Portál pre odborné publikovanie ISSN 1338-0087

Photovoltaic cells efficiency of electricity production

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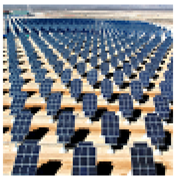
25.09.2013



The article deals with the issue of conversion efficiency of solar radiation into electricity, while in introduction are described the fundamental theoretical solutions for the calculation or efficiency analysis. Furthermore, the article is focused on a description of external factors affecting the efficiency change. Attention is also paid to factors that are not external, but significantly limit the photovoltaic conversion efficiency, and in some cases are expressed also measures for elimination respectively minimization these factors.

Introduction

Photovoltaic, as a one of the renewable energy sources, recently has achieved a dramatic development and expansion in the form of larger or smaller photovoltaic power plants building worldwide. The photovoltaic power plants issue consists in its current competitiveness against traditional power sources. Competitiveness of these resources depends on the efficiency of converting solar radiation into electricity, which ranges for commercially available photovoltaic cells at 20%, what is relatively low energy gain e.g. given the built-up area of solar power plant. Currently, it has worked on many analyses of negative factors affecting photovoltaic conversion efficiency and also are developed new photovoltaic cells based on various semiconductors and structures in order to increase the photovoltaic cells efficiency and improve the status of photovoltaics in the energy mix.

1. Photovoltaic cells efficiency

The photovoltaic cells efficiency can be divided into thermodynamic efficiency, reflectance efficiency, carrier separation efficiency and conductive efficiency. The overall efficiency is then the result of these particular efficiencies. Due to the difficulty in measuring these parameters directly, there are measured following parameters: thermodynamic efficiency, quantum efficiency, integrated quantum efficiency, open-circuit voltage UOC, short-circuit current ISC and fill factor FF. The overall photovoltaic cells efficiency is calculated from the following relation

$$\eta = \frac{P_{max}}{P_L} = \frac{FF.U_{OC}.I_{SC}}{P_L} \qquad (1)$$

where P_{max} is a photovoltaic cells output, P_L is a solar radiation power, U_{OC} is a open-circuit voltage, I_{SC} is a short-circuit current and FF is fill factor, which describes a curvature of I-V characteristic (for common commercial photovoltaic cells is FF>0,7 and for quality B cells in interval 0,4>FF>0,7). Theoretical efficiency limit for photovoltaic cells with one P-N junction was calculated at level 37,7% by Shockley-Quissler in 1961. For multijunction photovoltaic cells is determined limit at level 86%. [1]

2. Photovoltaic cell I-V curve

For comparison of particular photovoltaic cells and to predict their output under various operational conditions are used I-V characteristics (I-V curves). The most significant impact on I-V curve shape from the external impacts has solar radiation intensity and temperature. Among the internal impacts belong the characteristics of photovoltaic cell structure, concretely the series resistance R_s (should be as low as possible) and conductive resistance R_{sh} (should be as high as possible). [2] [3] In Fig. 1 is shown an I-V curve for photovoltaic module rated at 42Wp, where limit points are: short-circuit current I_{SC} (point A), open circuit voltage U_{OC} (point B), maximum power point MPP (point C) and the current position of the operating point (point D).

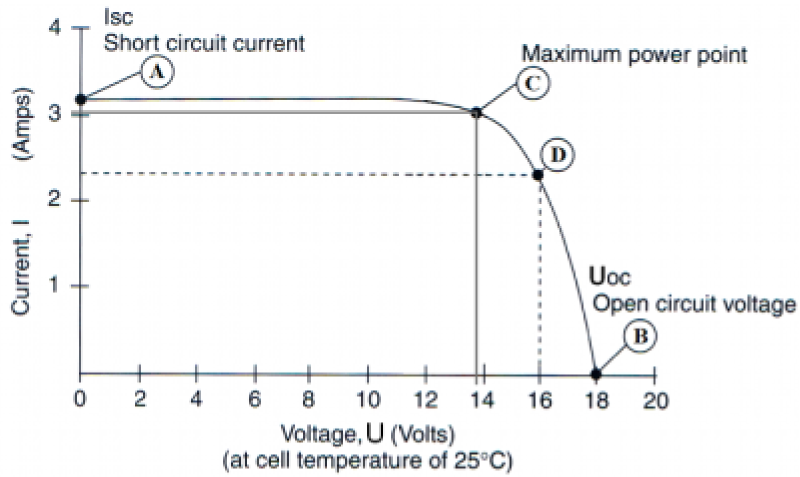


Fig. 1 The I-V curve for photovoltaic module rated at 42Wp

Short-circuit current I_{SC} is the highest possible current generated by photovoltaic cells, when the photovoltaic cell output contacts are “shorted” in full sunlight. Open-circuit voltage U_{OC} is the maximum photovoltaic cell voltage, which will be achieved in full sunlight, when the contacts are not connected to any load. Maximum power output MPP is the highest output value, which is possible from the photovoltaic cell operation to receive and can be determined as a product of voltage U_{mp} and current I_{mp}. There it is important to add that under short-circuit and open-circuit photovoltaic cell produces no output.

3. External impacts

As mentioned above, solar radiation intensity and temperature influence in the largest extent on photovoltaic cell output from the external factors. Current generated by photovoltaic cell is increasing proportionally with the solar radiation intensity (Fig. 2) and mathematically stands

$$I_L = I_{L1}.x \quad (2)$$

where I_{L1} is current equivalent to solar radiation intensity and x is concentration factor, what means that for concentrated solar radiation is possible to get even more generated power. Impact of change in solar radiation intensity to voltage is not very significant.

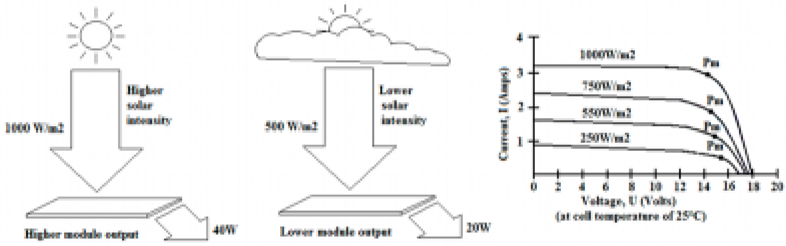


Fig. 2 Solar radiation impact to photovoltaic cell output [4]

Impact of temperature change on the photovoltaic cell output is not negligible, what is evident in the Fig. 3, where the I-V curve is changing with temperature impact in significant way. In the photovoltaic systems design for commercial applications is the temperature impact very important because on some types of rooftops can the cell efficiency decrease by 20%, which is relatively high value, and therefore such systems have to be installed in places where can be cooled as the maximum possible, e.g. with convection (wind). Therefore the aim is to minimize the impact of increased temperature on the photovoltaic cells. Due to the increased temperature the generated current changes only marginally, but the open-circuit voltage U_{OC} changes significantly due to the saturation current and for this change stands

$$\frac{dU_{OC}}{dT} = -\frac{1}{T}\left[\frac{\Delta W_z}{e} - U_{OC}(T)\right] \tag{3}$$

where the fill factor FF slightly decreases with increasing temperature.[4][6]

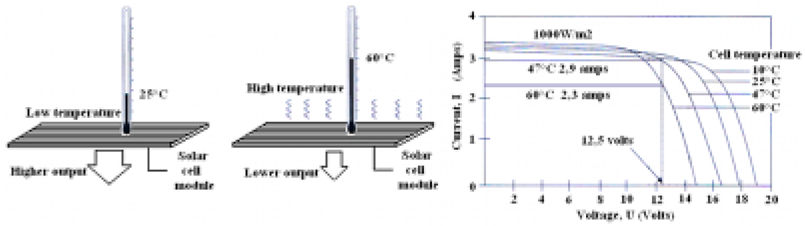


Fig. 3 Temperature impact on photovoltaic cell output

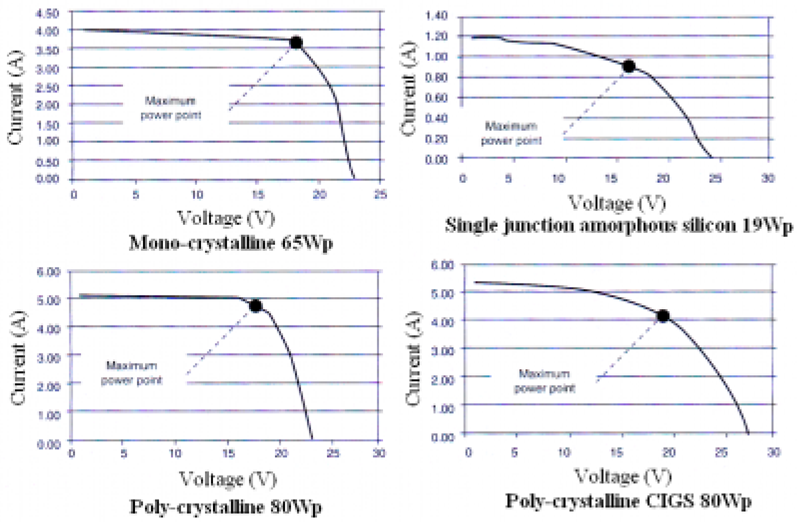


Fig. 4 The I-V curves comparison of selected photovoltaic cells [4]

4. Factors affecting photovoltaic cells efficiency

Until now, the attention was engaged in external factors affecting the I-V curves of photovoltaic cells and thus the overall efficiency. In general, the output and conversion efficiency of solar radiation into electricity depends on solar radiation intensity, the angle of solar radiation on the cell surface, photovoltaic cell temperature and voltage, when the load consumes power from photovoltaic cell. But there exist also other impacts which limit the efficiency, i.e. necessary physical factors, but some of them are possible to optimize and increase the overall efficiency this way. Among the main factors limiting the effectiveness include:

1) Photons of solar radiation have no needed energy to generate electron-hole pairs

2) Photons of solar radiation have higher energy as needed to generate electron-hole pairs

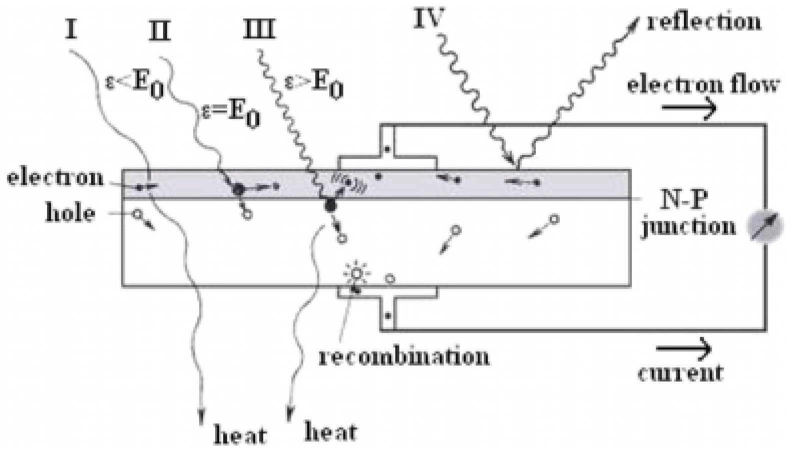


Fig. 5 The N-P junction behaviour by the various energy photons

In Fig. 5 are shown states, when on the photovoltaic cell falls photon with lower energy (state I, $\varepsilon<E_0$) as needed to generate electron-hole pair, and this energy will be converted only into the heat. In case that the photon energy is equal (state II, $\varepsilon=E_0$) or higher (as III, $\varepsilon>E_0$) than the energy gap, electrons will be activated from the valence band to the conduction band, while in the case of the high-energy photon will be the excess energy converted into the heat. Efficiency curve of photovoltaic conversion of some semiconductors, depending on the energy gap is shown in Fig. 6. This implies that in practice it is necessary to optimize the photovoltaic cells structure to such solar radiation wavelength, which has the highest energy (lower values of wavelengths).

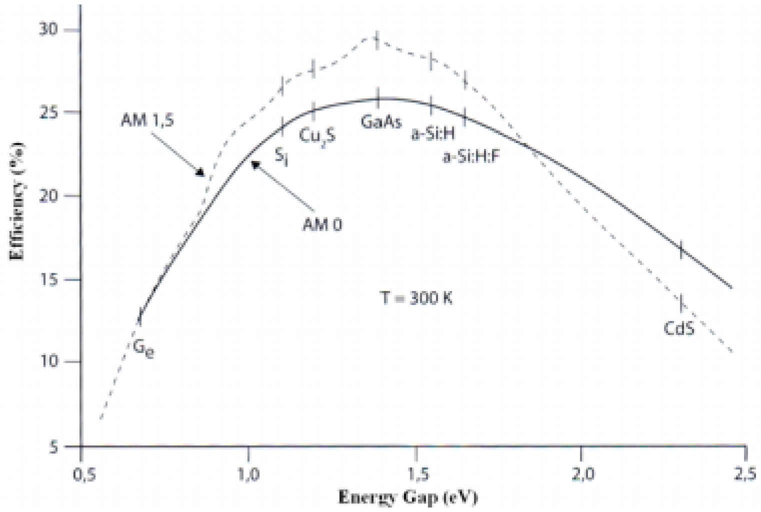


Fig. 6 Efficiency of selected semiconductors as a function of energy gap [4]

3) Reflectance on the surface of photovoltaic cell

Reflectance on the surface is associated with cells structure and modules construction, because there on the air-semiconductor boundary arise the refractive index of the solar radiation, and therefore it is necessary to use e.g. anti-reflective layer. At present, are often used glossy materials on the surface, and these cause strong reflectance, what leads to lower solar radiation absorption and thus efficiency as well.

4) Narrow absorption area

Generated electron-hole pairs of fallen photons recombine before the photons are separated at the semiconductor potential barrier and therefore the semiconductor must be placed as close to the photovoltaic cell surface.

5) Absorption spectrum

When solar radiation photons fall on the photovoltaic cell, part of the energy is absorbed for the electron-hole pair generation, but the another part of energy passes through and converts into the heat, what is eliminated with the use of multilayer semiconductor with more P-N junctions.

6) Series resistance causing Joule losses

Based on the above facts it is evident that the photovoltaic cells production is very difficult and requires a precision given the dimensions of these cells.

Acknowledgement

This publication is the result of the project implementation:
Finalizing of the National Centre for Research and Application of Renewable Energy Sources,
ITMS 26240120028, supported by the Research & Development Operational Programme funded by the ERDF.

Podporujeme výskumné aktivity na Slovensku/
Projekt je spolufinancovaný zo zdrojov EÚ

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