

Position Control for a Solar Panel Implemented with a Predictive Control Algorithm.

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Abstract– This article describes the development and implementation of a control system applied to a photovoltaic panel. The objective of the controller is the automatic tracking of sunlight, for which controllers based on PID and MPC are implemented. For the experimental development, a photovoltaic panel, a personal computer and an ARDUINO card were used as a communication interface. For the simulation, we worked in the environment of the MATLAB and SIMULINK platform. In the case of the analysis of the response of the MPC, three scenarios were used. Comparing the results of the PID vs MPC, it can be stated that better follow-up responses were achieved in the case of the control based on the MPC model.

Keywords-- Arduino, Inverter, LDR, MPC, Photovoltaic Systems, PID, Simulink.

I. INTRODUCTION

The objective of this work is to design and implement a control circuit for the positioning of a photovoltaic panel according to the maximum solar radiation obtained, using traditional and predictive control techniques since environmental protection is currently taking greater prominence [1]. Likewise, there are cases of implementation and selection of photovoltaic solar panels to achieve their massification in buildings and homes where other buildings can generate shadows and the panel must be located properly according to the highest solar radiation [2]. With the updating of final devices such as LED lighting, household appliances with INVERTER technology, it becomes more feasible to power them with photovoltaic systems, since less supply power is required, unlike conventional loads [3].

In a world where climate change increasingly triggers more alerts due to increased temperatures, and in turn is given more importance, where warming is developing more and more every day, the issue of renewable energies is addressed as a strategy allied with the objective of sensitizing and/or making the world population and industries aware of their use, since these alternative energies are a source of help to prevail the environment [4]. As an alternative, there is the use of clean energies which can be wind, photovoltaic, thermal, etc., the same ones that are currently used, but in a backup form [5]. Due to this, a prototype of a photovoltaic source has been developed, the same one that is automatically positioned according to the location of the sun. As a base, correctly installed photoresistors were used and by means of voltage dividers, they are transformed into variable voltages, which are sent to an Arduino interface and using the MATLAB Software as a platform.

A. J. F. Jiménez-Ortiz D. Biel, in his scientific article "Study and simulation of photovoltaic-electric conversion systems using Matlab/Simulink", describes a simulation tool developed in the Matlab/Simulink environment that allows

descriptive experiences of the operation of photovoltaic systems [6]. Said tool is formulated with the objective of supporting and supporting the learning of the fundamentals of photovoltaic-electric conversion systems. Simulation experiences have been developed to show everything from the behavior of photovoltaic cells to complex systems connected to the electrical network.

Cecilia Sandoval in her scientific article "Adaptive Control in VHDL Applied to a Solar Furnace", describes the design of an adaptive control application for managing the variable temperature in a solar oven, framed under the philosophy of configurable hardware, through the description in VHDL code (Very high-speed integrated circuit Hardware Description Language). Initially, she carried out a study of adaptive trends and models, for her description on an FPGA device [7]. The theoretical review allowed to define the requirements for various control algorithms with adjustment of coefficients, adaptive control, training of neural networks. The reference tracking behavior was validated in a first adaptive gain test and the control system for the solar oven was proposed, reporting the performance of the algorithms studied, resulting in efficient solar applications based on adaptive arrays of reflective panels for temperature control.

Next, the sections on materials and methods are developed, where the prototype used, the signal conditioning, the components of the photovoltaic system, etc. are described. Then the results of the identification process and the implemented PID and MPC controllers are shown. The document ends with the statement of the results and conclusions of the project.

II. MATERIALS AND METHODS

A. Prototype description.

Figure 1 shows the influence of the sun's radiation, which is captured by three photoresistors or LDR's placed at one end of the solar panel. The signals from the photoresistors are connected to a voltage divider and input to an Arduino Uno card that is the interface with the MATLAB software. From the Arduino card, a signal is sent to a signal conditioning module, so that it drives a DC motor M, which will rotate at an angular speed ω_1 according to the signal generated by the LDR's and the algorithm that the MATLAB software has. The motor M rotates in both directions with an angular velocity according to the PWM coming from the signal conditioning module. The voltage output of the photovoltaic panel is connected to a voltage regulator and this in turn to a battery and the DC / AC inverter, the same one that generates 120 V, 50 Hz.

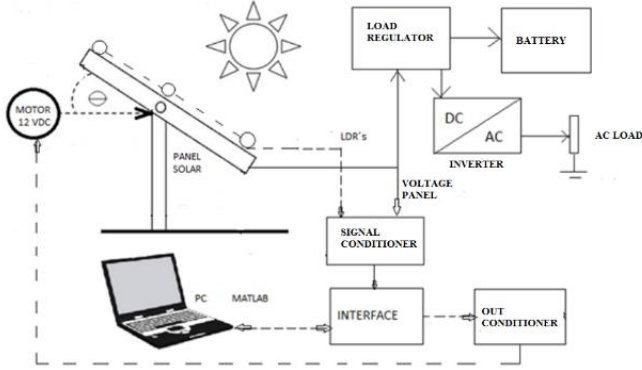


Fig. 1 Position Control System.

B. Signal conditioners.

For the voltage divider, a $V_{cc} = 5$ Volts with 10 K resistors is used. The signals from the photoresistors are sent to the analog inputs of the Arduino Uno. See figure 2.

Due to the principle of operation of the LDR, when there is lighter, the resistance value is reduced and a V_{out} will vary close to the maximum value, this will happen when the panel is positioned in front of the sun, at 90° between X and Y, as illustrated in figure 3. In the same way, when the LDR moves away from this position, the V_{out} will decrease.

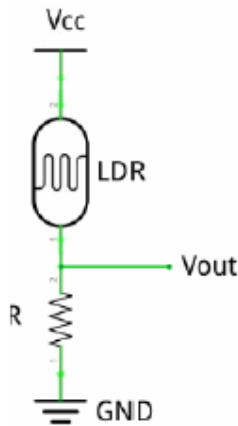


Fig. 2 LDR voltage divider.

If you subtract the voltage produced by LDR1 and the one located in the middle LDR2 ($V_{LDR2} - V_{LDR1}$), you will get a one-ended voltage reference. In the same way, by subtracting the voltage produced by LDR3 and the one in the middle ($V_{LDR2} - V_{LDR3}$), a voltage reference will be obtained from the other end. Now, if these two values are subtracted: $(V_{LDR2} - V_{LDR1}) - (V_{LDR2} - V_{LDR3}) = AV'$; where AV' is the input signal for position control. When the solar panel is at 90° between X and Y, V_{LDR} will have the voltage, so AV will be 0. In short, to obtain the ideal position of the solar panel, the control setpoint must be 0.

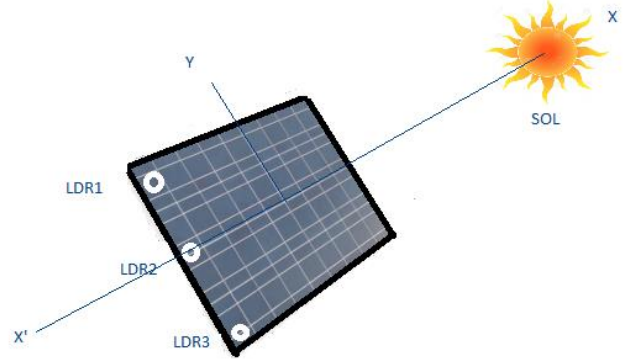


Fig. 3 PV panel position.

C. Control loop for the positioning system.

The control loop of the solar panel positioning system is shown in figure 4.

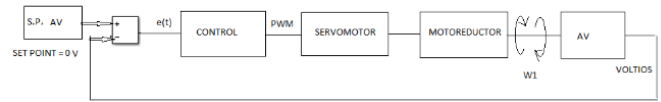


Fig. 4 Control loop for the positioning system.

D. PV System Components.

Figure 5 shows the complete photovoltaic control system which consists of the following parts:

1. Solar panel
2. Electrical panel
3. 12 Volt DC motor reducer
4. 12-volt battery
5. Laptop with MATLAB and Arduino
6. LDR's or photoresistors

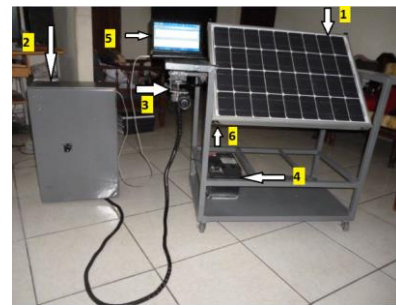


Fig. 5 PV System Components. [8].

In fig. 6. there is the interior of the electrical panel with the elements:

- a. fuses
- b. Charge regulator
- c. Arduino UNO
- d. Inverter 12 V DC to 120 V AC, 150 Watts
- e. engine controller Sabertooth [9].



Fig. 6 Electrical Panel.

Fuses protect the entire circuit. The charge regulator is responsible for controlling the voltage to protect the battery and the panel. The inverter converts the battery voltage from 12V to 120Vac. The Arduino card receives the voltage dividers from the three LDR's and with the help of Simulink, generates a PWM to the motor controller.

III. CONTROLLER DESIGN

A. System Identification.

To find the transfer function of the system, the MATLAB IDENT Toolbox was used as shown in figure 7.

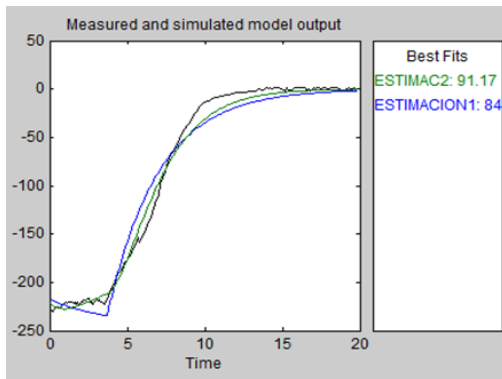


Fig. 7 System identification [10].

The transfer function obtained for the solar panel positioning system is shown in (1).

$$G(s) = 0.87212 / (3.556s^2 + 3.7719s + 1) \quad (1)$$

Where G(S) is the ratio of AV/W1.

B. PID Control.

To obtain the parameters P, I and D, the Simulink diagram indicated in figure 8 was used [11].

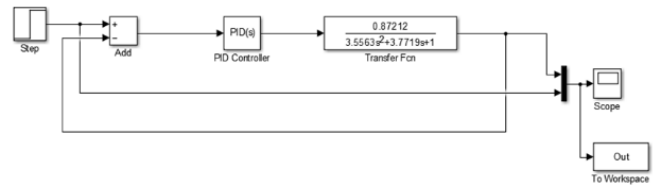


Fig. 8 Obtaining the PID parameters by self-tuning.

With the constants, P = 2.090, I = 0.79 and D= 0.620 for the PID controller; the AV output indicated in figure 9 is obtained.

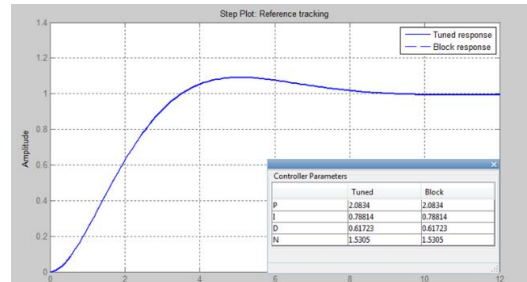


Fig. 9 Response obtained by self-tuning.

Figure 10 shows the PID control diagram for the positioning of the Panel. Some adjustment parameters of the PID controller have been calculated following the approach developed in [14] as a reference.

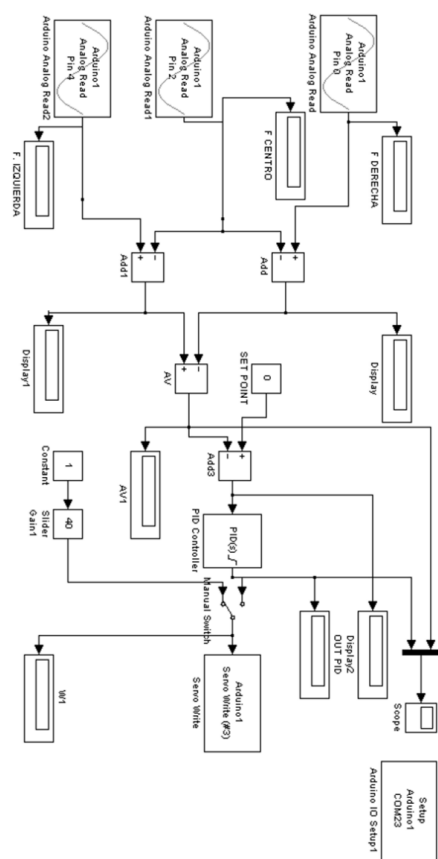


Fig. 10 PID based control diagram.

C. Positioning with MPC.

To proceed with panel position control with predictive control, the MATLAB tool MPC TOOL is used [12]. The transfer function is stated in (2).

$$G(s) = 0.87212 / (3.556s^2 + 3.7719s + 1) \quad (2)$$

Then, the AV model is discretized with a time of $T_s = 1$ s, using the command shown in (3).

$$G(s)_d = c2d(AV, 1) \quad (3)$$

Subsequently, we work with the MPC TOOL for the AVD model. The Control and Estimation Tools Manager window opens, where the model, interval, horizon, duration, weights are entered [13].

The diagram in figure 11 shows the Predictive control scheme in Simulink, where the reception of data from the voltage dividers of the photoresistors is observed, the voltage differences to obtain AV, which represents a manipulated output (mo) to the MPC block.

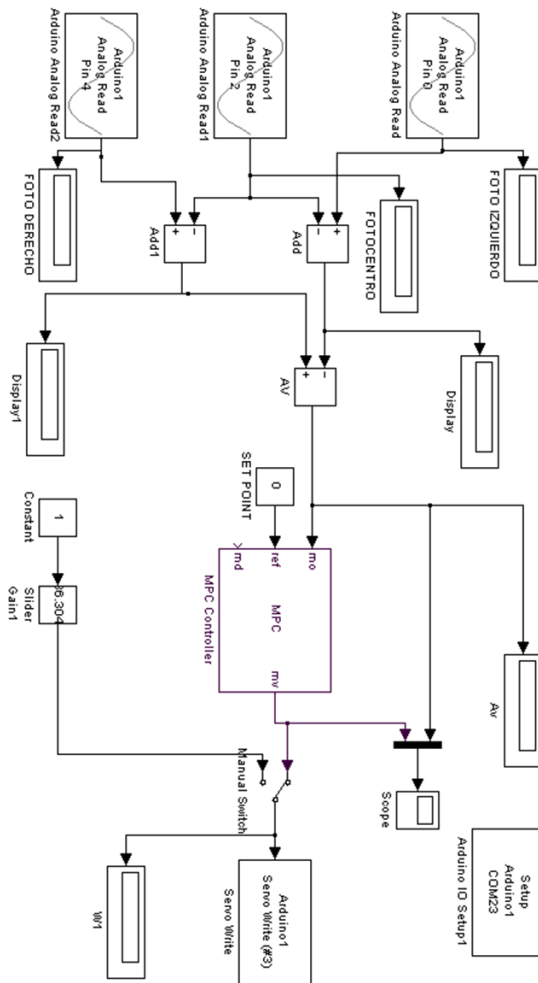


Fig. 11 MPC diagram for the positioning of the Solar panel.

The reference or set point indicates a reference (ref) which is adjusted with a value of 0 volts. The servo signal enters as a manipulated variable (mv) which represents the angular speed $W1$ with which the gear motor rotates and positions the panel photovoltaic.

III. RESULTS

A. PID Control

For the positioning of the panel with the PID controller, the Simulink diagram of figure 8 is used, obtaining: $P = 2,090$ $I = 0.790$ $D = 0.620$.

Figure 12 shows the AV graph where a maximum overshoot (M_p) = 18 u and a stabilization time (t_{ss}) of 12 sec are noted.

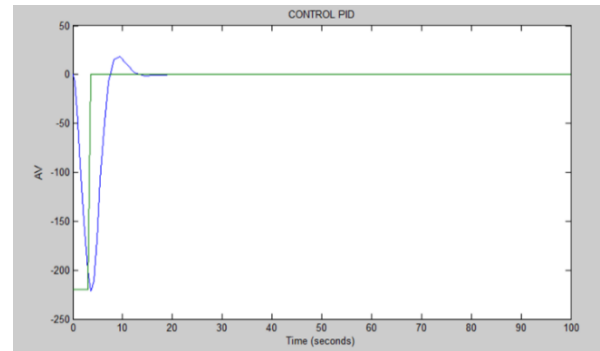


Fig. 12 AV. Measured process output variables (mo).

A real test with PID was carried out in the city of Guayaquil - Ecuador, between 12:30 and 12:50 with a clear sky, obtaining the results shown in figure 13.

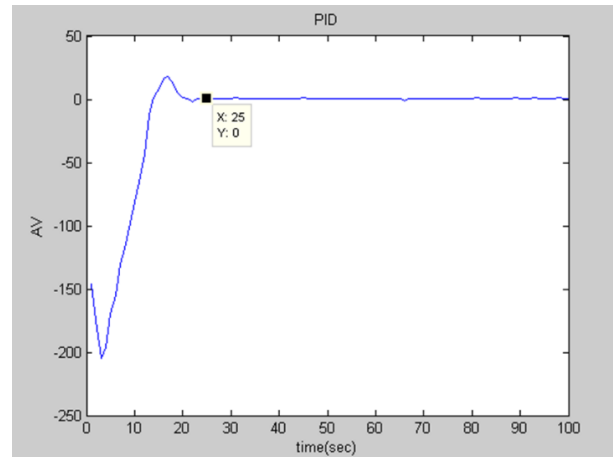


Fig. 13 Real AV output with PID.

As can be seen in figure 13, AV has a maximum Overshoot of 23 u and the output stabilizes in a time (t_{ss}) of 25 seconds.

B. MPC applied in three different scenarios.

When the respective parameters are entered, "Simulate" is executed and the input (W1) and output (AV) graphs are expected. The data and results for three scenarios are shown below.

TABLE I
MPC SCENARIO 1

Scenario	Control interval (sec)	Prediction horizon	Control horizon	Simulate time (sec)	Set point	Weights input	Weights output	Constraints
1	6	10	10	100	0	1	NO	NO

Figure 14 shows that since the control is turned on, the AV value stabilizes in 18 sec. (tss= 18 sec) with the setpoint of 0 volts.

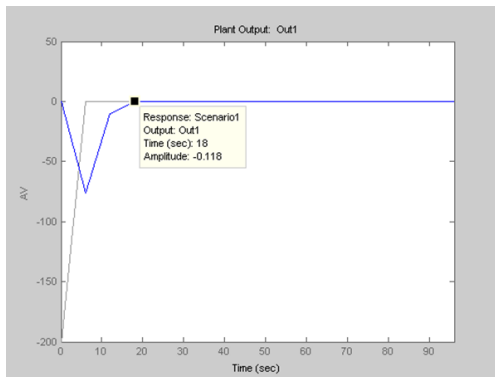


Fig. 14 AV output vs time in Scenario 1.

Figure 15 shows the angular speed W1, which stabilizes at 0 RPM, in the time (tss) of 18 seconds.

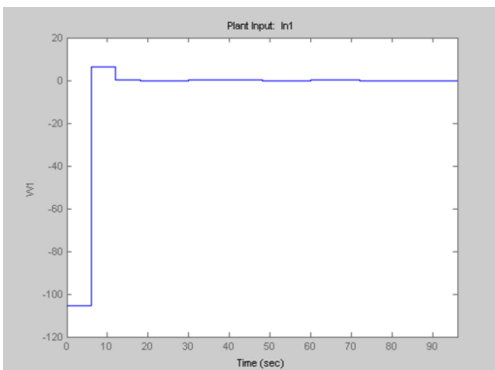


Fig. 15 W1 input vs time in Scenario 1.

TABLE II
MPC SCENARIO 2

Scenario	Control interval (sec)	Prediction horizon	Control horizon	Simulate time (sec)	Set point	Weights input	Weights output	Constraints
2	5	15	8	100	0	0.5	NO	NO

Figure 16 shows that since the control is turned on, the AV value stabilizes in 20 seconds. (tss= 20 sec.) with a setpoint of 0 volts.

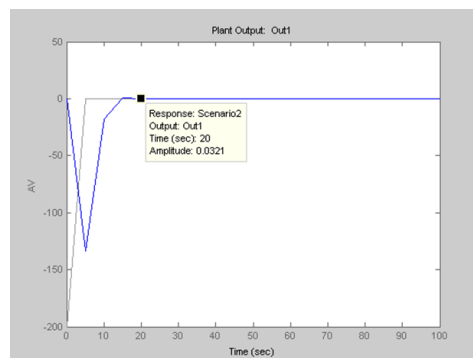


Fig. 16 W1 input vs time in Scenario 2.

In Figure 17, W1 stabilizes at zero with tss = 20 sec.

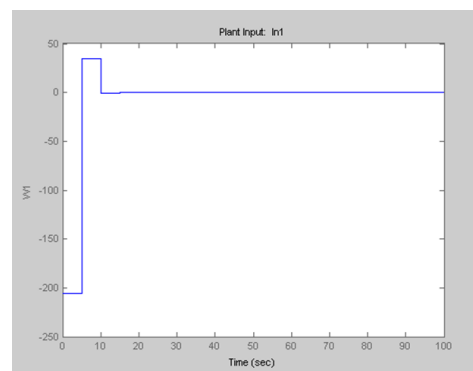


Fig. 17 AV output vs time in Scenario 2.

TABLE III
MPC SCENARIO 3

Scenario	Control interval (sec)	Prediction horizon	Control horizon	Simulate time (sec)	Set point	Weights input	Weights output	Constraints
3	3	20	2	100	0	0	NO	NO

Figure 18 shows that since the control is turned on, the AV value stabilizes at tss = 18 sec. with a set point = 0 Volts.

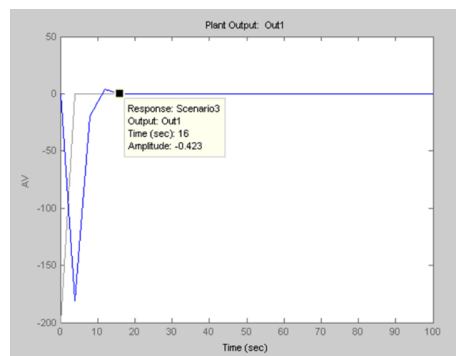


Fig. 18 W1 input vs time in Scenario 3.

In Figure 19, it can be seen that W1 stabilizes at zero in tss = 16 seconds.

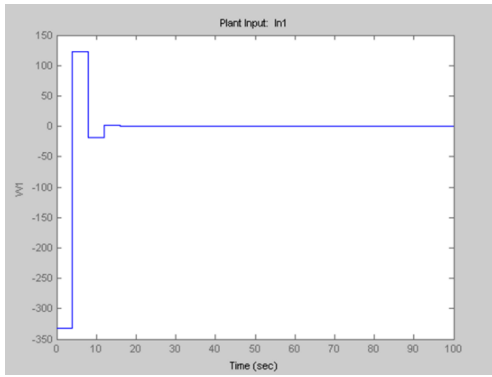


Fig. 19 W1 input vs time in Scenario 3.

C. Real test of the MPC. Best scenario.

With the data and graphs obtained, the best scenario is 3 because it has a lower tss. In the city of Guayaquil-Ecuador, a real test of the MCP was carried out between 12:30 p.m. and 1:00 p.m., obtaining the results shown in figure 20. the AV output stabilizes at 0 V with a tss = 15 seconds.

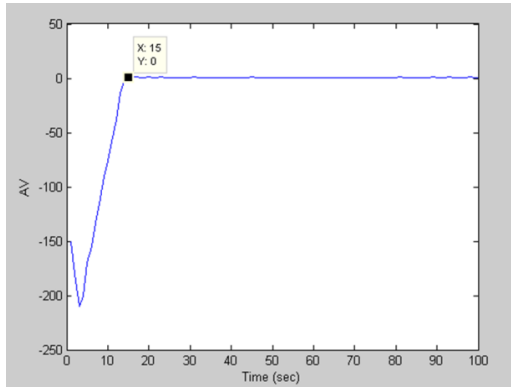


Fig. 20 Real AV output with MPC control.

The responses of the PID and MPC controllers are shown in figure 21. You can see the AV curve with PID (green), where tss. occurs at 25 seconds with an overshoot (M_p) = 24 u. The AV curve with the MPC (blue) has a tss = 15 sec. with an overshoot (M_p) of 2 u.

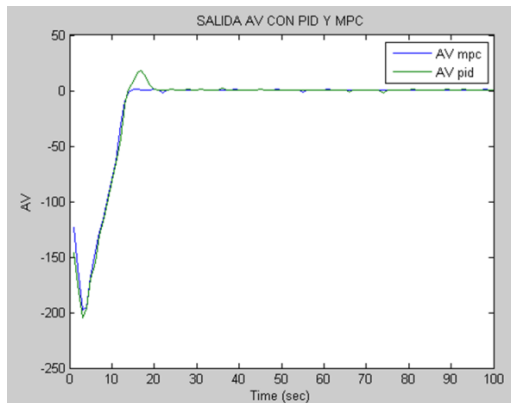


Fig. 21 Real AV output with PID and MPC controllers.

IV. CONCLUSIONS

According to the graph obtained in fig. 21, it is verified that with the Model Predictive Control (MPC) a better response was obtained than in the case of the PID, since the panel stabilized in front of the sun in a shorter time, with a lower overshoot (M_p).

The controller was developed in the most practical way possible, since it has a single switch to turn it on and immediately works for the position, once the PC is parameterized.

In the absence of sunlight, the panel is positioned at a point where there is the highest number of lumens possible.

ACKNOWLEDGMENT

This work was developed thanks to the contribution of the industrial processes research group (GIPI) of the Salesian Polytechnic University.

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