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CONSIDERATIONS ON METHODS TO INCREASE THE EFFICIENCY OF PHOTOVOLTAIC PANELS

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Abstract: A great advantage of using solar energy, compared to other forms of energy, is that it can be produced without affecting the environment through pollution. Another advantage of using solar energy is the fact that it is free, autonomous, inexhaustible, ecological (non-polluting), the installation does not require any kind of maintenance and is not influenced by price increases. This paper deals with the issue of increasing the efficiency of photovoltaic panels in generation of electricity. As a result of our documentation and research, we present a comparative overview of the maximum power point track methods, proposing the use of artificial intelligence, especially artificial neural networks.

Keywords: photovoltaic cell, MPP, solar cell model.

1. INTRODUCTION

Photovoltaic panels use a free and infinite source of energy, that is the energy from the sun. When the sun's rays reach the earth's surface, they contain approximately 2,000 times more energy than the total energy consumed on the globe in one year [1].

Recent statistics show that electricity generated from renewable energy sources covered over a quarter (28.8%) of the gross electricity consumption in the European Union, over half of the electricity used in Portugal (52.6%), Lithuania (52.2 %) and Denmark (51.3 %) coming from renewable energy sources. Estonia, Belgium and Poland recorded the fastest increases in the share of electricity generated from renewable energy sources.

The increase in the amount of electricity generated on the basis of solar energy came to exceed geothermal energy in 2008, and from only 1.5 TWh in 2005, it reached a level of 107.9 TWh in 2021. Over this period, the percentage represented by solar energy from the total renewable energy generated in the EU-27 increased from 0.3% to 18.2% [11].

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2. MODELLING THE OPERATION OF PHOTOVOLTAIC CELLS

The most used models for the operation of photovoltaic cells are those with single and double diodes. The described circuit of a simple diode takes into account the phenomena involved in the real operation of the photovoltaic (PV) cell. The current source connected in parallel with a semiconductor diode models an ideal cell, to which are added the two electrical resistances that model the current and voltage losses (Fig. 1).

The current produced by the source I_{ph} depends on the intensity of the solar radiation, the absorption coefficient of the wavelength of the solar radiation and the characteristic of diffusion and recombination of electrons in the material. Part of this current passes through the diode, a fact that models the phenomenon of recombination of charge carriers inside the solar cell. The small resistance of the edges of the solar cell leads to a new current loss highlighted by the existence of a parallel resistance R_p in the circuit, generally having a high value [10].

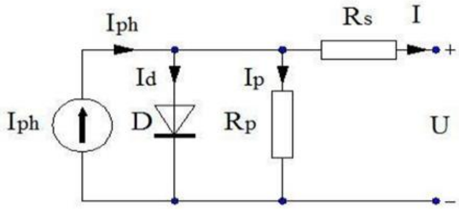

Fig.1. Simple diode model of a PV cell

The double diode model takes into account the variation of the ideal coefficient of the semiconductor diode. At high voltage values, the recombination phenomenon of the charge carriers takes place mainly in the surface regions and in the doping regions, with an ideal coefficient close to the unit value. At low voltage values, recombination takes place mainly in the region of the junction, and the ideal coefficient approaches the value of two. Recombination in the junction area is modelled by adding a diode in parallel with the first one (Fig. 2).

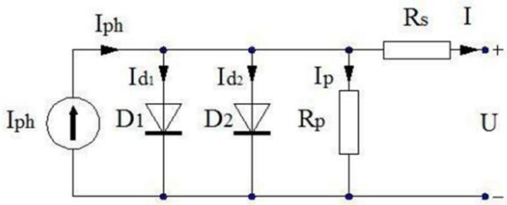

Fig.2. Double diode model of a PV cell

The electrical power provided by a photovoltaic cell is not sufficient for most domestic or industrial applications, so the photovoltaic cells are connected in series to increase the voltage value at the terminals and a panel (module) is made. The modules are connected either in series to increase the voltage even more, or in parallel to increase the current through the circuit and form the photovoltaic fields.

In the case of the series connection of photovoltaic cells, according to Kirchhoff's first theorem, the current drawn by each PV cell is the same, also equal to that at the terminals of the group. According to Kirchhoff's second theorem, the voltage at the terminals of the group is equal to the sum of the voltages at the terminals of each individual cell. Thus, the resulting I-U characteristic is obtained by arbitrarily choosing a value of the current and the sum of the voltages on the cells.

The voltage generated by a PV cell - approx. 0.5 V - is not sufficient for usual applications and several identical photovoltaic cells are connected in series or in parallel to obtain higher voltages. In certain applications mixed connections (series - parallel) of PV cells are used. Typically, PV generators are formed by the mixed interconnection of several PV modules. A PV module is formed by connecting a corresponding number of identical PV cells in series. For example, the BP 585 module of the British Petroleum company consists of a series connection of 36 PV cells, while the M220 module of the Solarwat company consists of 60 cells in series. Low-power PV generators are made by series interconnection of several PV modules, a configuration called a string of PV modules. Higher power PV generators are made up of several strings connected in parallel. For a mixed grouping of PV cells or modules, the names of area, array or photovoltaic matrix (by translating the English term array), or PV generator are also used.

If PV cells, constructively identical, are illuminated differently, such as the situation where one of the cells is shaded, or dirty, the short-circuit currents of the cells are different, so the currents at the terminals of each cell are different. The series connection, however, imposes the same current at the terminals of each cell, so part of the higher short-circuit current (that of the more illuminated cell) will close through the parallel diode, ensuring equality between the current at its terminals and that at the terminals of the shaded cell. The current of the series group will be imposed by the cell that has the lowest short-circuit current (the shaded cell), which limits the current of the entire group and implicitly the power generated by it [2].

For low terminal voltages (below 0.54 V), the power delivered by the shaded cell is negative, that is, with the on-state values adopted for U and I, it is actually absorbed. On the other hand, the total power is positive. Therefore, in this voltage range, the shaded cell consumes power from the brighter cell. Not only that it does not produce energy, the shaded cell also consumes part of the energy produced by the other cells.

For low values of the voltage at the terminals of the series group - in particular in short-circuit mode - the shaded cell consumes energy from the other cells. This energy is dissipated in the form of heat leading to the overheating of the shaded cell, i.e., to the appearance of a hot spot of the group. If the group contains many cells, the energy that must be dissipated is high, and overheating of the shaded cell can lead to its destruction and putting the module out of operation.

Fig.3. Bypass diode

To avoid overheating the shaded cell, a diode is connected in parallel with each cell, called a bypass diode (Fig. 3), which in normal mode is reverse polarized and does not intervene in the operation of the cell. The voltage that reversed biases the shaded cell, directly biases the bypass diode connected to it. In this way, the group current, which would otherwise have been strangled by the shaded cell, bypasses it through the bypass diode, which also limits the voltage on the shaded diode and implicitly the power dissipated by it.

It is not economical to connect a bypass diode in parallel with each cell of the module. A compromise solution is the connection of a bypass diode in parallel with a group of cells, usually consisting of half of the cells of the module. If one of the cells in a group becomes non-functional, the bypass diode connected in parallel with that group becomes directly biased thus supporting the failed cell.

In the case of parallel connection (Fig. 4), all cells have the same terminal voltage, and the group current is the sum of the currents at the terminals of each individual cell. Shading or failure of one of the grouping cells does not disable the grouping, as it happens in the case of the serial connection. No additional protective measures are therefore required. A point of the I-U characteristic of the group is obtained by arbitrarily choosing a value for the terminal voltage and then summing the corresponding currents of the individual cells.

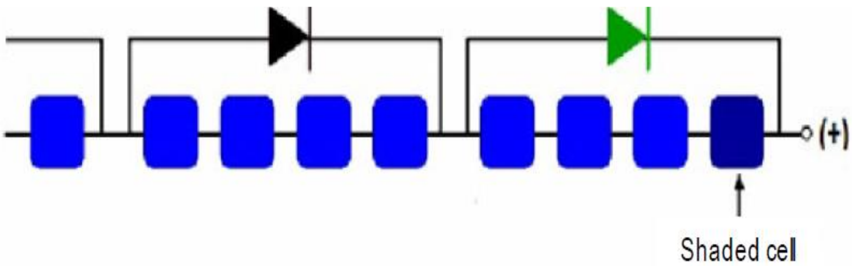

Fig.4. Parallel connection of photovoltaic cells

Although the shading effect of some of the cells of the parallel connection does not have the same effect as in the case of the series group, the power losses in the series and parallel resistors influence the way in which the power generated is distributed on the cells of the group.

3. COMPARATIVE OVERVIEW OF METHODS TO INCREASE THE EFFICIENCY OF PHOTOVOLTAIC PANELS

The voltage-current characteristic (U-I) of a photovoltaic module depends mainly on the intensity of the solar radiation and the temperature of the cells. For different meteorological parameters there is an operating characteristic of the photovoltaic generator. At the intersection of the U-I characteristic with the load characteristic at the PV generator terminals, the operating point is found, which generally differs from the maximum power point (MPP), at which the system can operate, when the optimal power transfer is achieved between the generator and the load [3]. Consequently, the MPP depends on the operating conditions of the photovoltaic generator, but also on the electrical characteristics of the load at the terminals. The goal of maximum power point tracking (MPPT) systems is to keep the operating point as close to the MPP as possible. In order to achieve the maximum power transfer between the PV generator and the receiver, a DC-DC converter is interconnected (Fig. 5). The DC-DC converter achieves the continuous adaptation of the load to the PV generator by using a control signal in modulated pulses.

The way to find the MPP is through repeated tests, that is, by changing the voltage at the generator terminals and by comparing the electrical power delivered in this case with the power from the previous step.

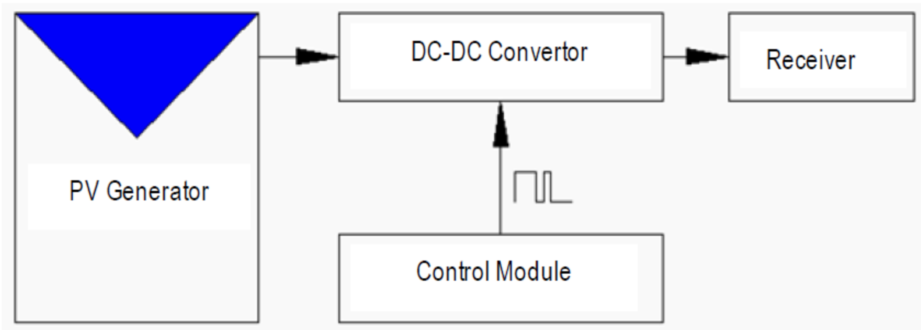

Fig.5. Adaptation of the resistive load user to the PV generator

There are several types of MPP tracking algorithms in the literature, and among the most used are the P&O (Perturb & Observe) algorithm, the Open and Short Circuit Method, the Incremental Conductance Algorithm and others [4]. Although these methods are widely used, they have disadvantages such as slow response to rapid variations in solar radiation intensity, oscillations around the MPP, or even tracking in the wrong direction.

In Fig. 6 we represented the P&O algorithm and the related logic diagram.

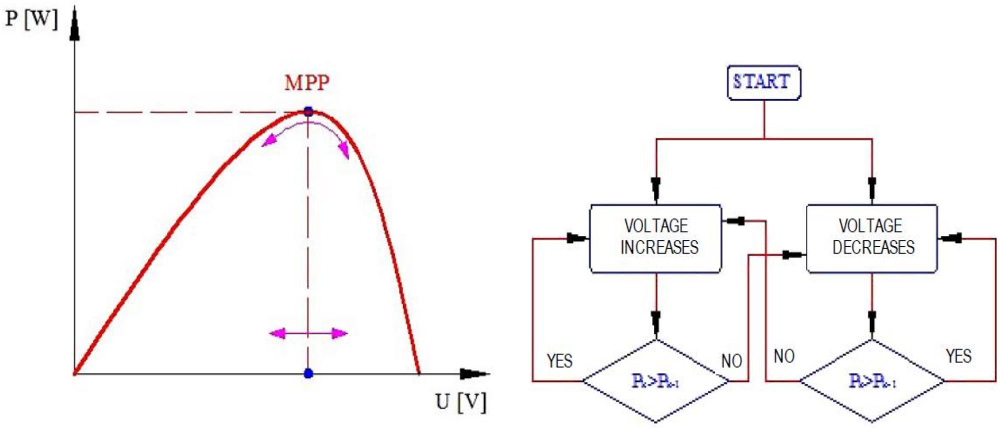

Fig.6. MPPT Perturb & Observe Algorithm

This algorithm is very simple and easy to implement. The way to find the MPP is through repeated tests, that is, by changing the voltage at the generator terminals and by comparing the electrical power delivered in this case with the power from the previous step. If the power from the current step is greater, the change of load continues in the same direction, and if it does not change in the opposite direction. This way of finding the MPP leads to oscillations around the MPP, even under stationary operating conditions, and in the case of sudden variations in the intensity of the solar radiation can even lead to tracking the MPP in the wrong direction

Another algorithm more commonly used in MPPT systems is "Incremental conductance". It is based on tracking the value of the derivative of the power with respect to the voltage, as shown in Fig. 7.

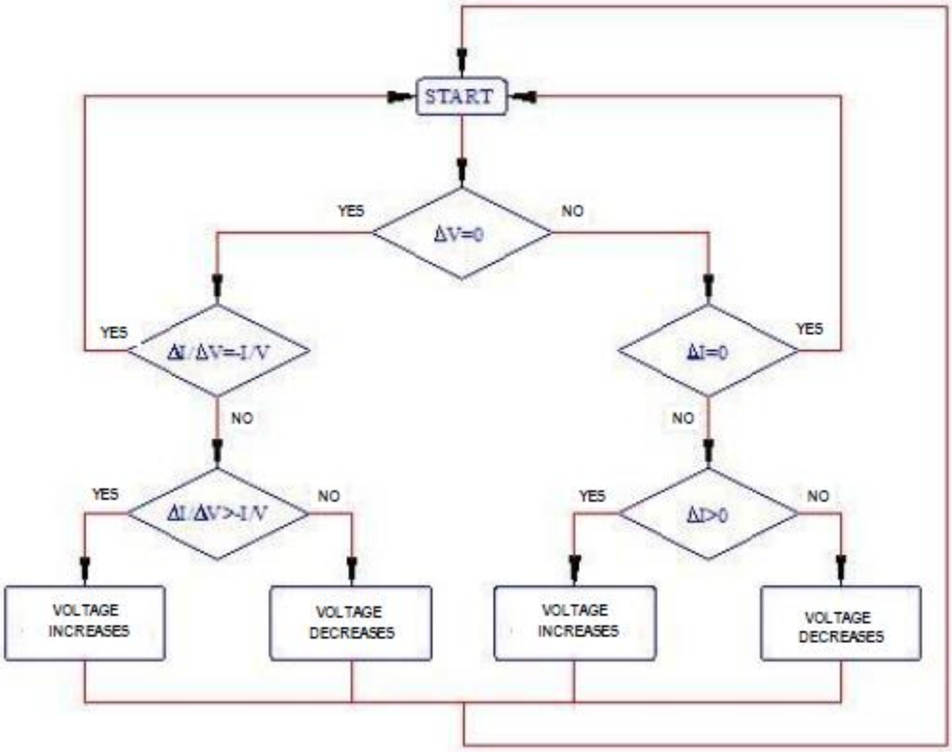

Fig.7. "Incremental Conductance" MPPT algorithm

Unlike the previous one, this algorithm does not present oscillations in operation nor the possibility of wrongly tracking the direction of the MPP, but it requires important computing resources and can influence the frequency of the current and the alternating voltage produced.

Research in this field is oriented towards two directions: either the optimization of already existing algorithms, or the development of new methods and algorithms. Regarding the first alternative, we can mention Taftich's work [5], in which an MPPT model based on measuring the voltage at the generator terminals is presented. The algorithm combines a non-linear method with the P&O algorithm. The results show a 17% increase in MPP tracking efficiency. The improvement of the P&O algorithm was also studied in Hua's work by modelling the transfer function and using multiple control signal models of the MPPT [6]. Another way to make MPPT systems more efficient is to create new algorithms. In general, they are based on the use of artificial intelligence techniques, especially artificial neural networks [7].

The applications of neural networks are very varied, but the prediction and control of processes is one of the most elaborated and together with genetic algorithms they can estimate the future state of a process, such as that of producing electricity using photovoltaic panels. [8]

The disadvantage of analytical models (single and double diode) is that they require numerical methods to solve the implicit equations, needing time and sufficient memory space. With the evolution of computers and the IT field in general, this problem has become much easier to solve. However, artificial intelligence techniques represent an alternative. [9]

Neural networks can learn from examples, are fault tolerant in the sense that they can handle incomplete data sets or signals with a significant noise component, can solve nonlinear problems, and once trained can make predictions and generalizations at a high computational speed. They have been successfully used in various applications of system control, robotics, shape recognition, medicine, weather forecasting, energy systems, optimization problems, signal processing, social and human sciences, etc. An important application is found in the modeling and identification of systems.

The applications of artificial neural networks (ANNs) in the field of renewable energy systems are among the most diverse: modeling of a solar steam generator, solar water heating systems, HVAC (Heating, ventilation, and air conditioning) systems, prediction of solar radiation and wind speed, modeling of the operation of photovoltaic cells, tracking algorithms of MPP etc.

In the case of photovoltaic panels, the parameter prediction refers to meteorological data - solar radiation intensity and atmospheric transmittance (clarity index) - necessary for the design of these installations or to internal variables of the system such as the electrical voltage, the current flowing through the circuit, the internal resistances of panel etc.

4. CONCLUSIONS

Although they are much studied and implemented, photovoltaic panels still present aspects that deserve to be taken into account. In this paper we tried to highlight the methods to increase their energy efficiency.

The problem with photovoltaic panels is related to the efficiency of converting solar energy into electricity. Also, the operating point of a panel, which is found at the intersection between the operating curve of the panel and the curve of its load at the terminals, is generally different from the maximum power point at which the panel can operate. There are thus several types of maximum power point tracking algorithm, but besides the fact that they show oscillations in steady state, they can even work wrongly in case of sudden changes in meteorological parameters. At the same time, the case of shading, which involves important energy losses, is not treated enough.

We approached the operation of a PV module as an electrical generator from several perspectives. Possible models, the analytical ones, use the single and double diode models, based on the properties of semiconductors. These models are widely studied in the literature, they have a very good accuracy, but they require numerical solution methods, since they are presented in the form of implicit equations. This fact makes it difficult to use them, at the moment, in systems with microcontrollers. However, in order to realize the maximum power transfer between the PV generator and the load user, it is necessary to know the position of the maximum power point. From this perspective derives the possibility of modeling the operation of PV modules using artificial intelligence techniques.

Currently, MPPT systems are installed at the terminals of PV fields. The maximum power point tracking system based on the artificial neural model can be implemented on each module of a PV field, thus reducing energy losses, implicitly improving the overall efficiency of the installation and giving autonomy to each individual module.

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