Research on Modelling and Output Characteristics of PV Cells Based on LabVIEW

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Abstract. The photovoltaic cells was modelled used LabVIEW2016, the simulation test of the model has taken into account the actual change of the climate and environment. The simulation results show that the simulation curve of using the model built by LabVIEW can accurately reflect the working characteristics of the PV cells in different climate environments, the results of this study have practical engineering significance for the research of photovoltaic cells.

1. Introduction
Photovoltaic (PV) energy is a green energy to concern in recent years, this energy mainly relies on PV cells for solar energy to electricity conversion. The battery manufacturer provides the test results in the reference test environment when the battery is shipped, such as peak power, operating current & voltage, short circuit current, open circuit voltage, conversion efficiency and other parameters when the irradiance of 1000 W/m² and the component temperature at 25 °C, and the scope of the allowable operating temperature. However, if we want to get the working characteristics of PV modules, we need to model and simulate the characteristics of the panel according to the parameters we set.

In this paper, we conduct the PV cell simulation research in LabVIEW2016. The PV cells are mathematically modeled in the block diagram, the analysis & research of the output characteristics of PV cell components in the front panel. The LabVIEW virtual instrument software is a graphical programming language that is based on G language, it has an intuitive front panel and block diagram. Compared with the traditional MATLAB simulation, the simulation speed is faster, it reduces algebra ring and other interference, the output waveform is more observable, and the data is exported and stored more conveniently, We can directly in the front panel controls for debugging. The simulation results show that the use of LabVIEW for PV cell modeling and simulation, we can accurately get the working characteristics of PV cells [1].

2. The mathematical model of PV cell
According to the photovoltaic effect, the external characteristics of each PV cell can be seen as a constant current source and a forward diode in parallel, the diode shows the phenomenon of molecular polarization, the $R_s$ & $R_{sh}$ represent losses, the internal capacitance effects can be ignored in engineering, so the equivalent circuit diagram of the PV cell can be shown in Fig.1 [7-8]. According to Kirchhoff's law, we can get its equivalent mathematical model as shown in Eq.(1).
\[ I_{pv} = I_{ph} - I_{d} - I_{sh} \]  

In Eq.(1), \( I_{pv} \) is the output current of the battery, \( I_{ph} \) for the diode reverse saturation current, \( I_{d} \) is the current flowing through the internal diode, then put the \( I_{d} \) and \( I_{ph} \) into Eq.(1), the output current \( I_{pv} \) can be written as Eq.(2)

\[ I_{pv} = I_{ph} \times \left[ \exp \left( \frac{q(V_{pv} + I_{pv}R_{sh})}{N_{sec}KT_{j}} \right) - 1 \right] \times \frac{V_{pv} + RI_{pv}}{R_{sh}} \]  

\[ I_{pv} = I_{w} \times \left[ 1 - C_i \left( \exp \left( \frac{V}{C_zV_w} \right) - 1 \right) \right] \]  

In Eq.(2), \( I_{ph} \) represents output current of the battery, and \( V_{pv} \) represents the output voltage. In the following, it is abbreviated as \( I \) and \( V \) for convenience, where \( q \) represents the electron charge \((1.602 \times 10^{-19} \text{C})\), and \( K \) is the Boltzmann's constant \((1.3806503 \times 10^{-23} \text{J/K})\). Large number of experiments show that the Eq.(3) and PV cells in the short circuit current curve is very close, while in the open circuit voltage region and the maximum power point has the approximate result of Eq.(4) [5-6]. In Eq.(4), \( I_m, V_m, I_{sc}, V_{oc} \) respectively represents the maximum operating current & voltage, short-circuit current and open circuit voltage. The output power of PV cells can be expressed as Eq. (5).

\[ p = I_{pv} \times \left[ 1 - C_i \left( \exp \left( \frac{V}{C_zV_w} \right) - 1 \right) \right] \times V \]  

Because the parameters \( I_{sc}, V_{oc}, I_{m}, V_{m} \) will change under certain conditions, after the introduction of the corresponding compensation coefficient, we can approximate the conclusion that the four parameters can be calculated at any illumination \( S \) and temperature \( T \) according to Eq.(6) [2, 9].

\[ \begin{align*}
I_{sc} &= I_{sc ref} \times \frac{S}{S_{ref}} (1 + aDT) \\
V_{oc} &= V_{oc ref} \times \ln(e + bDS)(1 - cDT) \\
I_{m} &= I_{m ref} \times \frac{S}{S_{ref}} (1 + aDT) \\
V_{m} &= V_{m ref} \times \ln(e + bDS)(1 - cDT)
\end{align*} \]  

\[ \begin{align*}
DL = \alpha (S / S_{ref}) DT + (S / S_{ref} - 1) I_{sc} \\
DV = -\beta DT - R_z DI \\
DT = T - T_{ref} \\
I' = I + DI \\
V' = V + DV \\
T_{ref} + \alpha + \beta
\end{align*} \]  

In Eq.(6), \( S_{ref} \) and \( T_{ref} \) represent the reference value of solar radiation and temperature, taking \( 1KW/m^2 \) and \( 25 \text{°C} \), respectively, \( DS \) is the difference between the actual light irradiance and the reference irradiance, \( DS = S - S_{ref} \), \( DT \) is the difference between the actual battery temperature and the reference battery temperature, \( DT = T - T_{ref} \). The parameters \( a, b, c \) for the compensation coefficient, respectively, typical values are \( a = 0.0025/ \text{°C} \), \( b = 0.0005W/m^2 \), \( c = 0.00288/ \text{°C} \). According to the literature [3], by moving any point \((V, I)\) over the characteristic curve at reference illumination and battery temperature, any work point can be obtained at new solar radiation intensity and the new cell temperature [3, 4], as shown in Eq.(7). Therefore, according to Eq. (3), the mathematical model of PV cell after considering climate change can be expressed as Eq.(8).

\[ I = I_{w} \times \left[ 1 - C_i \left( \exp \left( \frac{V - DV}{C_zV_w} \right) - 1 \right) \right] + DI \]  

In the above formulas, \( T \) represents the battery temperature under actual lighting, \( T_{air} \) is the ambient temperature, \( K \) is the battery temperature coefficient \((K=0.03 \text{ °C} \cdot m^2/W) \) under the change of illumination, \( \alpha \) & \( \beta \) respectively represent the current change temperature coefficient \((A/ \text{°C}) \) and
voltage change temperature coefficient($V/\degree C$) under the reference sunshine, $\alpha = 0.0012I_{sc}$ and $\beta = 0.005V_{oc}$. $R_s$ is the series resistance of the PV module, $R_s$ can be expressed as Eq.(9).

$$R_s = \frac{N}{N_p} R_{s,ref} = \frac{N}{N_p} (A_{ref} \ln(1 - \frac{I_{s,ref}}{I_{sc,ref}}) - V_{s,ref} + V_{oc,ref}) / I_{s,ref}$$

$$A_{ref} = (T_{ref} \mu_{isc} - V_{s,ref} + e N_i) / [(\mu I_{sc} T_{ref} / I_{s,ref}) - 3]$$  \hspace{1cm} (9)

3. Modeling and Simulation of PV Cells Using LabVIEW

We select the model for the DJB-18V100WK PV modules, use the block diagram for battery modelling in LabVIEW and analyse the output characteristics in the front panel. In order to get a continuously varying voltage from 0–50V, a straight line $y=x$ is generated using the formula node of LabVIEW, the range of $x$ is set to [0, 50], the block diagram is shown in Fig.2. In the previous section, the Eq.(3) shows the battery $I-V$ mathematical model, the Eq.(4) gives the mathematical expressions for the variables $C_1$ and $C_2$ in Eq. (3). The parameters $C_1$ & $C_2$ are solved in the block diagram of LabVIEW, and the block diagram constructed according to the mathematical model is shown in Fig.3, according to Eq.(3), the block diagram of the $I-V$ relationship of the battery is shown in Fig.4.

![Fig.2 Block Diagram of Varying Voltage](image1)

![Fig.3 Block Diagram of Parameters $C_1$ & $C_2$](image2)

![Fig.4 Block Diagram of $I-V$ Characteristics of Solar Cells](image3)

According to the mathematical model established in Fig.3 & Fig.4, the $I-V$ & $P-V$ characteristic curves of the solar cell can be obtained as shown in Fig.5. It can be seen from Fig. 5 that the $I-V$ curve of the PV cell presents a non-linear characteristic, and there is an inflection point in the curve. The voltage gradually decreases on the left of the inflection point, the current decreases rapidly on the right of the inflection point, the $P-V$ curve of the PV cell also presents non-linear characteristic. As the voltage increases, the power gradually increases until the inflection point, and then the power drops rapidly.

![Fig.5 Front panel of PV cell test curve](image4)

According to Eq.(6) & Eq.(9) in the previous section, take the values of $\alpha = 0.0012I_{sc}$, $\beta = 0.005V_{oc}$, we can solve the variation of voltage and current ($DV$ & $DI$) under different irradiance & temperature
conditions, the block diagram shown in Fig.6. According to Eq.(6) to Eq.(9), the block diagram of the model shown in Fig.7 consider the PV cell when the temperature changes and the radiation intensity is changed.

4. Characteristics Simulation of photovoltaic cell model

We designed the battery parameter input box in the front panel of LabVIEW, the middle variable display box for $C_1$, $C_2$, delta $I$, delta $V$, alpha , beta, etc. We enter the battery parameters: $V_{oc}=22V$, $V_m=18V$, $I_m=5.55A$, $I_{sc}=5.95A$ in the front panel, take $R_s=0.12$; the radiance of 900 $W/m^2$, 800 $W/m^2$, 700 $W/m^2$ respectively; temperature respectively 40 $^\circ$C, 25 $^\circ$C, 10 $^\circ$C.

![Fig.6 Block diagram of solution for $DI$ & $DV$](image1)

![Fig.7 Part of the block diagram of the PV cell](image2)

![Fig.8 The block diagram of the PV cell was takes into account the parameters change](image3)

![Fig.9 The $I/A$ curves of different irradiance](image4)

![Fig.10 The $I/A$ curves in different temperature](image5)
We can observe the PV cell output curves in the $X$-$Y$ diagram of a variety of different parameters after running the program. Here, we mainly study the characteristics of PV cells when the temperature changes but the radiation intensity is constant, as well as the radiation intensity changes while the temperature is not changed. For the convenience of comparison, we display the output curves of the PV cells under different temperatures and different lighting conditions in one $X$-$Y$ graph, the working curves as shown in Fig.9 to Fig.12. We can accurately get the working characteristics of PV cells through the use of LabVIEW.

From these Figs, We can be seen that the output current of PV cells increases with increasing light intensity, and the voltage increase is small, the temperature increases, the open circuit voltage decreases, the output current changes little, the output power increases with increasing light, the output power also decreases with increasing temperature.

5. Analysis and research of simulation results

The LabVIEW software provides a convenient data export function, so we can export the data to excel for analysis. Part of the measurement results of the voltage and power when the irradiation change has shown in tab.1. We can see from Tab.1 that with the increase of radiation intensity, the output power of the PV cells, when the irradiance of illumination is $700\text{W/m}^2$, $800\text{W/m}^2$, $900\text{W/m}^2$ respectively, the output power at the maximum when the voltage value of about 15V. The power also has the maximum value, the maximum power values were $61.5\text{W}$, $69.94\text{W}$, and $77.34\text{W}$ respectively. In order to compare the maximum power at different temperatures & irradiations, we list the $I$-$V$ and $P$-$V$ data for the changes in irradiance and temperature, respectively, as shown in Tab.2.

| Table 1 The output power and voltage under different irradiation |
|-----------------|-----------------|-----------------|-----------------|
| $900\text{W/m}^2$ | $800\text{W/m}^2$ | $700\text{W/m}^2$ |
| 0.08 V          | 0.45 W          | 0.49 V          | 2.38 W          | 0.89 V          | 3.81 W          |
| 1.08 V          | 5.97 W          | 1.49 V          | 7.28 W          | 1.89 V          | 8.08 W          |
| 3.08 V          | 17.03 W         | 3.49 V          | 17.07 W         | 3.89 V          | 16.62 W         |
| 5.08 V          | 28.09 W         | 5.49 V          | 26.86 W         | 5.89 V          | 25.15 W         |
| 8.08 V          | 44.64 W         | 8.49 V          | 41.53 W         | 8.89 V          | 37.94 W         |
| 10.08 V         | 55.59 W         | 10.49 V         | 51.21 W         | 10.89 V         | 46.36 W         |
| 13.08 V         | 70.96 W         | 13.49 V         | 64.65 W         | 13.89 V         | 57.88 W         |
| 15.08 V         | 77.34 W         | 15.49 V         | 69.64 W         | 15.89 V         | 61.5 W          |
| 16.08 V         | 76.27 W         | 16.49 V         | 67.78 W         | 16.89 V         | 58.86 W         |
| 18.08 V         | 45.18 W         | 18.49 V         | 34.52 W         | 18.89 V         | 23.43 W         |

We can see from Tab.2 that the maximum power is also different when the irradiance and temperature are different. When the temperature is $25\text{C}$, the maximum power increases from $61.5\text{W}$ to $77.34\text{W}$ when the irradiance rises from $700\text{W/m}^2$ to $900\text{W/m}^2$. When the irradiance is constant at $900\text{W/m}^2$, the maximum power is reduced from $84.25\text{W}$ to $70.11\text{W}$ when the temperature rises from 10 to 40.
degrees. When the irradiance is 1000\(W/m^2\), the temperature is 5 \(^\circ C\), the maximum power is increased to 94.95\(W\). The conclusion coincides with simulation using MATLAB or other software.

### Table 2  The output power and voltage of PV cells in different climates

| Irradiance | TEMP  | Voltage | Power  |
|------------|-------|---------|--------|
| 900W/m²    | 25°C  | 15.08 V | 77.34 W|
| 800W/m²    | 25°C  | 15.49 V | 69.64 W|
| 700W/m²    | 25°C  | 15.89 V | 61.5 W |
| 900W/m²    | 40°C  | 13.42 V | 70.11 W|
| 900W/m²    | 25°C  | 15.08 V | 77.34 W|
| 900W/m²    | 10°C  | 16.74 V | 84.25 W|
| 1000W/m²   | 5°C   | 16.89 V | 94.95 W|

6. **Conclusion**

According to the simplified mathematical model of PV cell equivalent circuit, we deduced the mathematical model under different conditions of different illumination & temperature in actual condition, we modelling the PV cells by using LabVIEW, given the \(I-V\) & \(P-V\) curves at different irradiance & temperatures in the front panel and the maximum power analysis was performed based on the data that was exported to Excel. We can see from the output curve and data sheet that the temperature and the Irradiance have influence on the power of the PV cells; this also verifies the accuracy of the model built in this paper. Benefit from the LabVIEW, the mathematical modelling of PV model is more convenient than use of Matlab, the emulation faster, and it reduced the algebraic rings. So we provide a kind of simulation ideas for the research of PV cells in the paper.

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