

Influence of the PV modules layout in the power losses of a PV array with shadows

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Abstract — The optimal location and orientation of a photovoltaic array is not sufficient to produce the maximum energy generation. The shadows are responsible for power losses. These can be reduced by the following: changing the type of PV cell used, the configuration of the bypass diodes, and also the dimension or the limits of adjustment in the MPP inverter search. In this paper, different scenarios have been simulated to compare and demonstrate the importance of the PV modules layout to minimize the power losses.

Keywords — alternative energy, photovoltaic, generation of electrical energy, modeling, renewable energy systems, solar cell system

I. INTRODUCTION

Photovoltaic arrays are formed by arrays of photovoltaic modules. Each PV module is a group of photovoltaic cells (PV cells) and diodes with multiple possible electrical configurations. PV arrays can be static or can follow the sun (PV trackers). In both cases, the goal is to receive the maximum annual radiation through an optimal orientation and location.

However, the influence of shadows caused by small objects (e.g. lampposts, poles, fences or elements of the structure that holds the panels) is sometimes underestimated. This can result in far higher losses of power than expected, in relation to the percentage of areas shaded.

This paper is aimed at explaining how objects, not taken into account when the optimal location of the PV systems is studied, can markedly affect the photovoltaic energy generation.

Several factors will determine the quantity of losses generated by shadows on a PV array. The most important are:

- The type of PV module: mono-crystalline, poly-crystalline, amorphous silicon, CIGS... [1] [2]
- The shadows layout on the panel. Stretched shadows, parallel, oblique or perpendicular to the module. [3]
- Bypass diodes: [4] [5]
 - Number
 - Configuration: overlapped or not.
 - Cells layout of each PV module with respect to the bypass diodes.
- The inverter: [6] [7]
 - Connection of the PV modules: series or parallel.
 - Minimum and maximum voltage that limits the search of the MPP.
 - Responsiveness to MPP changes.

Nevertheless, there is one aspect that it is not usually considered: the PV modules layout. The power losses can be notably reduced by changing the PV module layout, using a careful analysis of shadows cast on the PV array. I

II. DEVELOPMENT

A. Installation description

Fig. 1 presents the example of a PV array formed by 20 PV modules of 104Wp installed on a 2-axis PV tracker. It should be highlighted the existence of a damaged zone in the upper left corner (the white dot).

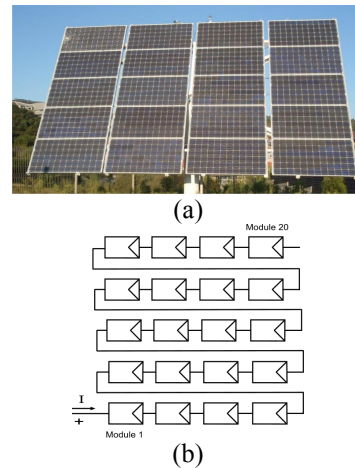


Fig. 1 PV array studied (a) photograph (b) electrical scheme

The PV modules are composed of 72 PV cells arranged in 3 groups, defined by 2 overlapped bypass diodes; hence, there is a group of overlapped PV cells. Each group consists of 24 PV cells distributed in 2 arrays of 12 cells parallel-connected (Fig. 2).

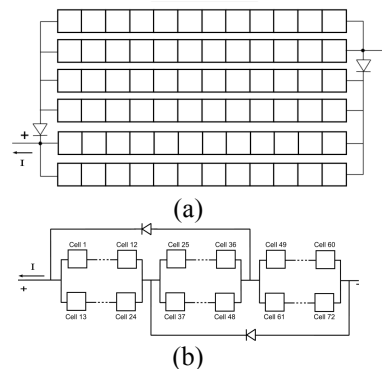


Fig. 2 PV module of the PV array (a) physical distribution (b) electrical scheme

The PV array has no immediate obstacles; however, the power plot on a sunny day shows two zones where there is a reduction in power generation (Fig. 3). These reductions are caused by obstacles with negligible shadow (Fig. 4): an anemometer and a lamppost.

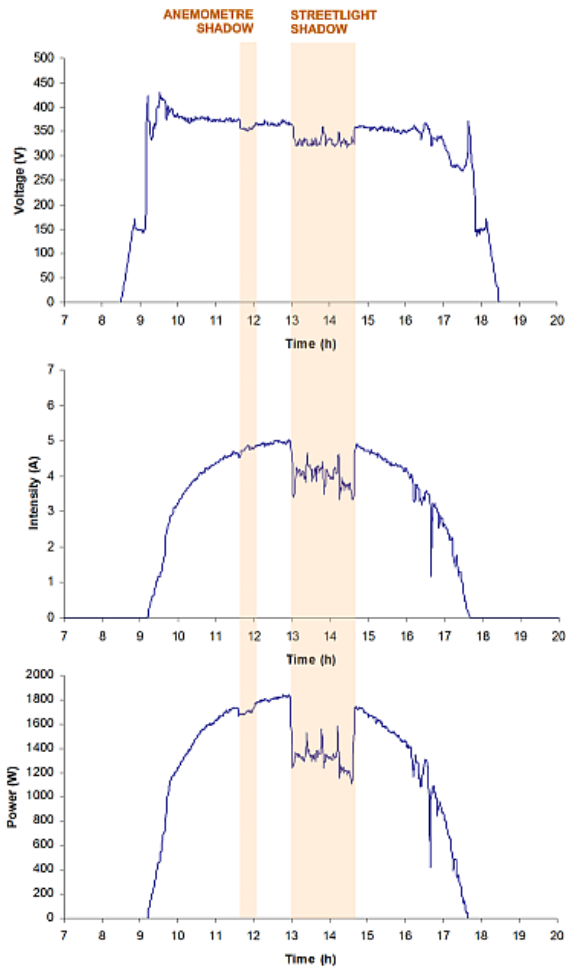


Fig. 3 Voltage, intensity and power curves of the PV array, the 15th of December 2009

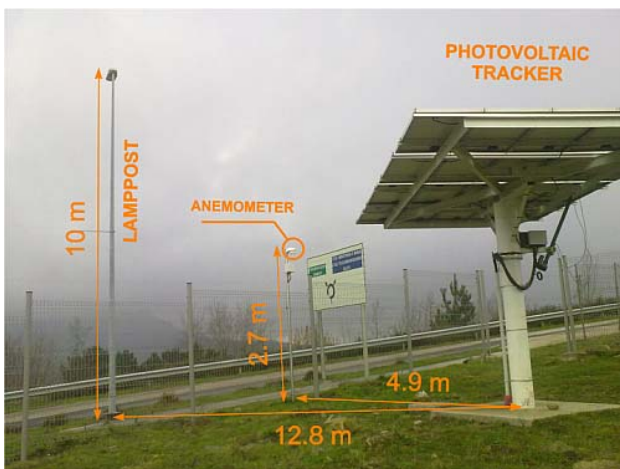


Fig. 4 Objects located south of solar tracker

The cases of the anemometer and the lamppost have been highlighted as the power losses caused by their shadows in the PV array are far greater than the

percentage of shaded surface in the PV array (Fig. 5 and Fig. 6).

B. Shadow analysis

1) Shadow of an anemometer

An anemometer is used to measure the wind speed. When the wind speed exceeds a prefixed limit, the PV arrays are pitched to avoid structural damages. This anemometer causes a shadow that covers from 1 to 4 PV cells (Fig. 5). The electrical power losses are approximately 60W due to the horizontal layout of the PV module and the overlapped diodes; this will be explained in greater detail in section D. In simple terms, a shadow of 0.2% of the total area of the PV system produces a loss of 2.9%.



Fig. 5 Shadow caused by the anemometer

2) Shadow of a lamppost

The lamppost shades 2.1% of the PV system surface, affecting 4 different PV modules (Fig. 6). This causes a loss of nearly 600W or, in other words, 30% of the power generated in that instant.



Fig. 6 Shadow caused by the lamppost

There is a change in the level of power losses when the lamppost shadow passes through the gaps between PV modules or between PV cells (Fig. 7). The smallest ripple is caused by the passing of the shadow between PV cells: when the lamppost shadow totally covers the PV cells, bypass diodes are forward biased, so the electrical current flows through them and the PV cells do not produce energy. When the shadow is between them, partially covering 2 consecutive PV cells, these PV cells produce energy, thus the PV module power generation is higher.

The highest ripple is generated when the shadow is between two different PV modules, because it barely covers the PV cells, it allows almost all of them to produce energy. There are 3 gaps between the 4 columns of PV modules, which correspond to the 3 power peaks in the graph. After the last peak, the power mean value of the lowest ripple is lower than the previous 3 because the lamppost shades 5 PV modules.

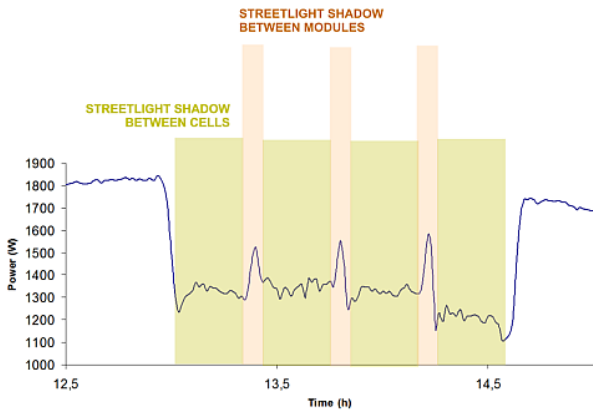


Fig. 7 Power generated along the lamppost shading of the PV array

The power losses caused by the lamppost cannot be ignored because they are the 35% of the maximum possible photovoltaic power in that moment, and they last 1 hour and 40 minutes. In other words, in that day the energy losses caused by the lamppost shadow were 7% of the total day's energy; the energy generated was 11.15 kWh and the energy losses were 850 Wh.

Findings have shown overheating occurs in the shaded PV cells. This is caused when two PV cells on each cell-row are shadowed, this being an insufficient number of shaded PV cells for the bypass diodes to enter into their forward zone. This occurrence could cause a slow deterioration of the modules.

C. Performance improvements

1) Diode bypass configuration

Using PV modules with non-overlapped bypass diodes can reduce the power losses. In one instance, when the anemometer shades the PV module, if non-overlapped diodes are used, two thirds of the PV cells are generating power (Fig. 8.a); whereas, using overlapped bypass diodes are used, only one third of the PV cells produces power (Fig. 8.b).

In another instance, when the lamppost casts a shadow, if non-overlapped diodes are used, the only electricity consumption is produced by the bypass diodes (Fig. 9.a); although, if overlapped diodes are used, not only the bypass diodes are consuming power, but also the overlapped PV cells (Fig. 9.b).

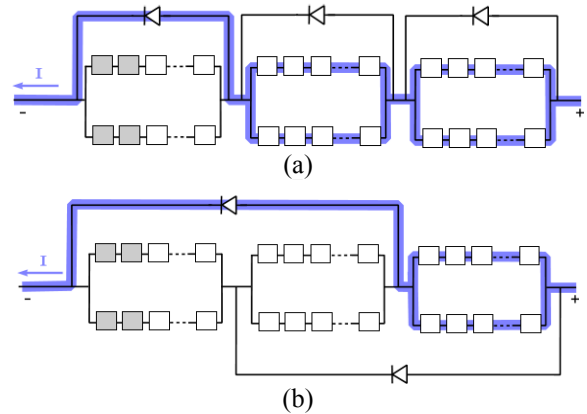


Fig. 8 Current flow when the anemometer shades the PV module with bypass diodes (a) non-overlapped (b) overlapped

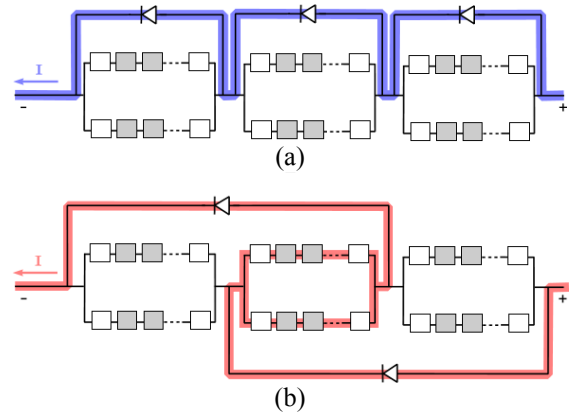


Fig. 9 Current flow when the lamppost shades the beginning of the PV module with bypass diodes (a) non-overlapped diodes (b) overlapped

Fig. 8 and Fig. 9 has plotted only the main component of the current flow, to highlight the power consumption in the central PV cells. In fact, for the rest of PV cells there is a current flow that is producing electrical power (Fig. 10). Although the three groups of PV cells have the same I-V curves, the working point of the central group is located in a zone of power consumption (Fig. 11).

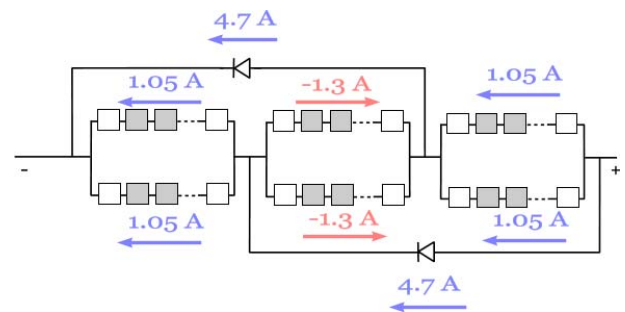


Fig. 10 Detailed current flow when both bypass diodes are forward biased

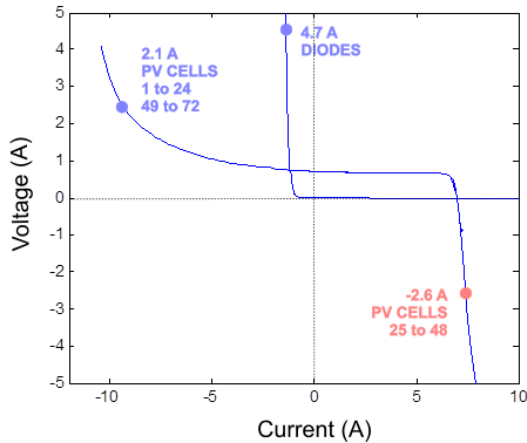


Fig. 11 Working points of PV cells group and bypass diodes

2) Influence of PV modules layout

A change in the modules layout can decrease the power losses, and therefore, more energy can be obtained. This will be demonstrated by comparing the power curves of different layouts, when the lamppost shades the PV arrays. In a hypothetical layout of vertical PV modules (Fig. 12), the power losses caused by the lamppost shadow would not exceed 150W, this represents 8% of the produced power and the fourth part of the 30% of the real layout (Fig. 1.a).



Fig. 12 Created image of the same PV array with vertical PV modules

Fig. 13 shows the power curve of the PV modules in a horizontal layout (pink) compared to a vertical one (green). 3 peaks can be seen in the pink curve and 7 peaks in the green curve. These power peaks correspond to the instants when the lamppost shadows are in between the gaps of the PV modules.

Additionally, in Fig. 13 the power curves are plotted for various layouts and bypass diodes configurations for that day. The pink curve represents the registered data of the real configuration; the rest of the curves are the result of simulated configurations. TABLE I details the power and energy losses taking into account the duration of the lamppost shadowing (1 hour and 40 minutes).

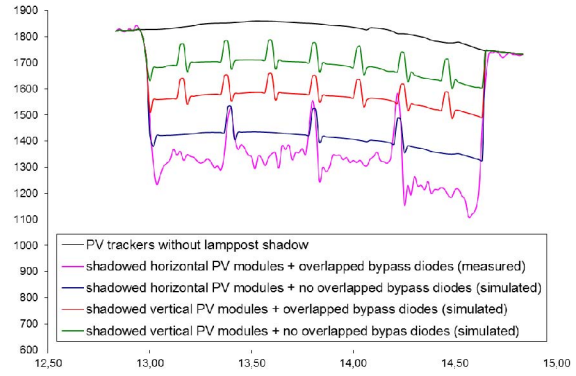


Fig. 13 Power curves produced by lamppost shadow for different PV modules layouts and bypass diodes

TABLE I. POWER AND ENERGY LOSSES FOR DIFFERENT PV ARRAY LAYOUTS AND BYPASS CONFIGURATIONS

Layout	Bypass	Power Losses (%)	Energy Losses (%)
horizontal	overlap.	30	7
	non-over.	24.2	6.2
vertical	overlap.	14.7	3.5
	non-over.	8	1.7

The explanation of why the mean power of the vertical layout is higher than the horizontal layout (Fig. 13) is the following; in the horizontal layout (Fig. 14.a), there are four PV modules, labelled as “I”, with the third part of its PV cells dissipating electrical power as heat (Fig. 15). Whereas, in the vertical layout (Fig. 14.b) not only are there fewer shaded PV modules, labelled as “II”, but also these PV modules have one third of its PV cells generating electrical power (Fig. 16). When the lamppost shadow is in between the gap of the PV modules, all the PV modules have their PV cells without shadows, like those labelled as “III” in Fig. 14, therefore all the PV modules have their PV cells generating electrical power (Fig. 17).

These losses are inverse proportional to the Sun elevation. Therefore, they rise from October to December, and they drop from January to March. In the rest of months of the year, i.e. from March to October, no losses because of the lamppost shadow are registered, because the shadow is not casted over the PV array. Supposing daily constant losses, the worst of the cases (overlapped bypass diodes, power losses 7%) would have annual losses of 1.7%.

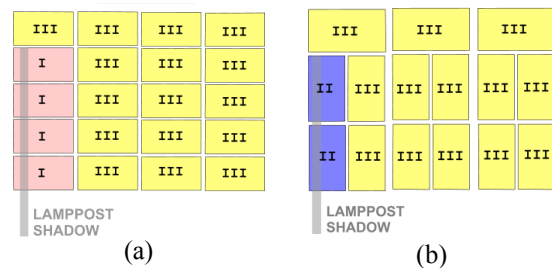


Fig. 14 Lamppost shadow over PV arrays with (a) horizontal layout (b) vertical layout

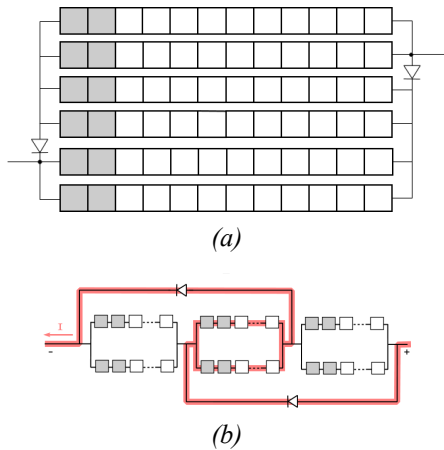


Fig. 15 PV modules "I" schemes (a) physical (b) electrical

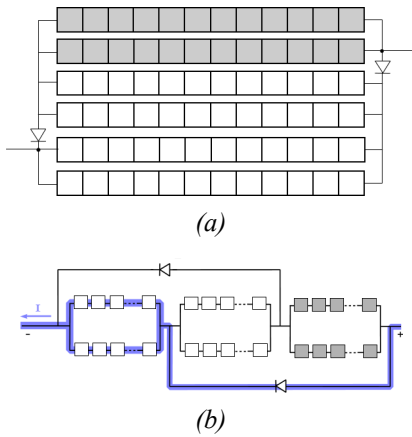


Fig. 16 PV modules "II" schemes (a) physical (b) electrical

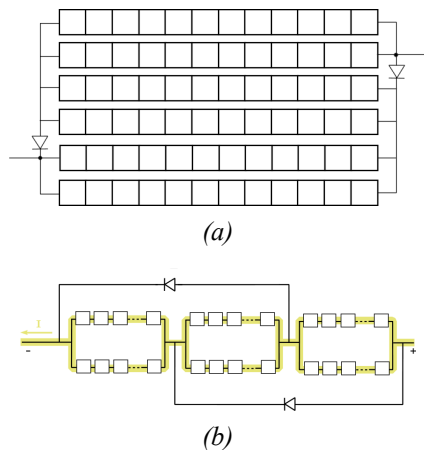


Fig. 17 PV modules "III" schemes (a) physical (b) electrical

III. CONCLUSIONS

In this article, a real PV system has been analyzed. Then, various simulations for different layouts and diode bypass configurations for the same system have been

made. Observing the power and energy losses for each one of them, two important aspects has been identified, that is necessary in order to obtain the maximum energy that has sometimes not been considered: its bypass diodes and the layout of the PV modules.

In order to obtain the maximum amount of energy, non-overlapped bypass diodes and layouts that concentrate shadows in few arrays of PV cells are preferred. Addressing these two aspects, an increase of 30% of the electric power can be achieved without changing the components of the PV system.

ACKNOWLEDGMENT

The authors would like to thank the Consellería de Innovación e Industria, Xunta de Galicia (Spain) Ref. ING825G, for their support and help.

REFERENCES

- [1] K. Matsunaga, T. Komaru, Y. Nakayama, T. Kume, Y. Suzuki, "Mass-production technology for CIGS modules" *Elsevier, Solar Energy Materials & Solar Cells*, Vol 93, pp. 1134-1138, March 2009.
- [2] M. A. Green, "Very High Efficiency Silicon Solar Cells – Science and Technology" *IEE Transactions on Electron Devices*, Vol. 46, No. 10, October 1999.
- [3] E. Karatepe, M. Boztepe, M. Çolak, "Development of a suitable model for characterizing photovoltaic arrays with shaded solar cells", *Elsevier, Solar Energy*, Vol. 81, pp. 977-992, 2006
- [4] S. Silvestre, A. Bornat, A. Chouder, "Study of bypass diodes configuration on PV modules", *Elsevier, Applied Energy*, Vol. 86, pp. 1632-1640, March 2009.
- [5] E. Díaz-Dorado, A. Suárez-García, C. Carrillo, J. Cidrás, "Influence of the shadows in photovoltaic Systems with different configurations of bypass diodes", *20th International Symposium on Power Electronics, Electric Drives, Automation and Motion*, June 2010.
- [6] Y. Ji, D. Jung, C. Won, B. Lee, J. Kim, "Maximum power point tracking method for PV array under partially shaded condition", *IEEE, Energy Conversion Congress and Exposition 2009*, pp. 307-312, 2009.
- [7] D. Nguyen, B. Lehman, "A reconfigurable solar photovoltaic array under shadow conditions", *Applied Power Electronics Conference and Exposition 2008*, pp. 980-986, 2008.