Effect of parasitic resistances on CdTe solar cell and validation with datasheet of FS-6450A in Matlab/Simulink

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Abstract. Cadmium telluride (CdTe) is the second popular choice after silicon for the solar cell in photovoltaic (PV) technology. Among the thin-film photovoltaic panels, CdTe reaches its first position to surpass crystalline silicon PV in cheapness and confined a large space in the PV market. Before constructing CdTe PV panels its operating characteristics should be properly judged. Any solar cell being related to a high level of nonlinearity, the model parameter is to be chosen judiciously. The operating characteristics can be well considered after the model circuit parameter comes accurately. In this paper operating characteristics of a thin-film CdTe solar module is shown with the variation of series and shunt resistance. Also considering parasitic resistances, the output characteristics of the solar cell varying climate condition is shown. Validation with FS-6450A PV module and all the simulation works are done in Matlab/Simulink environment. In the end, it is concluded with possible outcomes.

1. Introduction

PV energy is the greenest and cleanest among the other renewables like wind, small hydro, tides, geothermal heat and biomass. Thin-film solar cells are of four types and they are CdTe, CIGS (copper indium gallium selenide), CIS (Copper Indium Selenide), and A-Si (amorphous silicon). CdTe solar cells are having a strong potential in large scale energy production owing to their wide scalability and low production cost [1]. A cutaway structure of a CdTe solar cell is given in Figure 1.

![Figure 1. Cutaway structure of a CdTe solar cell](image)
First Solar has reported the efficiency of CdTe solar cell is 22.1% [2]. Still, modern researchers are much concerned about the effect of temperature and insolation which are the two major parameters upon which operating characteristics of a solar cell depends a lot. Then the performance of the PV module is highly affected. One of the most important parts of a PV system is the PV array or power generating unit. Solar cell to solar array configuration is given in Figure 2 below.

![Solar Cell to the solar array configuration](image)

**Figure 2. Solar cell to the solar array configuration**

It is reported with a theoretical efficiency of 29.07% for a CdTe solar cell and it is substantiated with the help of the ADEPT 2.1 photovoltaic simulation tool [3]. Different multi-crystalline PV modules are analysed in five and seven parameter model through Matlab [4]. With the increase of temperature, cell performance decreases [3]. The reverse saturation current density highly depends on the bandgap of the semiconductor material which affects the output of the solar cell [3]. For the thin-film technology, direct bandgap semiconductor material like CdTe is much popular due to its low manufacturing cost. When temperature, as well as sun insolation, varies P-V (power-voltage) and I-V (current-voltage) characteristics of a PV module affects a lot. Appropriate modelling and performance evaluation is quite necessary for building a reliable PV system. Parasitic resistances affect much infill factor of the solar cell [5]. This paper demonstrates for a thin-film CdTe solar module characteristics varying series and shunt resistance of the PV model. Also, the operating characteristics of varying temperature and sun insolation are well presented considering the parasitic resistances. Many researchers are trying to find an efficient way to find out more accurate characteristics of a PV cell. One of the current researchers has shown the job using Eureqa software [6]. I-V characteristics of a thin-film PV module has been well established varying temperature and insolation with an analytical approach [7]. The operating characteristics of a mono PERC solar cell have been analysed through the variation of the environmental parameter using Matlab [8]. In this paper, the whole work is developed in a Matlab environment. A reference datasheet [9] is used to simulate the CdTe PV module.

In this paper, section II describes the electrical modelling of a solar cell considering parasitic resistances. Section III CdTe PV model is developed using mathematical formulations in Matlab Simulink environment. Section IV describes the P-V and I-V characteristics varying series and shunt resistance (parasitic resistance). Also in this section, considering parasitic resistance, the output characteristics varying weather condition is well presented. Lastly, a conclusion is drawn.

### 2. Electrical circuit model

Any PV module requires an equivalent circuit to analyse the operating characteristics of a solar cell. The electrical equivalent circuit can be considered neglecting the losses for an ideal case study for easier computation and modelling. In [3], the authors discarded the contact loss and leakage loss in the solar cell and how temperature variation affects the cell efficiency is discussed. But in a practical scenario, it should be considered and the equivalent circuit for this is given as in Figure 3.

![Single diode solar cell with parasitic resistances](image)

**Figure 3. Single diode solar cell with parasitic resistances**
3. Simulink model

The complete equivalent circuit shown in Figure 3 is modelled in Matlab Simulink environment with the help of the following major equations [10-11].

\[ I_{ph} = [I_{sc} + \{k_i (T - T_n)\}]G / 1000 \]  

Where, \( I_{ph} \) = Photocurrent, \( I_{sc} \) = Short circuit current, \( K_i \) = Temperature coefficient of \( I_{sc} \), \( T \) = Operating temperature, \( T_n \) = Reference temperature, and \( G \) = Global radiation.

\[ I_n = I_{ph} - (e^{(\frac{(I_{sc} + V_o)}{qN_k})} - 1)I_{sd} - I_{sh} \]  

\[ I_{sh} = \frac{V_o + I_{sd}R_{se}}{R_{sh}} \]

Where, \( I_0 \) = Output current, \( q \) = Electron charge, \( K \) = Boltzmann constant, \( V_0 \) = Output voltage, \( n \) = Ideality factor of the diode, \( N_s \) = Number of interconnected series cells, \( I_{sd} \) = Saturation current of the diode, \( I_{sh} \) = Current in the shunt resistance \( R_{sh} \), and \( R_{se} \) = Series resistance

The Simulink model is shown in Figure 4 below at standard test conditions (STC).

![Simulink model diagram](image)

**Figure 4.** Simulink model of the CdTe thin-film PV module

| Maximum power(W) \( P_m \) | The voltage at maximum power(V) \( V_m \) | Current at maximum power(A) \( I_m \) | Open circuit voltage(V) \( V_{oc} \) | Short circuit current(A) \( I_{sc} \) |
|--------------------------|-----------------|-----------------|-----------------|-----------------|
| 450                      | 186.8           | 2.41            | 221.1           | 2.57            |

4. Result Analysis

Here the P-V and I-V characteristics varying shunt resistance (0.3kΩ to 2.1kΩ) shown below in Figure 5 and Figure 6 which is found at standard test condition (STC). STC is important for the rating of any PV panel and it is the condition of Sun insolation =1000W/m², Air mass 1.5, Temperature = 25°C. Maximum power \( P_m \), efficiency (\( \eta \)), fill factor all are tabulated in Table 2.
Table 2. Calculated efficiency and fill factor varying shunt resistance at STC

| $R_{sh}$ (kΩ) | 0.3  | 0.6  | 0.9  | 1.2  | 1.5  | 1.8  | 2.1  |
|---------------|------|------|------|------|------|------|------|
| η%            | 14.46| 16.93| 17.78| 18.20| 18.46| 18.63| 18.75|
| FF%           | 63.44| 73.85| 77.39| 79.08| 80.19| 81.38| 81.38|

Figure 7 and Figure 8 below represents P-V and I-V characteristics varying series resistance (0.01Ω to 10 Ω) and the quality of the cell varies accordingly which is shown in Table 3.
Table 3. Calculated efficiency and fill factor varying series resistance at STC

| $R_s$ (Ω) | 10  | 1   | 0.1 | 0.01 |
|-----------|-----|-----|-----|------|
| $\eta$%   | 16.06| 17.986 | 18.18 | 18.20 |
| FF%       | 70.347 | 78.21 | 79.03 | 79.08 |

From Table 2 and Table 3, it is seen that shunt resistance $R_{sh}$ to be very high and series resistance $R_s$ to be very low, then the output will become desirable. The solar cell is sensitive a lot in weather condition and a huge variation is seen in P-V and I-V characteristics varying temperature considering parasitic resistances, which is presented in Figure 9 and Figure 10. Considering $R_{se}$ and $R_{sh}$ and from P-V and I-V characteristics all parameters including fill factor are presented and for validation relative error is calculated in both the reference and proposed model, shown in Figure 13.

Figure 7. P-V characteristics varying parasitic series resistance at STC

Figure 8. I-V characteristics varying parasitic series resistance at STC
Sun insolation is another parameter that affects much in the performance of a solar cell. Varying insolation keeping temperature fixed at 25°C, the P-V and I-V characteristics are captured in Figure 11 and Figure 12.
Any solar panel is designed based on the STC rating. Fill factor is the most important issue to justify one’s model. Here all the parameters including fill factor and relative error are presented well in Figure 13. From the P-V and I-V characteristics found from Matlab Simulation, it is obvious that considering the practical scenario, the proposed model almost agrees with the reference one by selecting the proper value of series and shunt resistance.

![Figure 12. I-V characteristics varying insolation with temperature at 25°C](image)

In this manuscript, the Simulink model of a thin-film CdTe PV module is established in a Matlab environment. Parasitic resistances or the series and shunt resistance must be considered in the electrical circuit for modelling a PV module. Choice of $R_s$ and $R_{sh}$ is a crucial job to obtain the model accuracy. Here, operating characteristics (P-V and I-V) are presented varying series and shunt resistances and the quality of the cell has been judged. Also, choosing proper resistances, the P-V and I-V curve varying weather data like temperature and sun insolation is well established at standard test condition (STC). The degree of accuracy is very close to the manufacturer datasheet. Appropriate selection of different parameter of a solar cell is a vital issue to achieve an accurate model. Researchers still engage in proper and accurate parameter estimation to obtain a desirable PV model. The proposed model can help design a suitable and reliable PV system.

![Figure 13. Reference and simulated parameter of CdTe PV model at STC](image)
6. References

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