EVOLVABLE HARDWARE USED IN PHOTOVOLTAIC PANEL TRACKING

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REZUMAT. Obiectivul acestui articol este punerea în aplicare a unui sistem de control eficient pentru panouri fotovoltaice. Fiecare panou este bazat pe o oglindă şi un sistem de dirijare. Fiecare panou trebuie poziţionat astfel încât să primească direct lumina soarelui pentru putere maximă. În acest articol ne propunem o soluţie de control bazată pe un bio-algoritm (algoritm genetic), cu anumite caracteristici speciale date de punerea în aplicare propusă.

Cuvinte cheie: panou fotovoltaic, algoritm hardware genetic, hardware evolutiv.

ABSTRACT. The objective of this article is the implementation of an effective control system for photovoltaic panels. Each panel is based on a mirror and a routing system. Every panel should be positioned so it gets direct sunlight for maximum output. In this article we propose a solution of control based on bio-inspired algorithm (genetic algorithm) with certain special features given by the proposed implementation.

Keywords: photovoltaic panel, hardware genetic algoritm, evolvable hardware.

1. INTRODUCTION

The pursuit for clean energy has a great focus on solar power, as the Earth receives a total of 174 PW of incoming solar radiation, of which 120 PW reaches the surface, theoretically exceeding by a huge margin the total energy consumption on Earth. The regions with a constant solar flux and large unused surfaces of land are the most common places for large solar power plants. The conversion of solar radiation in electricity in mostly done through indirect conversion using concentrated solar power, directly by using photovoltaics or using other techniques like dye-sensitized solar cells, bio-hybrid solar cells, photon enhanced thermionic emission systems and luminescent solar concentrators. Systems relying on Concentrated Solar Power employ lenses, mirrors and tracking systems in order to focus the solar radiation from a large surface on into a small beam. The photovoltaic systems convert the light directly into electric current using the photoelectric effect. Earlier photovoltaic cells used to convert as little as 1% of the solar radiation received in electric current, whereas modern cells reach a 20% efficiency for the commercially available models and over 40% for research models.

The principle of operation of the photovoltaic panel based power plant – which this article is based upon – is presented in Figure 1 and will be described below.

Several photovoltaic panels are placed on mounts which allow adjusting their position. Adjustment has to be performed on both axes so that the orientation of the panel could be operated on both North-South and East-West. This is needed because, especially in temperate zones, the position of the Sun in the sky fluctuates during the year. The goal is to control all panels (the field can contain hundreds) so they get optimum exposure, and thus produce more electricity.

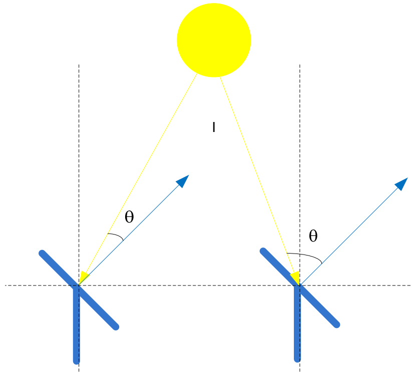


Fig. 1. Principle of operation of photovoltaic panels.

In general, photovoltaic panels are either tracking the movement of the sun or are stationary (mounted on fixed racks, on the ground or on roofs). Panels mounted on solar trackers are more mechanically complex and rely on different types of systems that sense or estimate the direction of the Sun. This article proposes a solution that considers increasing the efficiency by improving exposure, but at the same time lowering energy consumption for positioning the panels. The solution, described below, uses an additional small panel (with very low mass) on each panel. The small panel measures through its energy output the efficiency of the large panel. A bio-inspired solution for multi-criteria adjustment optimization is employed to decrease energy consumption and increase efficiency through optimal exposure.

2. PRECONDITIONS FOR IMPLEMENTATION

Providing a mechanism for adjusting the position of the panels in order to have optimum exposure is a major precondition in ensuring the functionality of the solar power plant. A principle is shown in Figure 1. The θ angle is the angle between the solar rays and a line perpendicular to the panel.

If the surface of the panel is S_0, then S is an equivalent surface area irradiated at some moment in time: $S = S_0 \cos\theta$; θ varies daily from $-\pi/2$ to $\pi/2$.

The energy produced as a result of an irradiation with the intensity I = 1100 W/m2 (as is produced by the Sun, thus neglecting losses through the atmosphere) is given by the expression:

$$W = \int I\, S_0 \cos\theta \mathrm{d}t = \int I\, S_0\ \cos\omega t\ \mathrm{d}t$$

where S_0 is the maximum exposure, calculated at noon or when θ is 0.

There are several solutions for adjusting the panels, described very comprehensive in *A review of principle and sun-tracking methods for maximizing solar system output* by Hossein Mousazadeh, Alireza Keyhani, Arzhang Javadi, Hossein Mobli, Karen Abrinia, Ahmad Sharifi [4]. Thus, tuning solutions can be divided into passive solutions, based, for example, on the property of materials to dilate with the rise in temperature [5], solutions which do not have any power consumption, but which are expensive because of the nature of the these materials; active solutions, which involve adjusting through the command of motors. Active solutions are controlled by microprocessors and logic circuits, according to the information received either from sensors or from a timetable with data for each day and hour or dual-faced solar cells.

The most numerous are the solutions based on microprocessors and logic circuits. In general, papers are geared toward finding the maximum exposure. They are based on the use of digital and analog light sensors and on a logic circuit for actuation of the panels: adjustment on the N-S and vertical axis [6] through a platform that rotates around the axis in a range of +/–45 °, two motors that operate the system one by one to reduce their consumption [7] and through the use of two separated photo transistors, placed in different parts of the mirror. When the values from the two different sensors are different a DC motor is activated. The system follows the Sun every 4 minutes in the horizontal plane and every 5 minutes in the vertical plane [8].

3. IMPLEMENTATION

This solution consists of two modules. The first consists of actuators placed at each panel individually on two small servo DC motors that move a small panel. The small panel energy output is transmitted to the central unit. The central unit responds in real time with commands for the servo motors.

The second module is made of the central processing unit itself and it is based on an integrated FPGA circuit running a hardware implemented genetic algorithm, providing real-time response to the system.

The hardware system for testing the optimum position is composed, as can be seen in Figure 2, from a microcontroller, a radio transceiver (ZigBee), two small size servo motors and a small mirror.

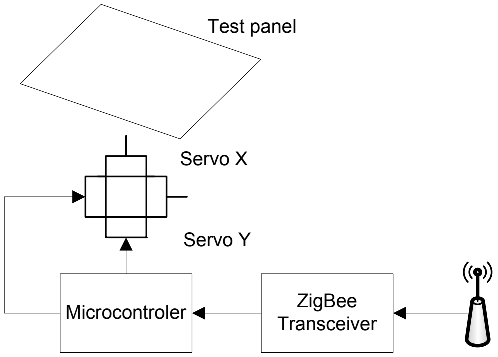
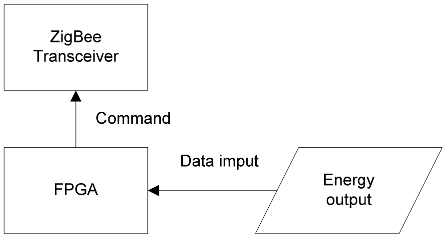


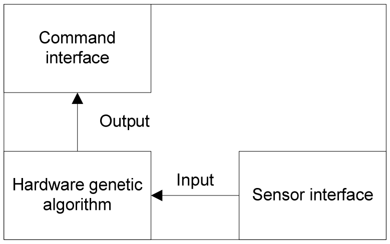
Fig. 2. Example of a test unit.

The central unit commands the servo motors, who adjust a small test panel in order to get maximum exposure to Sun rays. Given the small mass and inertia of the test panel, we can determine quite fast the amount of energy it receives. The cost of hardware testing system is justified by reducing energy consumption at the main engines, those that change the position of the mirrors. The experimental results presented below are made by the simulation of the control system. It was necessary, however, to specify the hardware components, to understand the input data that are taken into account in the simulation.

The central unit is based on a reconfigurable circuit running a genetic algorithm totally implemented in hardware. Central unit structure, shown in Figure 3*a*, is composed of the following elements: FPGA, central unit running the hardware genetic algorithm, radio transceivers that transmit the operating controls. Communication with the operating elements of the central unit takes place via a ZigBee network configuration in which the central unit shall act as coordinator and peripheral circuits as end points.



a) Hardware block diagram



b) In circuit – core block diagram

Fig. 3. Central unit block diagram.

Figure 3*b* presents the FPGA circuit. It consists of the following: communication interfaces with transceiver, processing orders module, hardware genetic algorithm module.

In Figure 4 the principles of operation of the system are shown.

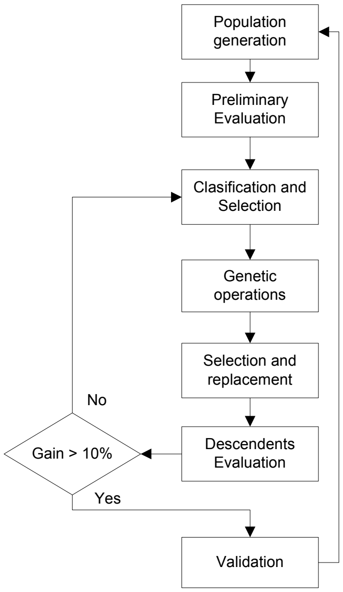


Fig. 4. The genetic algorithm flowchart.

We have used a hardware genetic algorithm because we needed a multi-criteria design – a system that responds to more requirements – but also a response in real time – so it justifies the use of hardware implementation.

The system that we intend to simulate is characterized by the following:

– 100 panels to be guided independently, so that they can focus a beam towards the collector;

– a central processing unit based on a FPGA circuit;

– a communication network based on the ZigBee protocol.

Each test system receives a command through which the state of the two servos is set. A command structure is shown in Figure 5. The order is composed of two parts: the servo travel on the X axis and the servo travel on the Y axis, each part has 4 bits. In total there are 16 possible states. The 0000 state reflects a maximum inclination on one side, while the state 1111 maximum inclination on the other.

The command for the test system is a chromosome (an individual). All orders (total of 100) represent the population. An individual is not the solution sought, but is rather a part of the solution. Each individual will be assigned to a test system.

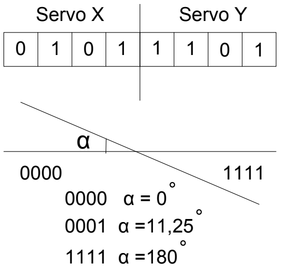


Fig. 5. Example of servo commands.

The genetic algorithm running on the central unit is characterized by the following:

– 100 individuals per generation – each individual represents a configuration for each of the 100 test systems;

– evaluation stage is carried out on each individual;

– crossing rate is 1/generation with crossing in one point;

– the mutation rate is 0.25/generation (average of 1 in 4 generations) with single gene mutation;

– the selection uses the roulette method.

The algorithm presented in Figure 4 performs the following steps: initial population is composed of random individuals. The second stage is the preliminary test. Preliminary testing involves the following: all of the engines are put into an initial state (specified at installation – this represents the reference condition), all servo drives testing systems are put into a neutral state which corresponds to horizontal position 10001000 – the reference state of engines is associated with a neutral status of the servo motors. Any subsequent command of the mirror will be referenced to the initial state.

At this stage every individual is tested separately by moving the test panels in the position determined by its assigned chromosome. We will have a power value – B_i – associated with each individual, which is obtained through the information sent by the test panel. After testing the whole population we would get a global value for power $B_{gi} = \sum_i B_i$. The difference between the global value and the individual value $F_i = B_{gi} - B_i$ is the individual fitness of each test system, which is used for classification of individuals. From this moment begins the evolutionary loop. It contains standard stages: the classification, the selection of parents, applying genetic operators (mutation and crossover), selection and replacement of weak individuals. Evaluation of the descendants is made by calculating the $F_{inew} = B_{ginew} - B_{gi}$ where B_{ginew} is the overall power determined by the positioning of the panels according to the data of the new generation (the descendants).

Development process stops when the population has reached an overall power greater than 110% of the initial power B_0. In this case, validation takes place and the large panel motors are ordered to move in the new position. After the validation phase, the entire process is resumed. The justification for the increase by at least 10% in the overall power is saving the energy, as it is not worth moving the large mirrors for less than that.

Why did we use an evolutionary algorithm? Because the criteria for determining the peak brightness are multiple: the movement of the Sun in the sky and changes from one season to another (particularly in temperate zones), the relative position of each panel, wind conditions (leading to the displacement of the panel from its original position), the weather conditions (if the sky is covered with clouds the sun position is lost so it must be retrieved in clear sky), the mutual shading caused by the panels (if they are too close together). All of these are very hard to determine, therefore we use an evolutionary solution for finding the maximum.

Why is the central unit based on a reconfigurable circuit (with a hardware implemented genetic algorithm) and not with a microprocessor or a computer? Because it needs a rapid convergence to determine the optimal solution. Unlike the solution implemented on a MCU or computer, the reconfigurable circuit can run in parallel a sequence of operations to be carried out for the same generation – for example sorting for selection, but also at the level of multiple generations – a kind of parallel pipeline: while one generation passes through a stage (e.g. evaluation), the other is subject to genetic operators. Time used by the reconfigurable circuit is very small and the solutions implemented in hardware have even reached as low as 5 ms to convergence.

ZigBee communication allows us to easily achieve the needed network for this project, as data transmission speed is high and the costs are low.

4. RESULTS

In the table below are the maximum values of energy obtained in 3 cases: without adjustment (fixed panels pitched at an angle equal to the optimal angle), our solution (values are only for 30 generations) and theoretical optimal value (in which all the mirrors reflect with maximum power, cannot be achieved in practice).

Table 1. **Results from simulation with 30 generations**

Hour	Fixed mirrors	Tracking with HGA	Theoretical optimum
6	0	8758.612	10016.6
7	0	7026.651	10573.44
8	0	8083.889	10664.71
9	0	7493.27	10064.01
10	934.166138	5689.393	9913.165
11	4835.890625	8396.688	10284.68
12	7268.770996	5918.3	11000
13	4836.031738	6042.171	10284.68
14	5820.20459	5280.083	9913.165
15	7515.023438	5180.677	10064.01
16	8199.984375	3912.108	10664.71
17	5719.225098	3975.041	10573.44
18	5057.509277	7321.234	10016.6
Day avg.	*3860.52356*	*6390.624*	*10310.25*

The figure below shows how the energy in a day fluctuates, from 6:00 to 18:00:

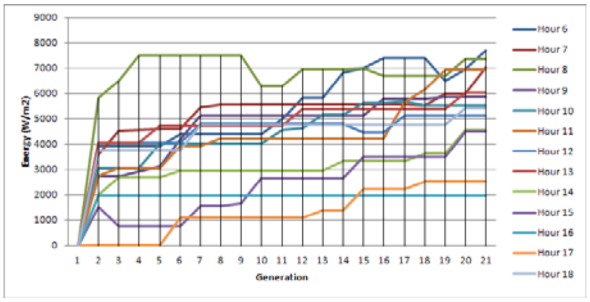


Fig. 6. Convergence tendency for the first 21 generations.

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