to describe the behaviors of the important factors of solar cell with respect to T are illustrated below

EXAMPLE 1

$$\text{Max } Z = 0.9240 \mu_1 + 0.5487 \mu_2$$

Subject to

$$0.55 ff \leq 0.9$$

$$4.0656 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method):
 $\mu_1 = 1.6364$, $\mu_2 = 24.5966$, **Max Z = 15.0082.**

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 $i = 1, 2, j = 1, 2$.

$$\text{Max } Z = (0.7240, 0.9240, 1.7240) \mu_1 + (0.3487, 0.5487, 1.3487) \mu_2$$

Subject to

$$0.55 ff \leq (0.7, 0.9, 1.7)$$

$$4.0656 pm \leq (99.8, 100, 100.8)$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 0.9840 \mu_1 + 0.6087 \mu_2$$

Subject to

$$0.55 ff \leq 0.96$$

$$4.0656 pm \leq 100.06$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is:
 $\mu_1 = 1.7455$, $\mu_2 = 24.6114$, **Max Z = 16.6985.**

EXAMPLE 2

$$\text{Max } Z = 1.0692 \mu_1 + 0.4444 \mu_2$$

Subject to

$$0.44 ff \leq 0.9$$

$$4.7045 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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 $(c_{ij} - \Delta_1, c_{ij}, c_{ij} + \Delta_2)$ and $i = 1, 2, j = 1, 2$.

$$\text{Max } Z = (0.8692, 1.0692, 1.8692) \mu_1 + (0.2444, 0.4444, 1.2444) \mu_2$$

Subject to

$$0.44 ff \leq (0.7, 0.9, 1.7)$$

$$4.7045 pm \leq (99.8, 100, 100.8)$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 1.1292 \mu_1 + 0.5044 \mu_2$$

Subject to

$$0.44 ff \leq 0.96$$

$$4.7045 pm \leq 100.06$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 0.9886 \mu_1 + 0.4855 \mu_2$$

Subject to

$$0.48 ff \leq 0.9$$

$$4.3498 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method):

$$1.8750, \mu_2 = 22.9896, \text{Max } Z = 13.0151$$

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 $i = 1, 2, j = 1, 2$.

$$\text{Max } Z = (0.7886, 0.9886, 1.7886) \mu_1 + (0.2855, 0.4855, 1.2855) \mu_2$$

Subject to

$$0.48 ff \leq (0.7, 0.9, 1.7)$$

$$4.3498 pm \leq (99.8, 100, 100.8)$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 1.0486 \mu_1 + 0.5455 \mu_2$$

Subject to

$$0.48 ff \leq 0.96$$

$$4.3498 pm \leq 100.06$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is:

$$\mu_1 = 2.0000, \mu_2 = 23.00034$$

$$\text{Max } Z = 14.6455.$$

EXAMPLE 4

$$\text{Max } Z = 0.9229 \mu_1 + 0.4722 \mu_2$$

Subject to

$$0.47 ff \leq 0.9$$

$$4.0608 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method):

$$\mu_1 = 1.9149, \mu_2 = 24.6257, \text{Max } Z = 13.3955.$$

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 $i = 1, 2, j = 1, 2$.

$$\text{Max } Z = (0.7229, 0.9229, 1.7229) \mu_1 + (0.2722, 0.4722, 1.2722) \mu_2$$

Subject to

$$0.47 ff \leq (0.7, 0.9, 1.7)$$

$$4.0608 pm \leq (99.8, 100, 100.8)$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 0.9829 \mu_1 + 0.5322 \mu_2$$

Subject to

$$0.47 ff \leq 0.96$$

$$4.0608 pm \leq 100.06$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is:

$$\mu_1 = 2.0426, \mu_2 = 24.6405, \text{Max } Z = 15.1213.$$

EXAMPLE 5

$$\text{Max } Z = 0.6825 \mu_1 + 0.3994 \mu_2$$

Subject to

$$0.39 ff \leq 0.9$$

$$3.0030 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method):

$$\mu_1 = 2.3077, \mu_2 = 33.3000, \text{Max } Z = 14.8750.$$

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 $i = 1, 2, j = 1, 2$.

$$\text{Max } Z = (0.4825, 0.6825, 1.4825) \mu_1 + (0.1994, 0.3994, 1.1994) \mu_2$$

Subject to

$$0.39 ff \leq (0.7, 0.9, 1.7)$$

$$3.0030 pm \leq (99.8, 100, 100.8)$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

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

$$\text{Max } Z = 0.7425 \mu_1 + 0.4594 \mu_2$$

Subject to

$$0.39 ff \leq 0.96$$

$$3.0030 pm \leq 100.06$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is:

$$\mu_1 = 2.4615, \mu_2 = 33.3200, \text{Max } Z = 17.1349.$$

EXAMPLE 6

$$\text{Max } Z = 0.7380 \mu_1 + 0.4186 \mu_2$$

Subject to

$$0.41 ff \leq 0.9$$

$$3.2472 pm \leq 100$$

$$\mu_1, \mu_2, ff, pm \geq 0$$

We get the optimal solution by using win QSB program (simplex method):

$$\mu_1 = 2.1951, \mu_2 = 30.7958, \text{Max } Z = 14.5111.$$

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 $i = 1, 2, j = 1, 2$.
 $Max Z = (0.5380, 0.7380, 1.5380) \mu_1$
 $+ (0.2186, 0.4186, 1.2186) \mu_2$
Subject to
 $0.41 ff \leq (0.7, 0.9, 1.7)$
 $3.2472 pm \leq (99.8, 100, 100.8)$
 $\mu_1, \mu_2, ff, pm \geq 0$

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

$Max Z = 0.7980 \mu_1 + 0.4786 \mu_2$
Subject to
 $0.41 ff \leq 0.96$
 $3.2472 pm \leq 100.06$
 $\mu_1, \mu_2, ff, pm \geq 0$

We get the optimal solution by using win QSB program (simplex method) of the above CLP problem is:
 $\mu_1 = 2.3415, \mu_2 = 30.8142, \mathbf{Max Z = 16.6162}$.

4. Conclusion

Integer linear programming as a mathematical method has been applied to calculate the physical factors of a silicon solar cell. These factors are measured experimentally. The obtained results with the comparison between them indicate a good agreement.

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