Shading effects in the \textit{IU} characteristic of a mono-crystalline PV module

Sebastijan Seme, \textit{University of Maribor, Slovenia} \\
(prof. dr. Gorazd Štumberger, \textit{University of Maribor, Slovenia})

Abstract

This work deals with the impact of the shading on the efficiency of the photovoltaic modules. Including the shading the efficiency of the photovoltaic modules is also influenced by the solar radiation, the temperature and the position. Often, the PV modules get shadowed, partially or completely, by the passing clouds, the adjacent buildings or by the trees, etc. The situation is of a particular interest in the case of the large PV power plants. In the case of the shading the characteristics of the PV module are more complex with the several peak values. Under such conditions, it is very difficult to determine the maximum power point (MPP). In this work the shading of the solar photovoltaic module is evaluated. The solar cells were sequentially and parallel shadowed, according to the bridging diode. The results presented show that the decrease in power of the photovoltaic module is not proportional to the shaded area.

1. Introduction

The main reasons for seeking the new sources of the energy are the increasing energy dependence and the limited amount of fossil fuels. The renewable energy sources have an inexhaustible potential and at the same time they are a future energy source. Among the renewable energy sources the energy of the Sun is the one that is the most promising nowadays. The solar radiation is converted directly into the electricity by the photovoltaic (PV) modules. The PV modules and DC/AC converters are the main elements of the PV system.

The efficiency of the PV systems depends mainly on the conversion of the solar energy into the electricity. So the emphasis is on the increasing efficiency of the PV system. In general, there are two ways of increasing the efficiency of the system: by improving the absorbent material or by using the tracking systems.

The efficiency of the PV systems is increased by using the different technologies and materials, but on the other hand it is often forgotten of their correct installation. It happens that the PV systems are (intentionally or unintentionally) installed in the way that the modules are partially or totally shadowed. The influences of shading on the production of the electric energy from the PV systems are already represented in [1] - [3].

The work deals with the influence of shading on the \textit{IU} and the \textit{UP} characteristics of the mono-crystalline module. In this case the standards which are given in [5] and [6] are used and they are currently valid in the field of measuring the characteristics of the PV modules. The influence of the solar radiation and the temperature on the characteristics of the PV module will be shown while in the results the influence of the shading will be evaluated.

2. Standards for measurement the photovoltaic modules

Because of the rapid development of the photovoltaic technologies an international technical committee IEC TC 82 (IEC TC 82 Solar Photovoltaic Energy System) was established in 1981. Its duty was to prepare the international standards for systems which convert the solar energy into the electricity - for all the elements of the photovoltaic system. This includes the characteristics and the concepts of the photovoltaic modules and also the whole systems for producing the electric energy and their connection into the distribution systems. In [6] it is a collection of currently valid standards, which have been published by IEC TC 82 in recent years. Twenty years after the establishment of the IEC TC 82 a Slovenian technical committee was established. It has been focused on the photovoltaic technologies called SIST/TC PVS. So it has been possible to get the technical report \textit{IEC TR 61836:1997 translated into the Slovenian language as SIST TP IEC TR 61836:2005 Solar photovoltaic energy systems – Terms and symbols} from the year 2005 on.

If the excerpt of standards related to the measurements of the PV modules’ characteristics is made, the \textit{Standard Test Conditions (STC)} for
measuring the characteristics of the photovoltaic modules are:

- **the solar radiation** has to be $G = 1000 \text{ W/m}^2$,
- **the air mass** factor (AM) (SIST EN 60904-3:2001), has to be 1.5,
- **the cell temperature** (SIST EN 60904-3:2001) has to be $T_j = 25 \pm 2^\circ \text{C}$ and
- **the incidence angle** (SIST EN 60904-3:2001) between the sunbeams and the normal to the surface of the PV module has to be $90^\circ$.

### 3. The $I_U$ characteristic of the photovoltaic module

The photovoltaic module is a set of solar cells. They are often connected in series. In general the photovoltaic modules are divided according to the type of solar cells or to the purpose of the use. Irrespective of the type of solar cells or of the purpose of the use, they have to suit the already mentioned standards, which determine electrical and also mechanical characteristics of the module.

To achieve the wanted voltage and current of the module, the individual solar cells can be connected parallel and/or in series. The serial connection of the solar cells in the module gives us the wanted voltage, while the parallel connection of the solar cells gives us the wanted current.

The $I_U$ characteristic of the photovoltaic module is determined from the characteristic of the photovoltaic solar cell. The example of the $I_U$ characteristic of the photovoltaic module, which is in greater detail described in [6] is shown in Figures 1 and 2. The most important points in the characteristic are: the short circuit current ($I_{sc}$), the open circuit voltage ($U_{oc}$) and the maximum power point ($P_{MPP}$). The solar radiation, the temperature of the solar cells and the partial or the complete shading of the module have the main influence on the electrical parameters of the photovoltaic modules.

Figure 1 shows the influence of the solar radiation on the electrical parameters of the module. Figure 1 also shows that increased solar radiation also increases the output current.

By solar radiation on a photovoltaic module it warms and that also changes its electrical parameters. Figure 2 shows the influence of the temperature on the electrical parameters of the module. It is clear that the open circuit voltage increases by decreasing the temperature and it is the highest at the lowest temperature of the module. The short circuit current increases by increasing the temperature but its increase is not as high as with the voltage.

The partial or the complete shading is the parameter that is often forgotten, but it has also got the influence on the characteristic of the module. Until all the solar cells in a module are identical and equally illuminated, the module gives the maximum power. If the module is partially shaded, the shaded solar cell does not generate the electrical power, but on the other hand the solar cells which are illuminated operate normally. The shut-off voltage appears on the shaded solar cell and sets the cell in a loaded mode operation. This leads to the creation of the hot spots, where the solar cell starts to overheat. In this way the bridging diodes which are parallel connected to a certain number of the solar cells are used.

Below the influence of the shading on the mono-crystalline photovoltaic module will be evaluated.

### 4. Results

For the mono-crystalline photovoltaic module, which has 12 x 6 solar cells that are connected in series, the influence of shading on the $I_U$ characteristic of the module has been evaluated. The power of the used PV module is 205 W and it is symbolically shown in Figure 3 including the three bridging diodes.
The influence of the shading on the $UI$ characteristic of the module has been evaluated in the way that a different number of the solar cells have been shaded. The first example represents the shading of the solar cells with the parallel bridging diodes, as shown in Figure 4. The one solar cell (Fig. 4 b), the two solar cells (Fig. 4 c), the three solar cells (Fig. 4 d), the four solar cells (Fig. 4 e), the five solar cells (Fig. 4 f) and the total number of the solar cells in the module (Fig. 4 g) have been shaded.

Figs. 5 and 6 show that shading has a strong influence on the $UI$ and the $UP$ characteristics of the module. When one solar cell (1.4% shading of the module) or two solar cells (2.8% shading of the module) are shaded the maximum power decreases for approximately 30%. When three solar cells (4.2% shading of the module) or four solar cells (5.6% shading of the module) are shaded the maximum power decreases for approximately 60%. When five solar cells (6.9% shading of the module) or six solar cells (8.3% shading of the module) are shaded the maximum power decreases for approximately 93%.

Another example represents the shading of the solar cells in series according to the bridging diodes, as shown in Fig. 7. The one solar cell (Fig. 7 b), the two solar cells (Fig. 7 c), the three solar cells (Fig. 7 d), the four solar cells (Fig. 7 e), the five solar cells (Fig. 7 f) and the six solar cells in the module (Fig. 7 g) are shaded.

Figs. 5 and 6 show the $UI$ and the $UP$ characteristics of the module at the shadings, shown in Fig. 4. In Figs. 5 and 6 the $UI$ and the $UP$ characteristics of the module without the shading are marked with 'a', while the $UI$ and the $UP$ characteristics of the shaded module are marked with 'b' to 'g' (Fig. 4).
Figs. 8 and 9 show the $UI$ and the $UP$ characteristics of the module at the shadings, shown in Fig. 7. In Figs. 8 and 9 the $UI$ and the $UP$ characteristics of the module without the shading are marked with ‘a’, while the $UI$ and the $UP$ characteristics of the shaded module are marked with ‘b’ to ‘g’ (Fig. 7).

If the voltage (as shown in Figs. 5 and 8) is high enough, the converter which is connected to a PV module, will still work but probably not in the maximum power point (MPP). Therefore, it is reasonable to avoid the shading in such cases. If the shading of the modules is presented, considering certain parameters the consumption can be reduced to the minimum. One solution is to connect the shaded modules to the separate converter. In this case only the power of the shaded set is lost, while the rest of the area still works on normally.

5. Conclusion

The work deals with the influence of the solar radiation, the temperature of module and the shading on the photovoltaic modules. The focus is on the influence of the shading on the $UI$ and the $UP$ characteristics of the module. The results show that the influence of the shading cannot be neglected and it is necessary to consider it in the installation of the photovoltaic systems.

Bibliography


Authors:

Seme Sebastijan
University of Maribor,
Faculty of Electrical Engineering and Computer Science,
Smetanova 17, Maribor
Slovenia
tel. (00386) 2 220 7179
fax (00386) 2 252 5481
e-mail: sebastijan.seme@uni-mb.si