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Operating Points and Topographic Dependence of the Thin Layer-Photovoltaic Cells as Relevant Characteristics for Modeling of the PV Cells

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Abstract —The level of the DC voltage measureable in solar cells depends of the material of the semiconductor. Besides, the level of the produced open-circuit voltage is to a great extent independent from the occurring insolation that is to say from the intensity of the incident light insolation. Indeed, with an increasing light intensity rise the maximum current drawn and therefore also the output power, but not the electric voltage. Three most used PV technologies: modules from amorphous double-junction- silicon cells (A-Si), Cd-Te thin layer cells and conventional mono-crystalline silicon cells (SC-Si) have different behavior compared with the occurring sunlight and with it, with the spectral responsivity. Hence, the climatic differences between the topographic regions have direct consequences on the solar spectrum measurable at the ground (change of the Air – Mass factor AM) and with it on the spectral irradiance - E (λ). Those changes, influence in further the module performance depending of the spectral responsivity which signifies, that PV modules of different technologies point out, with different wavelength λ, a different change efficiency of photons in available load bearer pairs. This work explains the operating points and effects of the topography on the parameters of the PV cells.

Keywords —PV technologies, Topography, Operating Points, Modelling

I. Introduction

Solar cells consist of semi-conducting materials with different doping. In the transition between the n-semi-conducting layer and the p- semi-conducting layer with incidence of light, the separation of charge occurs, with which charge carriers are released. Via suitable contacts an electric tension can be measured - in a closed circuit it comes to an electric current flow. The attitude of the electric tension measureable in solar cells is depending on material of the semiconductor. With the cells used for photovoltaic (PV) arrangements made by silicon, electric tension measureable amounts to about 0.5 V. Besides, the attitude of the generated open-circuit voltage is to a great extent independent of the occurring insolation that is to say from the intensity of the striking light insolation Indeed, with an increasing light intensity rise the maximum current draw and therefore also the output power, but not the electric voltage. The electric tension delivered in the normal mode is dependent basically on the load with a certain insolation, i. e. from the load current of the single solar cell or from the PV device. This is presented, according to [1, p.32] in the following figure.

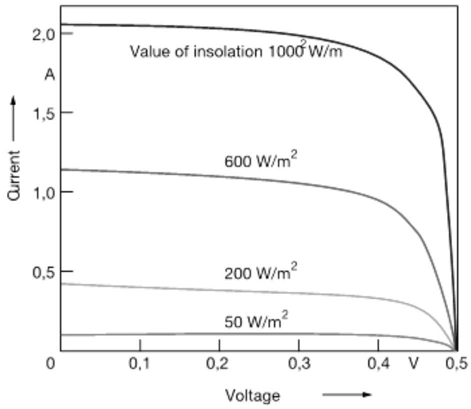

Fig. 1. Dependence of the electrical tension and current on the intensity of the occurring light insolation with solar cells.

II. Recognizable Trends in ICT Development Operating Points of the Thin Layer Photovoltaic Cells

In the practical case, three different operating points occur with the function of the PV cells. Those are: no-load operation (idle state), short-circuit state and regular operating state.

A. Characteristics of the no-load operation (idle state)

The electric voltage reaches in the idle state its maximum value, which is almost as high with a low illumination as with the strong illumination. The output power is zero because no electrical current flows.

B. Short-circuit state

The electrical current reaches its maximum value which depends on the intensity of the illumination as well as on the size and the efficiency of the respective solar cell. The electrical tension measured on the short-circuit cell is likewise as the output power zero valued.

C. Normal operating state

The working (operating) point is adjusted in that way, that a maximum output power by the solar cell is delivered. In addition electrical tension and current by the power inverter are, according to the lighting situation, adapted constantly to the optimum values. Operating points are presented in the Figure 2.

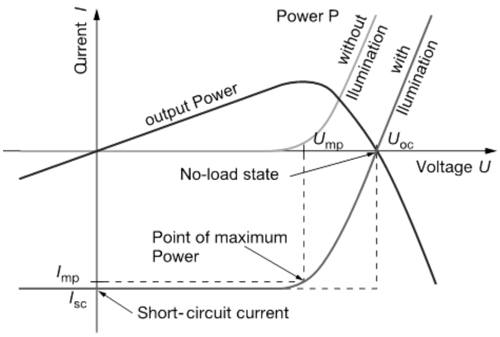

Fig. 2. Operating points of the PV cell.

Without illumination no charge carriers are released within a solar cell, so that no electrical current flow is possible. Also with low luminosities, e.g., with moonlight, firelight, road lighting or with application lighting of the fire department, extremely dangerous electrical tensions can appear in the PV devices. During the operation of the PV devices in the idle state, e.g., by disconnection of the DC cutting unit or by interruptions by ruined modules, it is absolutely possible that the electrical tensions reach the so called rated voltage of the PV device. However, the output power and the current will be only low on account of the low insolation intensity. Nevertheless, a danger for the application forces of the e.g. fire department or other rescue forces by the appearing electrical tensions is given; in any case, i. e. independent of the present lighting situation. The definition of the operating points is crucial information for the realization of the equivalent model of the PV cells.

III. Topographic Dependence of the Thin Layer-Photovoltaic Cells

There are different studies which show a strong dependence of the performance of the PV modules (cells) on changes in the insolation spectrum in module level as a result of changed environmental parameters as well as from the topographic location [2,3,4,5]. In order to be accurately measured, the free flied measurements needs to be carried out at least two places with the explicit topographical difference, which can be distinctive e.g. in terms of attitude (high/low) where the investigated PV modules are placed. For the measurement at different places, the same conditions have to be used, especially regarding the mounted degree of module inclination (in the regular case 30°-45°). The typical electric parameters of the PV modules for every technology as well as the influence of the surroundings parameters like insolation intensity, wind speed, temperature and cloudiness degree needs to be grasped in order to get accurate measurement. Also, in order to investigate the interconnection between the altitude of the sun and the PV module orientation the modules need to be oriented in each case towards different direction as e.g. to the west, the south and the east. Different measures carried out shows that the basic behavior of the climatic circumstances is similar at the different locations. Determined can be increases of the insolation to midday, followed by a decrease up to the evening. Indeed, the daily course of the insolation factor (irradiance) E differs for the case that locations are differing considerable and based on it the topographical conditions are substantially different regarding their insolation range. Based on the study done by [5, p.60] such values for the locations of 170m over the MSL and for 1600m over MSL are presented in the next figures.

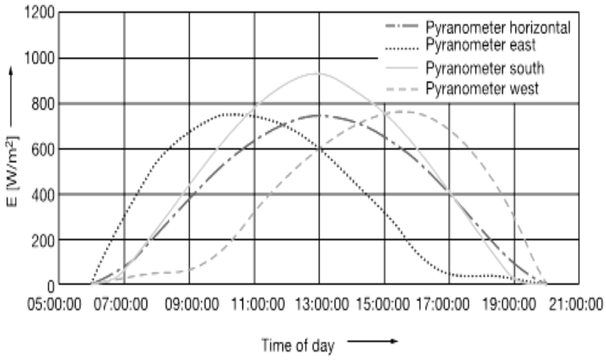

Fig.3. Values of insolation in dependence of orientation at 170m over the MSL

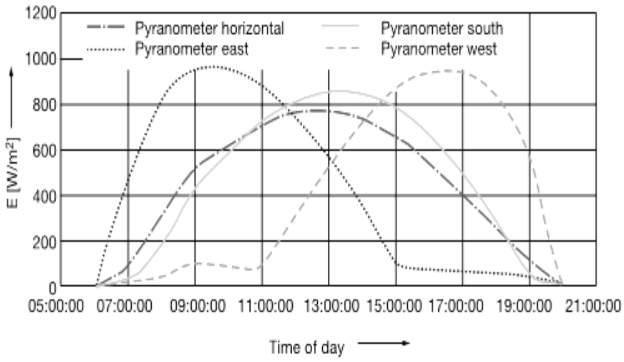

Fig.4. Values of insolation in dependence of orientation at 1600m over the MSL

The sensors and modules which are in the each case oriented to the west or to the east register for both locations in the morning or in the evening only vague insolation because of lacking direct sunlight. Only diffuse insolation becomes registered by the sensors. The climatic differences between the topographic regions, have direct consequences on the solar spectrum measurable at the ground, which can be explained with the change of the Airmass Factor and with it the occurring change of the spectral irradiation intensity in dependence of the wavelength - E (λ). Those changes influence in further result the module performance via spectral responsively which signifies, that PV modules of different technologies point with different wavelength λ, a different change efficiency of photons in available pairs of charge carriers. Air Mass (AM) explains that the solar radiation (insolation) is decreased on their way through the terrestrial atmosphere by reflection, absorption (by aerial molecules and aerial particles) and dispersion. The decrease of the insolation grows, the longer the way of the radiation through the terrestrial atmosphere is. The factor AM declares how long the way of the solar radiation is thought the terrestrial atmosphere and it is given in proportion to atmosphere-thick. With the vertical solar state, the light takes the shortest way through the atmosphere, so that in that case is AM scored with “1”. If the sun stands a little bit sloping, its way through the atmosphere is extended, so that in that case AM grows. By using of the Air Mass calculator [6] with the following settings (Rayleigh atmosphere (no aerosols), full multiple scattering, with refraction, spherical atmosphere, no clouds, US standard atmosphere) here are shown some examples for the Air Mass in dependence of solar zenith angle calculated by using of the different attitude (500m and 150mm) and Albedo (10 and 90) with the constant wavelength of 500 nm.

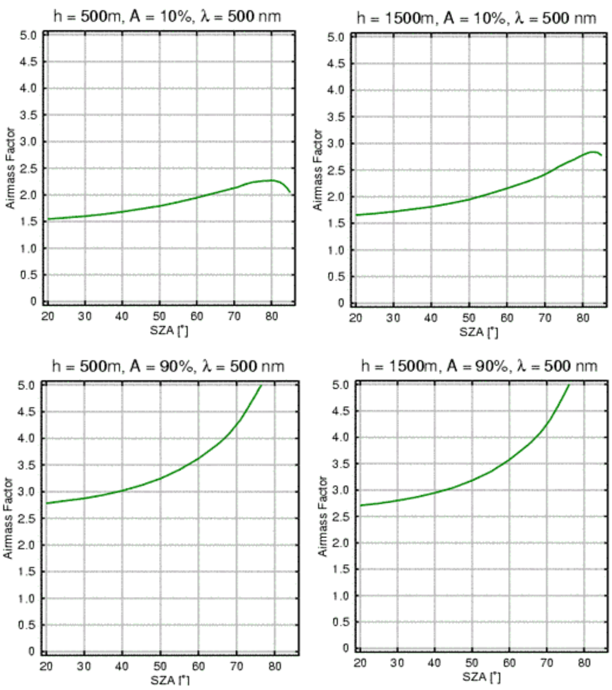

Fig.5. Air Mass (AM) factors at 500m (left) and 1500m (right) with different Albedo factors

Albedo factor describes the reflection of the sunlight on the earth surface. It is given in percent to the incident light and amounts on the earth surface to about 10-20% in the normal case, and with a reflective surface (e.g. snow) about 80%. By the calculation of the portion of a certain wavelength in the respective whole spectrum, of the spectral component p (λ) different times of day, weather conditions and insolation intensities can be directly compared. Such comparisons has been made by e.g. [6,7]. The results show that on the basis of the processes of dispersion in the atmosphere which basically depends on the Rayleigh dispersion and Mie dispersion [8, 9]) the portion of the short-wavy light (<500 nm) lies with the integral insolation intensity E is higher than the portion of the long-wavy light (> 700 nm). By contrast is spectral component for attitudes above 1,600 ms over MSL for all wavelengths and time of day are roughly consistently [2, 3, 5, 7]. Rayleigh scattering (dispersion) can be described as scattering in the small size factor regime. Dispersion from larger spherical particles is explained by the Mie theory for a random size parameter. For small size factor the Mie theory reduces to the Rayleigh approximation. Rayleigh dispersion explains the greater proportion of blue light (short-wavy light) scattered by the atmosphere relative to red light (long-wavy light). According to [5, p.61], comparing the short – circuit currents characteristics at 6h P. and M 8h A.M. (I_{SC}(6h p.m.) / I_{SC} (8h a.m.)) , by using the Modules from amorphous Double-Junction- Silicium cells (A-Si), Cadmium-Tellurid (Cd-Te) - thin layer cells and conventional mono-crystalline Silicium cells (SC-Si), as reference cells, the comparison of the short – circuit currents is presented in the following Table:

	East	South	West
>170m MSL			
SC-Si	1	1	1
A-Si	1.50	1.08	0.71
Cd-Te	1.29	0.92	0.94
>1600m MSL			
SC-Si	1	1	1
A-Si	1.26	1.04	0.70
Cd-Te	1.04	1.08	0.92

TABLE 1. Comparison of the short – circuit currents characteristics at 6h p.m. and 8h a.m (I_{SC}(6h p.m.) / I_{SC} (8h a.m.) of SC-Si , A-Si and Cd-Te modules

The figure show the behavior of the modules concerning the short circuit current I_{SC}. The I_{SC} values of the mono-crystalline silicon modules (SC-Si) in comparison with the thin layer modules (A-Si and Cd-Te) show only very small variations. For the attitude under 170 ms MSL, looking on the A-Si modules and Cd-Te modules oriented to the south, however, the I_{SC} value measured in the morning decreases in comparison to evening values less strongly than with the SC-Si modules. Looking at to the east oriented A-Si and Cd-Te modules; it can observed, that I_{SC} (6h p.m.) / I_{SC} (8h a.m.) shows even an increase. By contrast I_{SC} decreases with the A-Si-aimed to the west and Cd-Te modules in the day course. The changes directly arise from the different spectral components p (λ) and the orientations. This effect is further strengthened by purely vague isolation, that is to say bigger portion in blue and ultraviolet light. Generally the effects become more evident in the areas of the smaller attitudes (170 m) in regard of the spectral components, than in the areas of higher attitudes (1,600 m). Looking on the Table 1 it can be observed that with the exception of the modules oriented to the west, all thin layer modules in comparison with the mono-crystalline modules at 6h p.m. shows higher currents than around 8h a.m.. The effect can be explained with the adjustment, the topography of the locations and the day-temporal changes of the solar spectrum in the module level. That information can be used for modeling of the certain cells in regard of the topographic influence on the solar cells.

IV. Conclusion

For the modeling of the PV cells behind the general operating modes also topographical influences on the cells made by using of the different production technologies are important.

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