CONTROL OF DISCRETE-EVENT SYSTEMS FOR 3D POSITIONING ROTARY TABLES WITH PHOTOVOLTAIC CELLS

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***Abstract*—The use of solar energy for electricity generation is already a reality. Several countries in the world are reconfiguring its energy matrix with the support of this energy source. To contribute to the worldwide renewable energy demand, an Electronic Intelligence Device (EID) systems is developed to manager the power generation process through the sunrise, enabling the use of intelligent techniques and new architectures of control devices, to ensure the solar panels operation at Maximum Power Point (MPP). Aiming high performance of the proposed system, the development of a control system based on discrete event systems theory and optimization methods is presented in this paper, the small photovoltaic cells is assembled on table with three-dimensional movement that is controlled by a Programmable Logic Controller.**

***Index Terms*—Electronic Intelligence Device; Programmable Logic Controller; Placement of solar panels**

I. INTRODUCTION

The power generation issue for utilization in day-to-day of the urban communities has reached its critical point. The relation supply/demand is close to one, what means that actions have not been implemented to increase this relation, driving the value of this connection for permissible security levels that ensures energy delivery for urban centers with high population density or isolated communities. To overcome these problems, the following actions can be implemented to improve the supply/demand relation: a) mitigate the shortage of resources to meet the existing energy demand, b) reduce the cost of generating units distribution, c) reduce the environmental damage caused due to the use of polluting inputs by the energy industry. In this way, the collapse of industries, commercial and services is avoided in a medium period of time.

Thus, it is presented a proposal for an intelligent positioning system to increase the efficiency of power generation of small solar panels according to climatic variations and generation device displacement [1]. It is all presented a control design method to track moving targets. In our case, the proposed method is applied to allocate solar panel to absorb the maximum sun radiation, i.e. The EID must detect panel position that gives maximum power point (MPP) tracking in small and medium-sized solar panels. These clean energy sources can be installed at fixed locations or that are in motion. The proposed EID aims to detect variations in the solar position and provide the coordinates point to the MPP. Therefore, the positioning system processes the information, providing the positioning angle of the solar panel.

The overall objective of this article is to present the development of an Electronic Intelligence Device (EID) for moving target tracking [2]. This article presents a design method for the development of a positioning system of small and medium-sized solar panels in the Maximum Power Point (MPP). These clean energy sources are installed at fixed locations or that are in motion. The proposed EID has the objective to detect the variation of the sun's position and provide the coordinates related to the MPP. By this way, the tracker processes the information, providing the positioning angle of the solar panel and the control system positions the plate in intended angle. The specific objectives are to develop a 3D positioning system for maximum power point (MPP) of small and medium-sized solar panels, an intelligent sensor to detect the solar position, a low-cost system to improve energy efficiency in solar panels.

The moving target problem and its proposed solution is presented in Section II, the control of discrete event systems theory is associated with the characterization of each element of the electronic intelligente device, such as sensors, actuators, controller and plant. In Section III is presented the development of moving target system, where discussed the main characteristics of the electronic intelligent device based on discrete event systems theory and hardware, such as: programmable logic controller, actuation and detection devices. The moving target system is customized to positioning of the panel to absorb the maximum solar radiation is presented in Section IV.

An application of moving target system in solar panel position is presented in Section IV, where is presented a control logic that is coded in Ladder Language to manage sensors and actuators of 3D- dimensional table, as well as, it is analysed the performance test of proposed system. Finally, in terms of EID architecture associated with the performance evaluation, in Section V is presented the conclusion and comments regarding the applicability and efficiency of the proposal.

II. The Moving Target Problem and Solution

The description, formulation and proposed solution are the main topics of this section.

A. Problem Description

One of the renewable energy sources is solar energy, especially solar photostatic. With advances in recent years in relation to this technology and the growing interest in it, it increased the need for technologies that enhance the investment made and increase its yield.

The photovoltaic systems efficiency depends on several aspects, among which might be mentioned: quality and shading on photo voltaic cells, ability to chase the sun to maximize the incidence of solar radiation, among others.

Among the technologies that can be used to increase the efficiency of the photovoltaic cell are solar trackers. The interest in this technology is due to the fact that it is relatively simple allowing in most cases, significant increases in production in exchange for a relatively low investment when compared to the photovoltaic panels cost. A solar tracker is a mechanical device which aims to ensure that the photovoltaic panels always stay in a better position to capture maximum sunlight. The cost of a tracking system, when taking into account the value of the project of a photovoltaic system, it has an increase of 20% of this amount. However, it should be taken into account that such system could increase the generated revenues by about 40% [3]. Photovoltaic (PV) trackers systems have usually low maintenance cost.

B. Problem Formulation

The formulation of the problem is based on event-driven system approach, the elements of the control system structure is associated to with the conceptual diagram in Figure 1.

The Discrete-Event System (DES) control is based on a pre-established procedure or a fixed logic that establishes a procedure, performing orderly each stage of control. [4] comment that this type of control aims to complement logical systems so that they respond to external or internal events according to new rules that are desirable from a utilitarian point of view.

Important characteristics verified in the control of systems to discrete events: a) Evolution occurs in an instantaneous way; b) the process has asynchronous nature and c) if it is formed by several subsystems, the routines executed there will occur in parallel, that is, independent. It is also worth noting that this type of control is characterized by a finite number of variables, which can be shown mathematically [5].

The diagram elements represent the control device and 3D-dimensional table, where the solar panel is assembled [6].

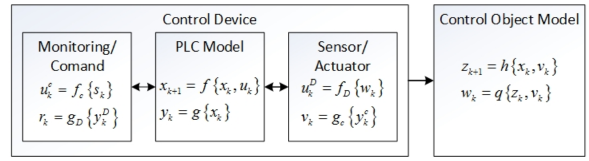

Fig. 1. Conceptual Diagram of Control Systems Design Structure for Event-Driven System

C. Proposed Solution

The moving target detection and its position computation are the mains events that are necessary to startup the tracking process. Generally, these two stages are represent in terms of solar energy intensity in a certain day time is captured by the sensor and its position. The energy and position mapping are given by

$$\Xi : (T,V,I,t) \quad \rightarrow \quad \xi, \tag{1}$$

where T,V,I are the set of variables that allows the moving target ξ detection in given time t.

The mapping of the target position is given by

$$\Theta : \xi \quad \rightarrow \quad \theta \tag{2}$$

where ξ is desired detection and θ is the position that is associated with ξ.

III. Moving Target System

In this section is presented the application of the proposed platform in a process of solar energy generation

A. Solar Energy Generation Process

The process model for maximum power purposes generated by the cell is given by electrical equivalent circuit as shown in references [7]. Figure 2 presents equivalent circuit of the photovoltaic cell [8]. In this model the anti-parallel diode is replaced by a source of current controlled [7], allowing the representation of cells connected in parallel and / or series in a single circuit with the details of each cell.

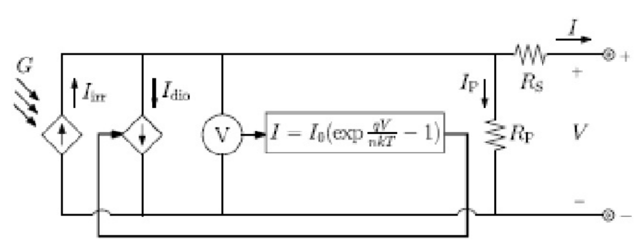

Fig. 2. Equivalent Circuit of the Photovoltaic Cell.

Associated with the electrical equivalent circuit of the solar cell in the Fig 2, the current in the panel terminal is given by $I = I_{irr} - I_{dio} - I_p$, where I_{irr} is radiation current that is generated by sunlight incident on the cell, I_{audio} is the current in the anti-parallel diode that is responsible for generation and nonlinear characteristic of the cell PV , I_p is the current due shunt resistor R_P.

The Radiation Current can be calculated by $I_{irr} = I_{irr,ref}\frac{G}{G_{ref}}(1+\alpha'_T(T-T_{ref})$, been α'_T as temperature coefficient for the short-circuit current, representing the rate of variation of short-circuit current in relation to temperature. The manufacturer's relations for this parameter is given by $\alpha_T = \alpha'_T I_{irr,ref}$.

The current in the anti-parallel diode is given by $I_{dio} = I_0\left[exp\left(\frac{q(V+IR_S)}{nkT}\right)-1\right]$, $q = 1.602\times10^{-19}$ C as electric elementary charge, $k = 1.38\times10^{-23}$ J / K is the Boltzmann's constant T is the cell temperature, i_0 is the diode saturation current, n is the ideal factor diode R_S and R_P represent series and shunt resistances, respectively. The calculation of these parameters is given by the following relations.

The saturation current depends on the temperature on the panel which is a variable of interest. The calculation of this current is given by $I_0 = I_{0,ref}\left(\frac{T}{T_{ref}}\right)^3\left(\frac{E_{g,ref}}{kT_{ref}}-\frac{E_g}{kT}\right)$, G is the band gap energy for silicon in eV. According to [9], the analytical relationship for E_g is obtained in [31], this relation in function of temperature T is given by $E_g = 1.17-4.72\times10^{-5}\frac{T^2}{T+636}$.

The current due shunt resistor is given by $I_p = \frac{V+IR_S}{R_P}$, and the resistance values are: $R_P = R_{P,ref}\left(\frac{G}{G_{ref}}\right)$, $R_S = R_{S,ref}$ and $n = n_{ref}$.

1) Characterization of Photovoltaic Array: Figure 3 shows the behavior of the voltage / current on solar panels, the I-V performance curves for different $G_1 < G_2 < G_3 < G_4 < G_5$ values of solar radiation.

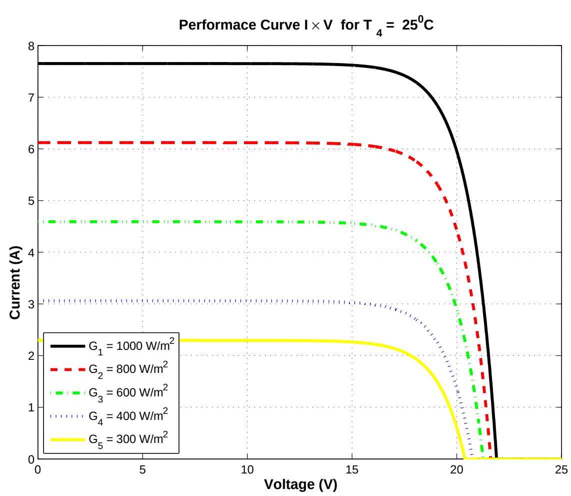

Fig. 3. Performance $I-V$ Curves of Solar Panels for Different Solar Radiation values

Figure 4 shows the behavior of the voltage/current on solar panels, the I-V performance curves for different $T_1 < T_2 < T_3 < T_4 < T_5$ temperature values.

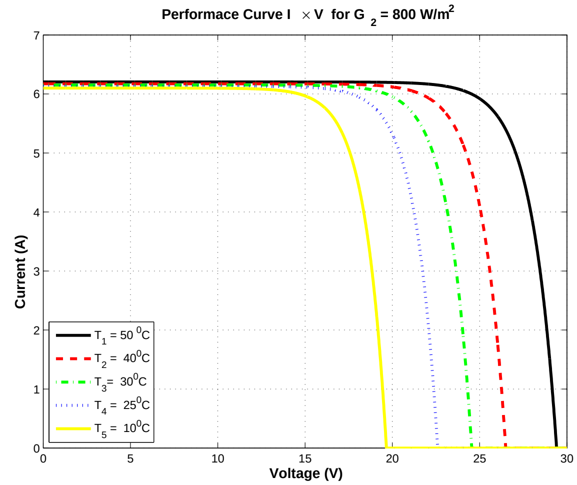

Fig. 4. Performance $I-V$ Curves of Solar Panels for Different Temperature values.

In the photovoltaic cell arrays the current I_{irr} and I_0, the resistances R_P and R_S and n depend on solar radiation (G), the cell temperature T and benchmarks, G_{ref}, T_{ref}, I_{irrref}, $I_{0,ref}$, R_{Pref}, R_{Sref} and n_{ref}.

The characteristic curves $I-V$ performance for photovoltaic cell arrays, Figures 3 and 4 presents characteristic curves $V\times I$ for solar panel $PSOLAR-X$.

B. Control Project

In reference to Figure 5, the Discrete Event Systems (DES) are sets of elements, material or immaterial, in which can define a relationship operating as an organized structure. The Control Systems for DES are formed by: control devices, monitoring devices, control realization devices, actuation devices, detection devices and Control object [10].

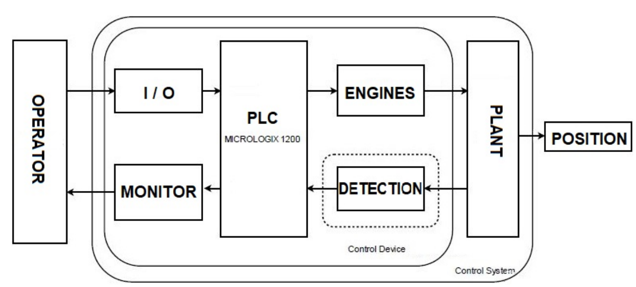

Fig. 5. DES Control System Conceptual Basics Diagram

The proposed Moving Target System based on DES-EID for 3D table positioning is presented Figure 6, where can be seen this equipment playing the role of plant/process, PLC MicroLogix 1200 as controller, the 4 contactors that perform the electric motors's (actuators) command, analogic expansion cards that receive and digitize the signals from the positioning sensors.

Fig. 6. Solar Position Tracking System

1) Control Device: In the project, it will be used as device of control realization the PLC (Programmable Logic Controller) which is basically a control device of a plant from computer programming with no need to change the hardware. The controller replaced the relay panels, thus increasing the operation time through process automation. It is used to control machinery, elevators, transport systems.

The PLC chosen for project is MicroLogix 1200 controller has up to 24 inputs and 16 digital outputs. In this type of controller, there is the possibility to add up to three expansion modules analog inputs and outputs.

For the reason that MicroLogix 1200 has only digital inputs and outputs, there was the need to add analog inputs to the plant positioning sensor could capture the angle of the sun. For this, it was used the 1762 family expansion module, which has a voltage range of 0 to 10 volts DC. In each expansion module there is the possibility of adding two analog voltage and / or current inputs. In the case of the plant, two voltage inputs were used.

2) Actuation Device: The actuation device used in the project was an electric motor of direct current permanent magnet type, due to its low power and good torque when connected to a gear motor.

3) Detection Devices: One of the strategies used to determine the position of the sun was to resort to using sensors. The sensors used are typically composed of at least one pair of photo sensors, generating different voltages/currents that are not always aligned with the sun. The photo sensors can be mounted on inclined surfaces to increase the sensitivity. In the project it was proposed a sensor consisting of a semi-circle with 5 small solar panels arranged on the 30 degrees range in the photo voltaic panel.

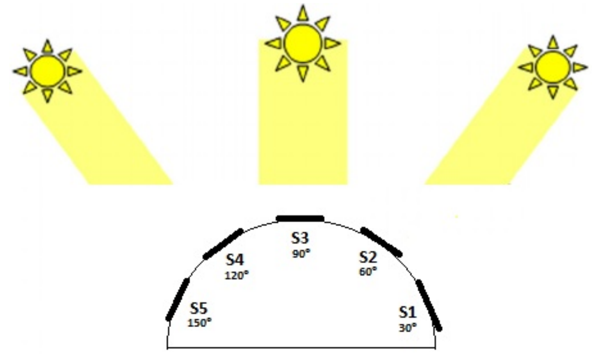

Fig. 7. Solar Positioning Sensor

IV. Solar Panel Position Application

This section presents the control system hardware and intelligent sensor. Initially. Figure 6 presents the process hardware and Control and Tracking System to board the algorithms of the virtual sensor and 3D table positioning control [11].

The 3D table, as the name suggests, can move in three axes XYZ allowing the object attached to it moves assuming the desired position by the control device. Therefore, this equipment has as actuators - two engines, one responsible for movement in the XY axis and another in the Z-axis, a half gear that helps in moving the XY axis and a photovoltaic panel over the table to transform solar radiation into electrical energy, all the parts of 3D table they can been seen in Figure 8.

Fig. 8. Solar Panel and movement Gear of 3D table

A. Photovoltaic Cell

The system will be self-sufficient due to electric power generation by photovoltaic flat plate as it appears in Figure 9. The flat plate is attached to 3D table that will allow the movement of translation and rotation on its axis [12].

Fig. 9. Rear view of the 3D table and Solar Panel.

Table I presents the data plate of the photovoltaic panel manufactured by Komaes.

TABLE I
DATA PLATE OF KOMAES MODEL KM(P)85

Peak Power	(Pmax)	85 W
Maximum Power Current	(Imp)	4.70 A
Maximum Power Voltage	(Vmp)	18.10 V
Short-Circuit Current	(Isc)	5.10 A
Open-Circuit Voltage	(Voc)	21.63 V
Power Tolerance	-	±5 %
Application Class	-	A
Weight	-	7.9 KG
Dimension	(mm)	940*x*680*x*35
Maximum System Voltage	-	750 V

B. Control Device

The *Electronic Intelligent Device* (EID) of the control systems and indirect measurement of Figure 10, consists in a control panel and processing of 3D table for the photovoltaic panel positioning.

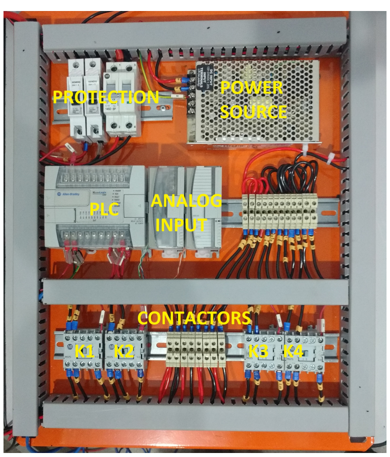

Fig. 10. EID of the Control Systems and Indirect Measurement.

Figure 10 presents the control device that has the virtual sensor algorithms to capture the position of the moving target at the moment k and 3D table position control toward the moving target .

C. Command Circuit

The wiring diagram of the control and power circuit of 3D table is present in Figure 11, that can receive the voltage or current signal of four sensors S1 to S4, and control the rotation direction of 2 engines, K1 or K3 clockwise and K2 and K4 counterclockwise.

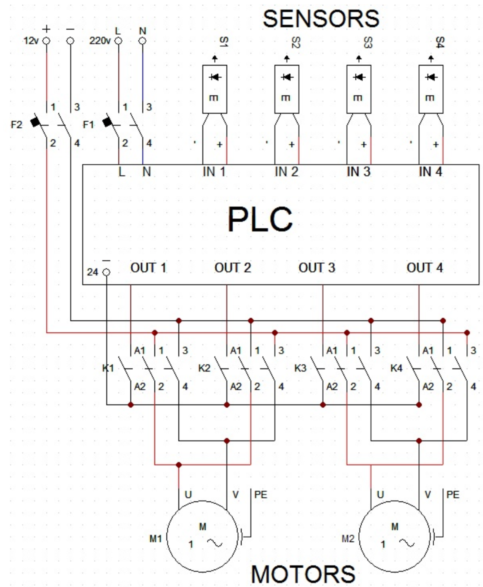

Fig. 11. Wiring diagram.

D. Control Logic

In this logic, the sensors (mini photovoltaic panel) are attached to the 3D table, following its movement. By this way, the logic is based on maintaining the highest level of voltage/current in the sensor at 90° (perpendicular to plate). The Ladder (the PLC's programming language) of this logic can be seen in Figure 12

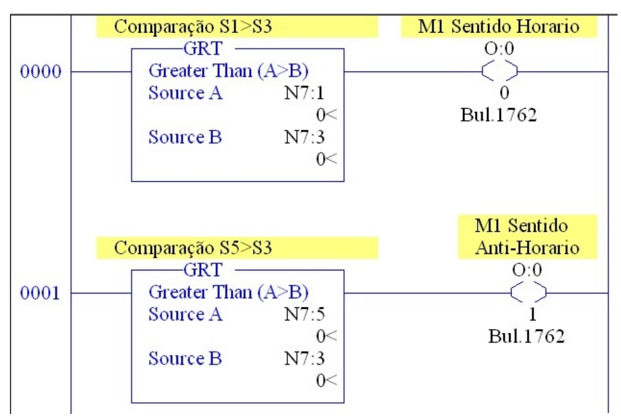

Fig. 12. Ladder Logic for Mobile Sensor.

In line 000, GRT instruction compares if the value of the sensor S1 (N7:1) is greater than the value of the sensor S3

(N7:3). If the instruction is true, the motor M1 is turned clockwise, which means that the sun is below the line perpendicular to the solar panel, so the panel should be lower.

In line 001, GRT instruction compares if the value of the sensor S5 (N7:5) is greater than the value of the sensor S3 (N7:3). If the instruction is true, the motor M1 is activated in the anti-clockwise, which means that the sun is above the line perpendicular to the solar panel, thus the panel must rise.

E. Indoor Tests

In this section will be presented the results of the indoor tests of EID to the solar positioning.

The test is based on measuring the voltage (volts) generated by the board for a day from 7:00 in the morning until 17:00 pm. The board was connected to a fixed load with 1.2 amps of current, the measurement results are shown in Table II.

TABLE II
RESULTS OF VOLTAGE MEASURING IN ONE DAY

Hours	Fixed (voltage)	With EID (voltage)
07:00	14.23	17.5
08:00	15.85	17.8
09:00	16.7	17.47
10:00	17.7	17.7
11:00	18.01	18.01
12:00	18	17.9
13:00	17.7	17.8
14:00	16.4	17.8
15:00	12.8	17.5
16:00	10.4	17.6
17:00	6.7	17.6

The total energy generated in watts by the two systems was $197.4W$ with the fixed plate and $223.6W$ with EID already considering the consumption of 10w engines during the day, noting that the tests were done in a controlled environment thus failing to reach the maximum power of the board.

V. CONCLUSION

To increase the efficiency of energy generation via photovoltaic panels that is assembled on table with three-dimensional movements, the development of an electronic intelligent to device based on discrete event systems theory, ANN, indirect measurements of the sun radiation, photovoltaic cell and programmable logic controllers was presented in this paper.

The moving target search method allows the solar generation system always works in the Maximum Power Point (MPP). The results showed an increase in the efficiency with use of DES-EID over the fixed plate, proving the improvement in the production of energy by the user of the intelligent electronic device proposed in the work.

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