

Mathematical Modeling and Simulation of Photovoltaic Array

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1. Introduction

This work deals with modeling and simulation of PV system which can be connected to the distribution power network. It means photovoltaic array. I try to draw up a specification of PV array problems because these sources have certain specific features, that are given by their characters. I give a attention to the characteristics of PV cells that influence the reliability and quality of the power supply. I also deal with these behaviour of PV array in the distribution grid, their possible influence on a voltage regulation, influence of their power variation on voltage waveform at the point of connection and also an examination of different variants of PV array connection.

Key words:

Microgrids, renewable energy, renewable power sources, optimalization, PV cell, mathematical model of PV cell, Swing

2. Mathematical model of PV cell

We can substitute PV cell by equivalent electric circuit where is included a power supply and a diode. The power supply produce the current I_{ph} which depends on impinging radiation. Through diode flows the current I_D . The current I which flows to load is difference between I_{ph} and I_D and it is reduced by the resistance R_S which represents resistance of cell and connection among cells.

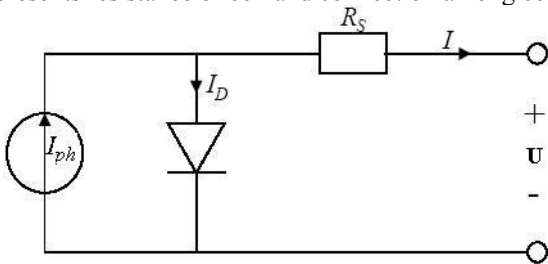


Fig 1: Equivalent electric circuit of PV cell

The cell has a constant current while the voltage go up until specific value and after that current go down steeply to zero – diode is opening, I_D goes up. It is shown in Fig 2.

If we connect a resistive load R to cell then working point of cell will be on crossing point voltampere characteristic of cell and load characteristic. Voltampere characteristic of load is a straight line with slope $1/R$. If value of R is too low, the working point is in area between M and N where cell behaves like constant current source. It is more or less short circuit current. But if value of R is high, the working point is in area between P and S where cell behaves like constant voltage source. It means about a open circuit voltage.

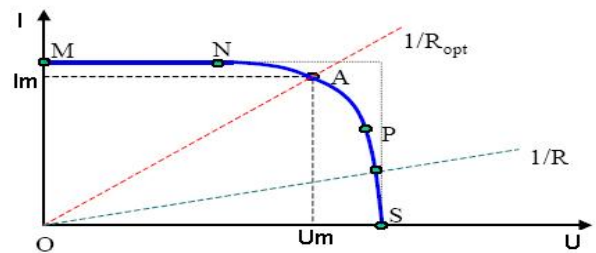


Fig 2: Typical voltampere characteristic of PV cell

Connection with optimal resistance R_{opt} means that PV cell generates maximum output power which is given to product of voltage U_m and current I_m . Working point where is the maximum of power and efficiency is in the flexion of voltampere characteristic.

In Fig 3, an voltampere charastecistic of a PV cell for only a certain ambient irradiation G_a and only a certain cell temperature T_c is illustrated. The influence of the ambient irradiation G_a and the cell temperature T_c on the cell characteristics in presented in Fig 4.

Fig 3 shows that the open circuit voltage increases logarithmically with the ambient irradiation while the short circuit current is a linear function of the ambient irradiation. The arrow shows in which sense the irradiation and the cell temperature, respectively, increase. The influence of the cell temperature on the voltampere charasteristics is illustrated in Fig 4. The dominant effect with increasing cell's temperature is the linear decrease of the open circuit voltage, the cell being thus less efficient. The short circuit current slightly increases with cell temperature.

It is seen that voltampere characteristics of series interconnected cells can be found by adding, for each current, the different voltages of the individual cells. On the other hand, for parallel cells the currents of the individual cells must be added at each voltage in order to find the overall voltampere curve.

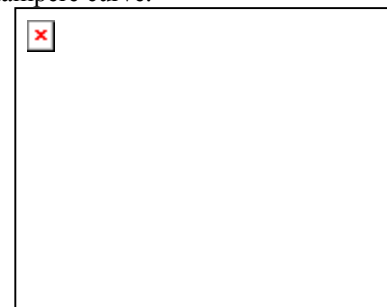


Fig 3: Influence of the ambient irradiation on the cell characteristics

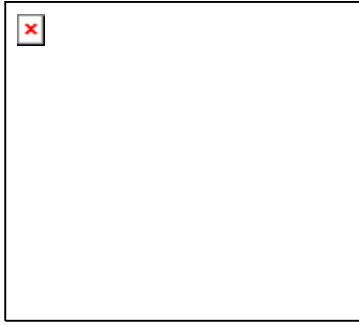


Fig 4: Influence of the cell temperature on the cell characteristics

3. Parametres of PV cell for normal specification

standard conditions:

Impinging radiation $G_{a,0} = 1000 \text{ W/m}^2$

Temperature of cell $t_{c0} = 22 \text{ }^\circ\text{C}$.

- short circuit current $I_{SC,0}^c$ – the maximum current generated by cell with short-circuited output, ($U_C=0$).
- open circuit voltage $U_{OC,0}^c$ – the maximum voltage of cell with disconnected output ($I_C=0$).
- maximum power $P_{Cm,0}$ – maximum power of cell, $P_{Cm,0} = U_{Cm} * I_{Cm}$ [W]

From these parametres we can assign so called the Fill Factor: $FF = U_m * I_m / U_{SC} * I_{SC}$ [-]

The Fill Factor for good cells would be higher than 0,7.

All parametres are valid only for standard condition. If impinging radiation G_a or temperature of cell t_c change, then open circuit voltage, short circuit current and flexion of voltampere characteristic change as well.

Parameter change of PV cell by influence of change G and t^c

1) Influence of G



Fig 5. Influence of radiation change G [(W/m2)*0,1] on current and voltage of PV cell.

Open circuit voltage go up logarithmic when impinging radiation go up but short circuit current go up linearly.

2) Influence of t^c

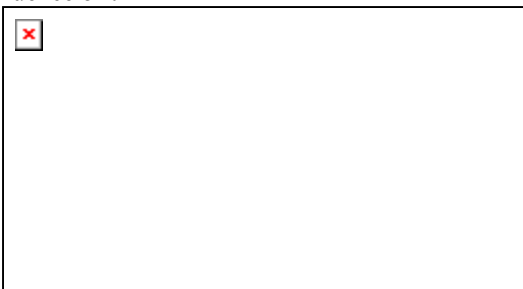


Fig 6. Influence of temperature change t_c [$^\circ\text{C}$] on current and voltage of PV cell

When temperature of PV cell go up then open circuit voltage go down linearly and short circuit current go up.

4. Equation describing a behavior of PV cell

a) Equation for computation of PV cell current I_C depending on impress voltage U_C .

(it describes waveform of voltampere characteristic):

$$I^c = I_{sc}^c [1 - \exp(U^c - U_{oc}^c / U_i^c * m)] \quad [A]$$

b) Computation of short circuit current depending on impinging radiation G_a and temperature of cell T_C :

$$I_{sc}^c = C1 * G_a + k1 * (T^c - T_0^c) \quad [A]$$

$$T_{c0} = 273,15 + t_{c0} = 295,15 \text{ [K]}$$

c) Computation of open circuit voltage depending on impinging radiation G_a and temperature of cell T_C :

$$U_{oc}^c = U_{oc,0}^c + C3 * (T^c - T_0^c) - \exp\left(\frac{G_a - G_{a0}}{K3}\right) / K4 \quad [V]$$

d) Computation of cell temperature depending on ambient temperature and impinging radiation G_a :

$$T^c = t_a + 273,15 + C2 * G_a \quad [K]$$

Impinging radiation G_a gives a rise to a heating effect of PV cell.

e) Computation of so called the thermal voltage depending on temperature of cell:

$$U_i^c = k * T^c / e \quad [V]$$

Constant $k = 1,381 * 10^{-23}$ [J/K] is Boltzmann's constant.

Constant $e = 1,602 * 10^{-19}$ [C] is elementary electric charge.

Constants C_1, C_2, C_3, K_3, K_4 are different for different materials. It depends on cells.

5. Conclusion

Solar cells in PV array work only in part of voltampere characteristic near working point where is maximum voltage and maximum current. We assume that photovoltaic system works most of time with maximum efficiency. It means that for modeling of PV cell we should use constants for specific kind of cell near working point.

References

- [1] Lorenzo, E.,: *Electricidad solar – ingeniera de los sistemas fotovoltaicos*, Universidad de Politécnica de Madrid, PROGENSA, Spain, 1994
- [2] Luque, A., Hegedus, S.,: *Handbook of photovoltaic science and engineering*, Universidad de Politécnica de Madrid, University of Delaware, WILAY, Spain, USA, 2003
- [3] Skočil, T.,: *Interconnection Optimization of Power Units with Renewable Power Sources (RES) to Distribution Network*, University of West Bohemia, Plzeň, 2008
- [4]http://www.solar2006.org/presentations/tech_sessions/t6_1-99024.pdf
- [5]<http://ieeexplore.ieee.org/iel3/4263/12206/00564054.pdf?arnumber=564054>
- [6]<http://sel.me.wisc.edu/trnsys/downloads/trnsedapps/demo/pvh-array.htm>