ANALYSIS AND INCREASE OF ELECTRICITY AVAILABILITY OF PHOTOVOLTAIC PANELS APPLYING FUZZY LOGIC CONTROL

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ABSTRACT: In the paper, the authors analyzed the possibilities of increasing the availability of electricity produced by photovoltaic panels by means of fuzzy controllers. They are based on fuzzy logic principles and can be implemented in solar trackers. These devices work as a principle by changing the position of the photovoltaic panels so that the solar radiation is perpendicular to them, in which case the efficiency is maximum in the production of electricity. The authors propose a model for assessing the availability of electrical energy in photovoltaic systems based on the construction of a fuzzy system with input variables formed by the parameters that influence the availability of electrical energy of solar panels. Among these factors, the position of the panels in relation to the sun, the shading, the provision of energy accumulators, the pollution with polluting particles, the duration of the radiation, the intensity of the radiation or the electrical reservation were analyzed. As an application, a system for adjusting the angle of inclination of photovoltaic panels through fuzzy controllers was formed so that the use of the potential of solar energy is used to the maximum.

KEYWORDS: Fuzzy logic, photovoltaic panels(PVP), availability, solar tracker

1. INTRODUCTION

The role of energy sources is to ensure quantities of electricity according to the destination, at the quality parameters necessary for consumption and under conditions of maximum environmental protection. There are indicators that define availability through specific calculation formulas. But by using the principles of fuzzy logic, the authors propose a method of assessing the availability of electricity produced by photovoltaic panels that can also be applied to other sources. On the basis of some linguistic variables, a fuzzy system was created that allows, on numerical value intervals, an evaluation of the availability as an output quantity from a contour that includes one or more photovoltaic panels with the possibility of optimal energy regulation, taking into account the factors that influence production, factors that constitute input quantities of the system. The regulation of the availability of electricity can be done as described in the paper by controlling the position of the photovoltaic panels with the help of trackers driven by electric motors, so that the rotation according to the sun allows maximum efficiency in electricity production.
The limitation of production lies in the yield of the sources, but when there is the possibility of maximum extraction of energy from the natural potential, this desired must be achieved [2].

2. ABOUT FUZZY LOGIC. FUZZY CONTROLLERS

Fuzzy logic was defined and imposed in 1965 by L. Zadeh, laying its mathematical foundations. Fuzzy logic offers a certain standardization that describes a data system with the treatment of numerical values that will be expressed in linguistic expressions. A specific feature of a fuzzy system is the possibility of simultaneous control of numerical data and knowledge through lexicon. Fuzzy systems are considered a distinct special case of expert systems. There are several types of fuzzy methods according to the type of reasoning used: Mamdani, Larsen, Sugeno – Takagi, Tsukamoto etc.[10]. Fuzzy controllers function as regulators of automation systems or installations and use the principles of fuzzy logic. They include a software part with working algorithms implemented through fuzzy modeling and a hardware part with external data acquisition elements - sensors and transducers and a process computer that processes the data and generates decisions or a programmable logic controller through which adjustment commands are given to the execution elements: electric motors, relays, smart switches, etc. In the speed controller used in vector control of electric motors, the reference speed can be controlled by an external operator and the output of the controller is the reference electromagnetic torque that the control-converter-machine assembly must generate.

Fuzzy regulators can be static or dynamic and have a small number of inference rules (often 20, usually under 10).

Typically, the rule base of fuzzy controllers has two input variables and one output variable. Through their so-called learning (adaptation) capacity, fuzzy controllers are components of artificial intelligence. Artificial intelligence is the ability of computers or machines to perform tasks and functions commonly associated with human intelligence (and other methods such as genetic algorithm, neuronal networks orbayesian grids). In Table 1 are given examples of fuzzy variables for PVP availability and Figure 1 shows the structure of a fuzzy system.

Table 1. Examples of variables and dimensions

Input variable	Comparison	Output variable
Exposure intensity	Low	Availability
Duration time	Medium	Efficiency
Pollution	High	Workspace

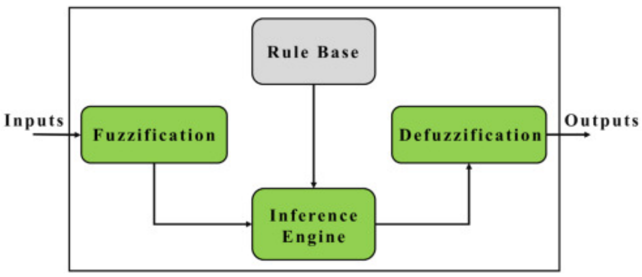


Figure 1. Fuzzy system building

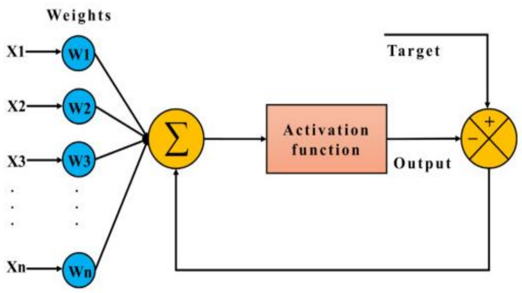


Figure 2. Fuzzy selected inputs in system

Figure 2 shows the relationship between the selected input variables and the output of the fuzzy system.

In classical logic, the separation of levels is done according to a fixed, deterministic value. Instead, in the fuzzy logic, such a division, for example, of the speed intervals and the values in km/h that a moving car records and that characterize its movement, can be: slow (1÷25 km/h), moderate (20÷65 km/h), fast (50 ÷ 90 km/h). These intervals can be interpreted in fuzzy logic according to each individual's perception of the linguistic value assigned. For example, for a Formula 1 driver, a speed of 90 km/h is slow, but for a cyclist, traveling at this speed is considered fast (Figure 3).

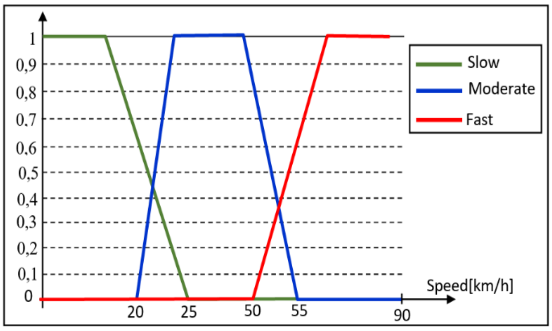


Figure 3. Motion speeds per ranges, in the fuzzy logic

In fuzzy modeling, the boundaries of each level will merge by overlapping because there is a different perception from people on them. The example which is given in Figure 3 shows how a certain value of the speed of a vehicle is considered differently depending on the driver category. When using fuzzy logic in the analytical and deliberative process, it starts from the premise that human perception is imprecise. Fuzzy representation can be perceived as a very high-level programming language, where the algorithm consists of specific rules of type „if-then”, and the "and/or" compiler as an interpreter, utilizes a nonlinear programming algorithm [11][12].

Considering X as a universe of discourse, which includes elements denoted by x, we define a fuzzy set A related to the universe of discourse X with the characterization of a membership function $A(x)$ associated to any element x that has a membership degree $\mu A(x)$ in the set A evaluated as follows [13]:

$$\mu_A(x): X \rightarrow [0,1] \tag{1}$$

To represent a fuzzy set, it is necessary to first state its membership function. In this case, a fuzzy set A, is completely defined by the association of doublets:

$$A = \{[x, \mu_A(x)] \mid x \in A\} \tag{2}$$

As membership function μA has the role of associating to each element x the degree to which it belongs to the given fuzzy set A. This membership degree μ expresses the form in which an element of the fuzzy set belongs to it.

There are several types of membership functions such as: singleton, triangular, gamma, “S”, „ π”, trapezoidal, gaussian, etc chosen by destination [2][6].

3. ELECTRICITY AVAILABILITY OF SOLAR PANELS

The factors on which the availability of electrical energy from photovoltaic panels (PVP) depends and which are also input variables in dedicated fuzzy systems are: radiation intensity, irradiation duration, panel efficiency depending on the construction material, panel orientation or incident angle of radiation with the panel; shading and cloudiness, reservation or redundancy, energy accumulation, inverter efficiency, air polluting particles (atmospheric pollution), panel fouling, dust deposits and other forms of particles. Some of these variables can be adjusted, others cannot because they do not depend on human intervention. The availability of energy in a conversion system can be defined by the next relationship:

$$A = \frac{T_E}{T_E + T_W} \tag{3}$$

in which A = Energy Availablity, TE = time of energy existing production and T_W is time without producion of energy.

4. ABOUT SOLAR TRACKERS

Solar trackers are devices that ensure the movement of photovoltaic panels following the sun so that the incidence of sunlight is optimal for operation at the maximum yield. [4]. The movement of these devices by regulators with fuzzy logic controller in photovoltaic power systems reach to the maximizing of PVP array efficiency. The PV system’s output power depends on irradiation and temperature, so the PV system requires a maximum power point tracking (MPPT) controller to maintain the service at the global maximum [1] [3].

The movement is ensured by electric motors, which can be of several types. In this paper is considered, the case of stepper motors for the electrical drive of photovoltaic panels (Figure 4). They work by performing rotational movement steps and control can be made relatively simple.

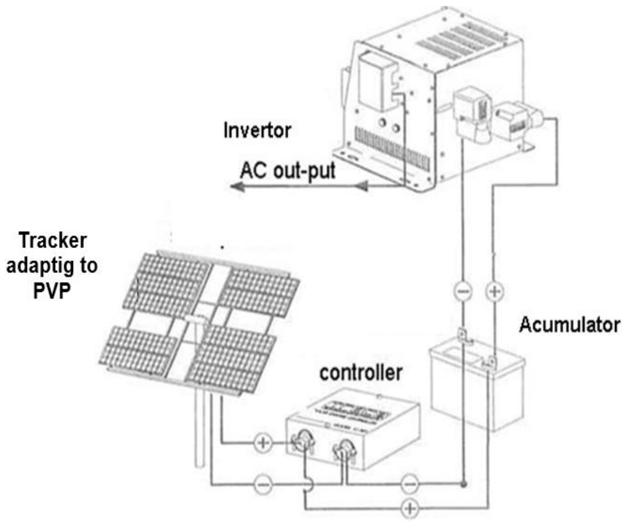


Figure 4. Structure of a PVP tracking system

The step angle, for a general case of a stepper motor having multiple teeth for each stator pole and for the rotor, is determined by the formula:

$$\theta_p = 2\pi\left(\frac{1}{Z_s} - \frac{1}{Z_r}\right), \quad \textbf{(4)}$$

Where, the notation $Z_s = 2p_s n_{dp}$ expresses the total number of teeth on each stator pole with n_{dp} = the number of teeth assigned to each pole in the stator, and Z_r indicates the total number of teeth belonging to the rotor.
The number of steps per rotation is a parameter directly dependent on the value of the step angle. As example, for a motor stepper with θ_p= 1,8° corresponds to 200 rotation steps. This ratio is in formula:

$$n_p/rot = 360/\theta_p \quad \textbf{(5)}$$

The photovoltaic installation has the following components: photovoltaic panel with tracker, inverter, fuzzy controller, storage batteries, voltage stabilization system, distribution board [5][6]. The tracker can be of single construction, i.e. it serves a single photovoltaic panel, or it can be placed either on a pillar supporting a frame with several photovoltaic panels (Figure 5) or on a system with horizontal rods for photovoltaic panels mounted in line (Figure 6). The movement can be designed on one axis, on two or with more degrees of freedom. [7][8][9].

Figure 5. Rotative tracker on pillar (> 2 axis)

Figure 6. PVP tracker system in line (1 axis)

Figures 7 and 8 show how the motor of tracker-driven photovoltaic panels track the sun, in winter and summer, so that production efficiency is maximum.

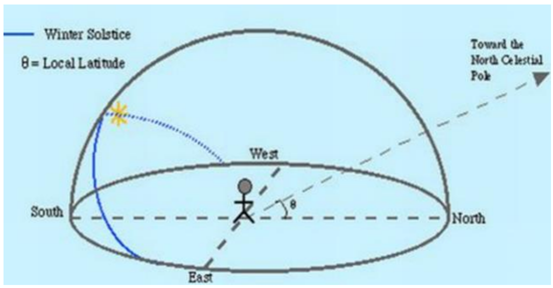


Figure 7. Solar control of maximum functioned power point of photovoltaic panel in winter

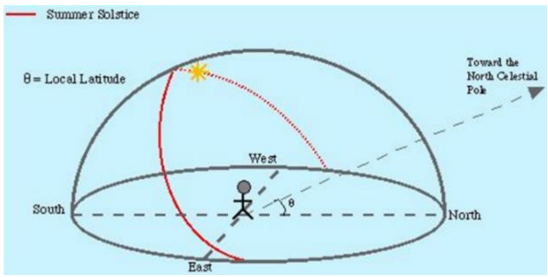


Figure 8. Solar control of maximum functioned power point of PVP in summer

Solar radiation must be perpendicular to the PVP for it to have maximum efficiency in energy production. At the geographical level of Romania, to meet this condition, the inclination of the panels in fixed installation is 30÷32 angular degrees. In figure 9 is a flow diagram with the influencing factors of electricity availability that can be adjusted.

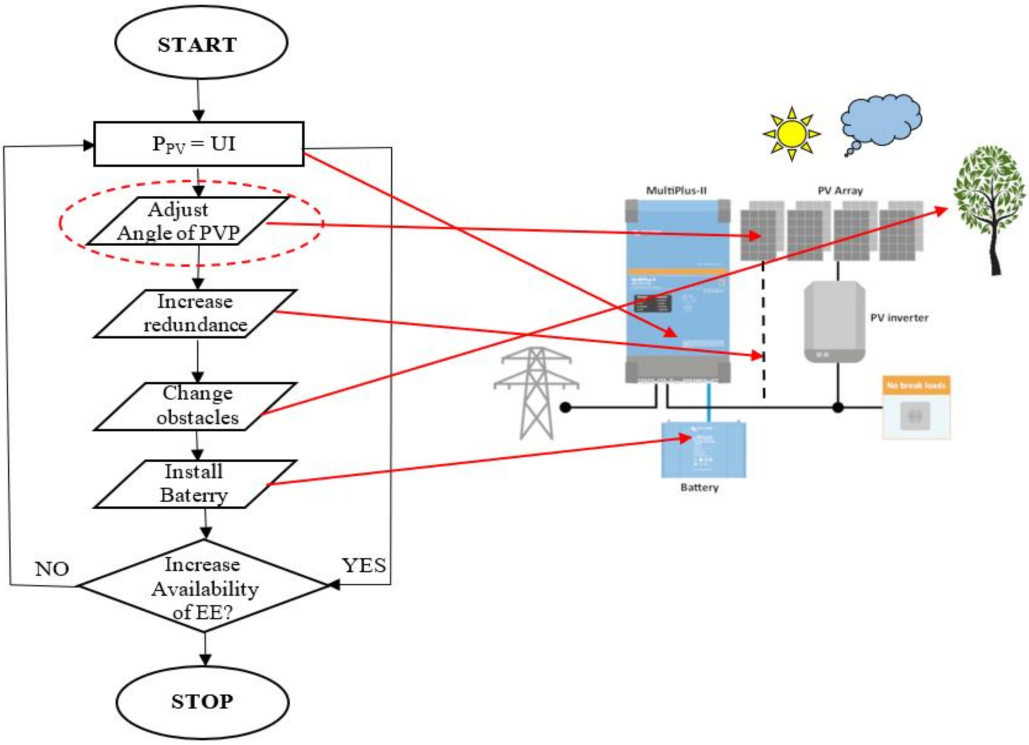


Figure 9. Simplified flowchart for PVP fuzzy availability modeling

5. FUZZY MODEL FOR AVAILABILITY ASSESSMENT AND CONTROL

The assessment of electricity availability at PVP can be done using the Fuzzy Toolbox in Matlab software [14]. The input variables are entered from the dedicated function. The data entry interface is shown in Figure 10. The fuzzy controller configuration can be achieved along two axes - on the equivalent plane - in the considered case following the sketches in Figure 11 and Figure 12. The inference rules are formed based on the authors' assessment of the degrees of influence of the various input parameters (an example is given for the PVP tilt adjustment with solar trackers), through linguistic expressions and numerical values.

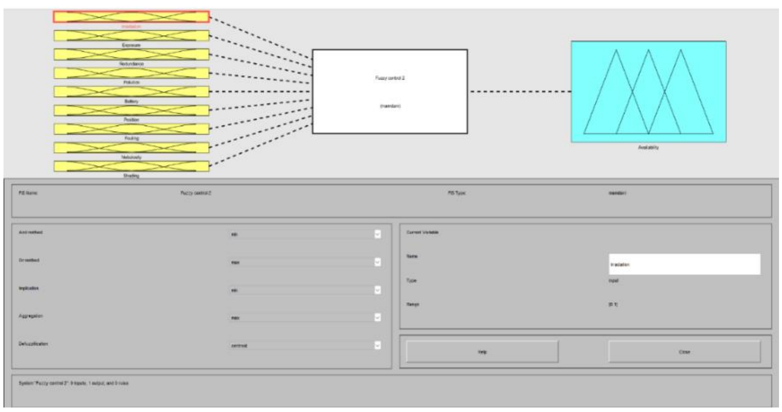


Figure 10. Fuzzy logic variable for inputs

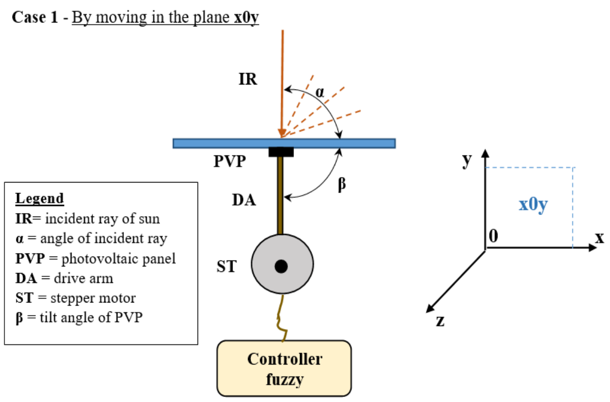


Figure 11. Variables for configuring the vertical fuzzy control of the PFV

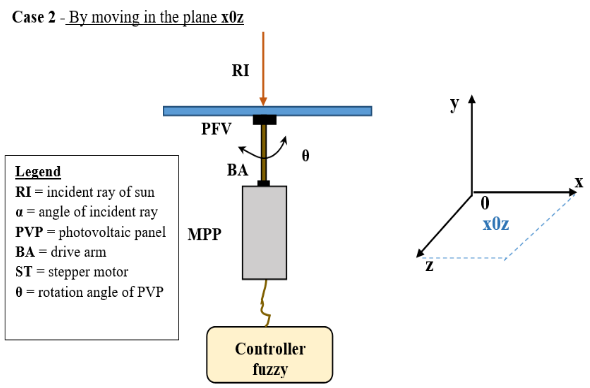


Figure 12. Configuring the PVP circular-horizontal movement regulator

For example, the fuzzy adjustment of the PVP tilt angle in the xOy plane is analyzed. The maximum point PM as a function of the PFV is considered when the incidence ray is perpendicular to the PVP at the maximum radiation density. But since this principle cannot be respected throughout the day but only during the midday hours between 12.00 and 13.00 in summer with clear skies, this is ignored in the case of the present application, but in practice the controller command is given based on the data provided by a device called pyranometer which evaluates the intensity of solar radiation. It is considered that the adjustment parameters as input variables in the attached fuzzy system are only the angle of incidence and the angle of inclination of the PFV and movement in a plane. The adjustment step is considered to be 10 angular degrees. A few examples of inference rules for two adjustment cases with the considered inclination relative to the 180° angle of PVP:

a) For the case from Figure 13-a

If $\alpha_1=10^o$ and $\beta1=180^o$ then $\beta_2=80^o$ in negative sense and $\beta_3=100^o$. The stepper motor will move 8 steps in the positive direction.

b) For the case from Figure 13-b

If $\alpha_1=30^o$ and $\beta1=180^o$ then $\beta_2=60^o$ in positive sense and $\beta_3=120^o$. The stepper motor will move 6 steps in the negative direction.

The motor rotation step is 10°.

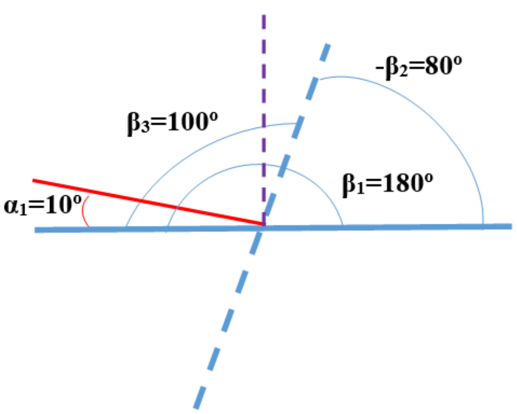
By combining two input variables in the fuzzy system, such as the PVP angle and the exposure duration, the following rules can be formulated for assessing energy availability, for example:

A). If the exposure is long and the angle is small then the availability is increased;

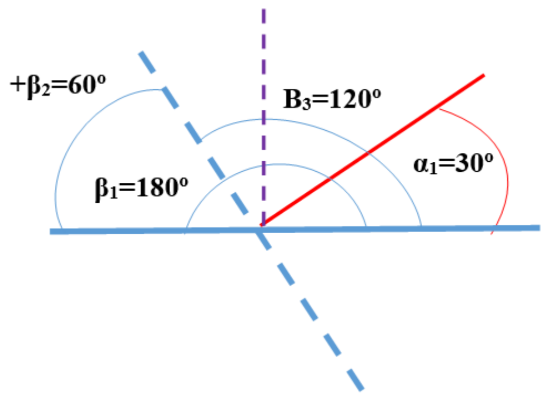
B). If the exposure is short and the angle is large then the availability is reduced

C). If the exposure is medium and the angle is medium then the availability is medium.

To observe the mode of rotation in Figure 13 is given the scheme of angle adjusting for different inclinations of PVP.



a.



b.

Figure 13. PVP angle adjust for obtain MPPT: a-negative sense, b-positive sense

All inference rules considered to ensure the rotation angle given to the photovoltaic panel by the stepper motor and the fuzzy controller are presented in Table 2. As can be seen, the settings imposed on fuzzy controllers are very simple from a conceptual point of view.

For the entry angle can be considered several intervals which may differ from other authors.

The angle values are assigned as follows: 2÷10 degrees = very small; 11÷30 degrees = small; 31÷50 degrees = medium; 51÷70 degrees = large; > 70^o = very large.

These intervals can be divided as much as desired, but this would lead to an increase in the number of inference rules, the principle of adjustment being the same.

Table 2 The complete set of fuzzy rules for all settings

Rule number	Optimum incidence angle	Real incidence angle	Horizontal angle of PVP	Adjust angle of PFV	Motor step	Steps number of motor
1	90^o	10^o	180^o	**+80^o**	-1	8
2	90^o	20^o	180^o	**+70^o**	-2	7
3	90^o	30^o	180^o	**+60^o**	-3	6
4	90^o	40^o	180^o	**+50^o**	-4	5
5	90^o	50^o	180^o	**+40^o**	-5	4
6	90^o	60^o	180^o	**+30^o**	-6	3
7	90^o	70^o	180^o	**+20^o**	-7	2
8	90^o	80^o	180^o	**+10^o**	-8	1
9	**90^o**	**90^o**	**180^o**	**0^o**	**0**	**0**
10	90^o	80^o	180^o	**-10^o**	+1	1
11	90^o	70^o	180^o	**-20^o**	+2	2
12	90^o	60^o	180^o	**-30^o**	+3	3
13	90^o	50^o	180^o	**-40^o**	+4	4
14	90^o	40^o	180^o	**-50^o**	+5	5
15	90^o	30^o	180^o	**-60^o**	+6	6
16	90^o	20^o	180^o	**-70^o**	+7	7
17	90^o	10^o	180^o	**-80^o**	+8	8

Three essential stages are present here: an input stage, a processing stage, and an output stage. During the input stage, data from the solar sensor or other sources, such as switches or the stepper motor shaft, is mapped to corresponding membership functions and truth values. The second stage applies each rule based on the given conditions, generates an outcome for each rule, and integrates all these outcomes. Lastly, in the output stage, the combined result is transformed into the specific control value required at the output. The signs "+" and "–" indicate the reference directions considered.

6. CONCLUSIONS

The efficiency of the operation of the photovoltaic systems by increasing the availability of the electricity produced can be achieved by making the most of the solar energy potential using panel orientation systems or other solutions that are reflected as actions of the influencing factors of electricity production. The analysis of these factors and the appreciation of the influence of availability - of any kind in an adjustable way - can be done by modeling with fuzzy logic. This operation also allows the control of the orientation of the photovoltaic panels through regulators. The positioning of the panels towards the sun contributes to the increase in the availability of the electrical energy produced. Solar trackers are an advanced solution for photovoltaic panels due to the easy control method through fuzzy regulators that control electrical drive systems.

Considering that one of the most widespread applications of fuzzy logic is in decision-making in automation processes, based on input variables, outputs can also be optimized in the case of photovoltaic systems.
These are or are intended to be automated to increase energy availability. Thus, based on the proposed model, on the one hand, internal components can be used to increase the continuity of the electrical power supply to the receivers, and on the other hand, switching through commands on external components, i.e. those belonging to the electrical network to which the consumer is connected, with the same purpose.

The transition between controllable inputs in the adopted photovoltaic system model, such as batteries, reservations or the inclination of solar panels, is controlled depending on the level of input variables independent of human will. The decision can be made, for example, when the availability of solar radiation is reduced.

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