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IMPLEMENTATION OF PID POSITION CONTROL FOR A PHOTOVOLTAIC SYSTEM USING MATHEMATICAL MODEL AND LABVIEW

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ABSTRACT

Photovoltaic solar panels, and those for heating water, achieve maximum performance when the sun's rays fall perpendicular to their surface. For this reason, electromechanical systems have been created that enable tracking the position of the sun through proportional control, which functions based on the signal received from the sensor, but with a significant error value. These types of systems tend to oscillate around the specified position with a certain amount of error in position and time, reducing the performance from the maximum values. Keeping these processes in a sustainable state is another challenge for the designer. This article will analyze a positioning panel process, will build the mathematical model of the system and based on this mathematical model will program a high-precision Proportional-Integral-Derivative control, which will be able to keep the position of the panel at the desired point. The article also aims to highlight the difference between the traditional feedback control system methods such as the proportional system and the PID system. For the implementation of this control, we will use a programming language such as LabView.

Keywords: Solar Panel, Mathematic Model, Computer Simulation, PID, LabView.

1 INTRODUCTION

Photovoltaic solar panels, as well as water heating panels, are in most cases mounted in a fixed position, they reach their maximum performance at the moment when the sun's rays fall perpendicularly on their surface. To have a maximum value of their yield all the time, the panel must be rotated following the sun so that its rays always fall perpendicular to the surface of the panel. In this article, we delve into developing a mathematical model that characterizes the dynamic movement of solar tracking systems. By integrating this model into a PID (Proportional-Integral-Derivative) control framework, we aim to achieve precise solar tracking, minimizing fluctuations around the desired position determined by sensors.

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Unlike simpler proportional control methods, which may exhibit oscillations or lag, PID control offers a more sophisticated approach to optimizing solar panel orientation in response to changing solar angles.
We will build through the mathematical model that expresses the movement of the system and through it we will program a PID (Proportional-Integral-Derivative) control system in such a way that the tracking of the sun from the panel is precise and without fluctuations around the point determined by the sensor, as happen with the proportional control, see the figure.1.[9][10][11][13].
The PID control works based on the reading of the sensor located to evaluate in real time the position of the axis of the panel, evaluates the error created between the desired position and the actual position and calculates the value of voltage and current necessary to compensate this error through three coefficients which are: the proportional coefficient, the integrative coefficient and the derivative coefficient.

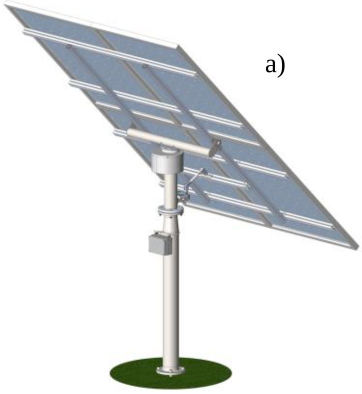

Figure 1a Solar Panel with rotation Option.

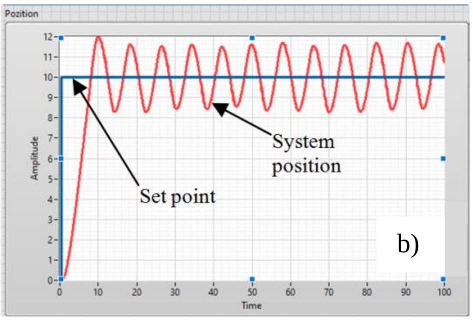

Figure 1b Proportional control.

Each of these coefficients has its influence on the exact determination of the position. for example, the proportional coefficient takes into account the error at the time of measurement, the integrative coefficient calculates the error starting from the previous errors, while the derivative takes into account the errors that may occur in the future. Figures 2a and 2b schematically show the functional mode of the closed PID system. [5][1][12]. In Figure 2a, the yellow rectangle represents the rotation system of the solar panel, while the green rectangle represents the control system.

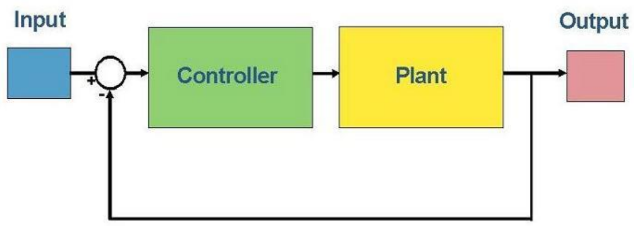

Figure 2a Closed Loop Control [9].

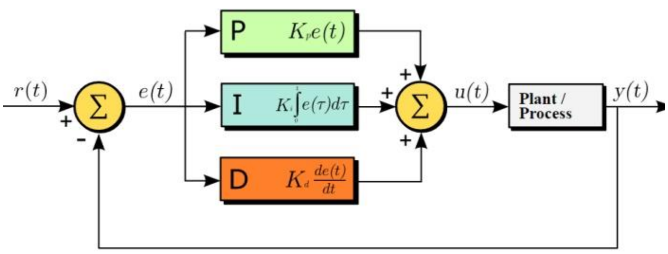

Figure 2b PID Control [9].

Schematically, the PID control system is presented in the diagram shown in Figure 2b. In this scheme with (e), we have marked the value of the error calculated as the difference between the value of the given input (R) and the measured value of the current position in the panel (Y). Evaluating the error value (e) the PID control system will calculate as shown in figure 2.b) the integral $K_I \int e(t)$ and derivative $K_D \frac{d}{dt} e(t)$ of error (e). The command signal (u) given by the PID system is now equal to the error value multiplied by the proportional coefficient K_P plus the integral of the error multiplying the integrative coefficient K_I plus the derivative of the error multiplying the derivative coefficient K_D. [1][5][8][14].

$$U = K_{pe} + K_I \int edt + K_D \frac{de}{dt} \tag{1}$$

The signal that comes out as a result of these actions will command the motor of the rotation system of the solar panel. The position sensor will then measure the new position and generate the signal (Y). The serial signal will be read by the PID control system which will recalculate the integral and the derivative of the error again from the difference between the input and the output. The PID control system discussed above can be presented through the following relation.

$$K_p + \frac{K_I}{s} + K_D \cdot s = \frac{K_D \cdot s^2 + K_p \cdot s + K_I}{s} \tag{2}$$

In this relation, K_p represents the proportional coefficient, K_D is the derivative coefficient, and K_I is the integrative coefficient. In the PID control system, the proportional coefficient K_p contributes to the reduction of rise-time, but it cannot eliminate the steady-state error. The derivative coefficient K_D contributes to the reduction of overshoot, thus increasing the stability of the system. The integrative coefficient (K_I) contributes to the elimination of steady-state error, its increased values could worsen the transient response. Table 1 summarizes the effects of each coefficient in the PID closed-loop control system.

Table I - Controllers Kp, K_D, and K_I

PID coefficients	Rise-Time	Oveshoot	Steady-State Err
Proportional (K_p)	⇩	⇧	⇩
Derivativ(K_D)	⇩	⇧	Eleminate-error
Integrativ (K_I)	minimal changes	⇩	minimal changes

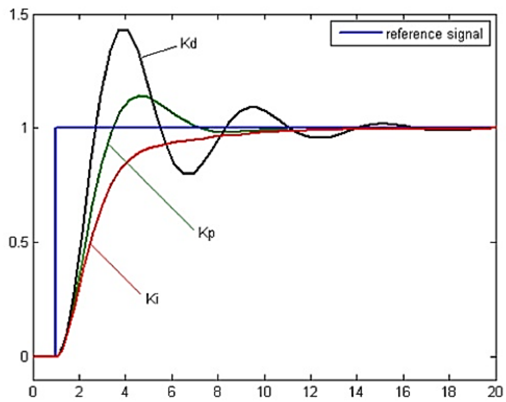

Figure 3 Effects of each of the controllers K_P, K_D, and K_I on a closed-loop system [8].

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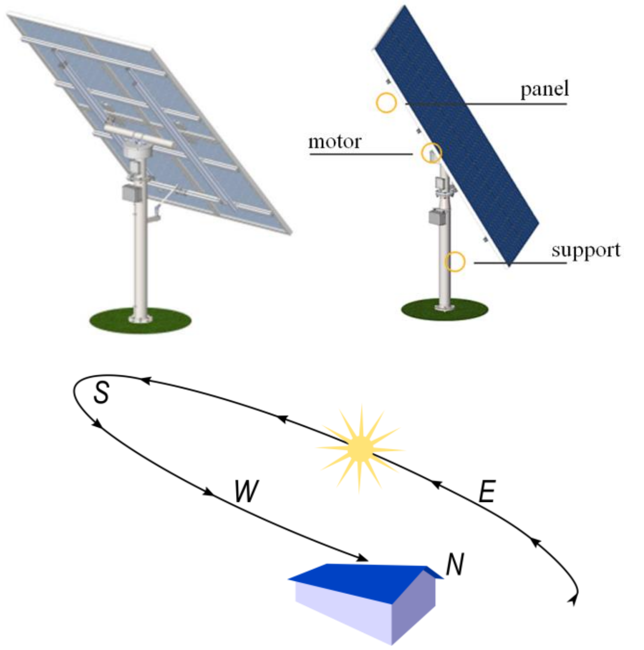

Figure 4 The trajectory of the sun's movement and the way the panel moves [9].

2 MATHEMATICAL MODEL

To describe the movement of the panel around the axis where it is mounted, we refer to Newton's second law for rotational motion.

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}(T - K_d \cdot \frac{d\theta}{dt}) \quad (3)$$

where:

- θ Angular position.
- $\frac{d^2\theta}{dt^2}$ Angular acceleration.
- J Moment of inertia of the rotating object (panel).
- T Engine torque
- K_d Damping constant.
- $\frac{d\theta}{dt}$ Angular velocity.

In this equation on the left side, we have the change of the angular acceleration of the rotation $\frac{d^2\theta}{dt^2}$, and on the right-hand side the difference between the external moment of force (T) and moment of damping resistance(K_d·dθ/dt), divided by the moment of inertia (J). This equation describes how the rotation of the object changes over time depending on the forces acting on it and its characteristics. To describe the movement created by the electric motor for a given electric current and voltage, we have referred to Kirchhoff's law for an electric circuit.

$$\frac{di}{dt} = \frac{1}{L}(V - K_g \cdot K_f \cdot \frac{d\theta}{dt} - R \cdot i) \quad (4)$$

$$T = K_g \cdot K_t \cdot i \quad (5)$$

This differential equation describes the change in electric current in the presence of a certain voltage and a resistive component.

- $\frac{di}{dt}$ the change of electric current as a function of time
- L the inductance of the electrical circuit
- V applied electrical voltage
- K_g electromotive force constant
- K_f constant that shows how electric voltage affects changes in angular velocity
- R electrical resistance of the electric motor
- i the intensity of the electric current

3 PROGRAMMING IN LABVIEW

Based on the mathematical model described above, using the LabView programming language, we have built a PID control for the solar panel.

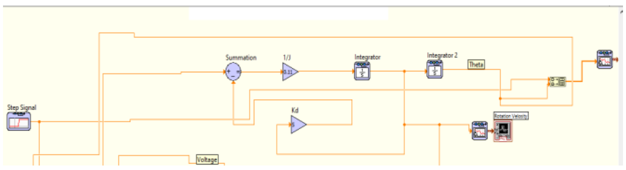

Figure 5 The program built for the simulation of the rotating movement of the panel [15].

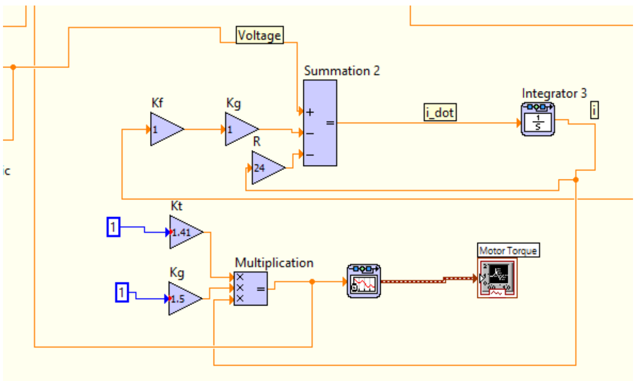

Figure 6 The program built for the simulation of the electric motor [15].

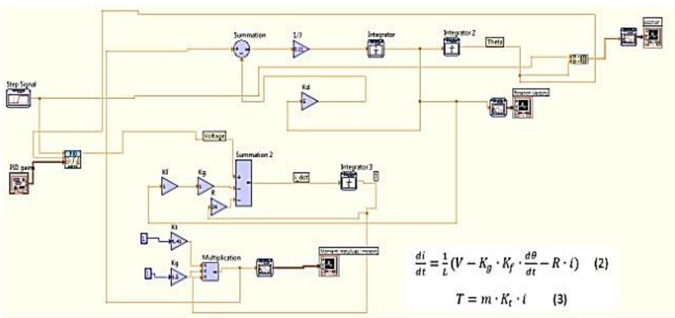

Figure 7 PIDcontrol built into LabView [15].

4 SIMULATION RESULTS

To check the built program, we applied a signal to the input of the built PID control and followed the response of the system as in the figure below.
Determining the coefficients K_P, K_I and $K_D$is a challenge in itself. K_P=10, K_I=0.001 dhe K_D=0.

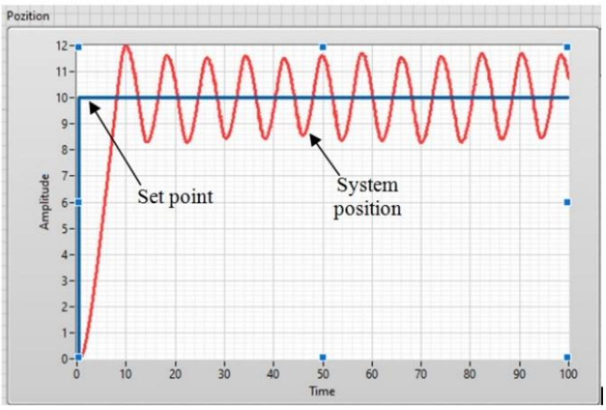

Figure 8 System behavior with proportional control (P) [15].

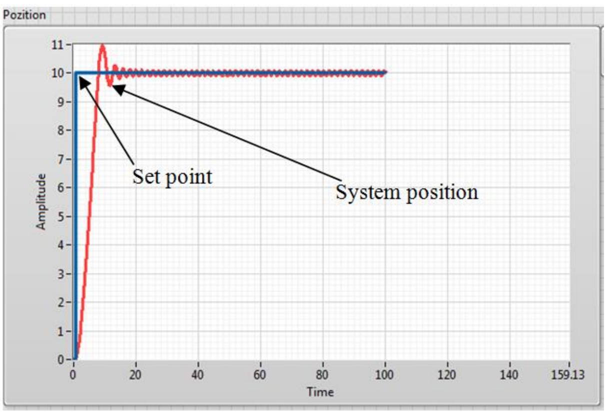

Figure 9 System behavior with proportional and integrative control (PI) [15].

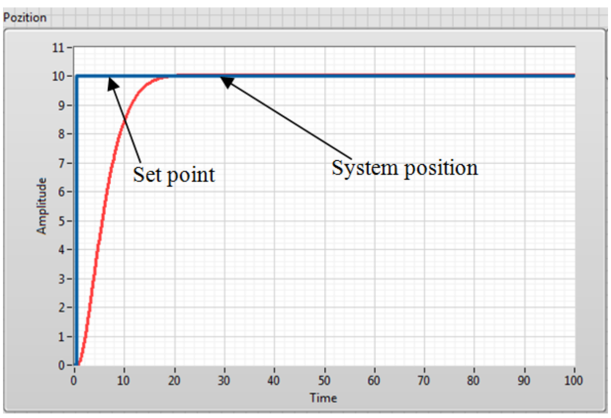

Figure 10 System behavior with PID control [15].

In Figures 8, 9 and 10, the graph in blue shows the command given to the system, and in red the follow-up by the system consisting of the motor and the panel. In the graph of Fig. 8, which shows System behavior with proportional control only. it can be seen that the system oscillates around the desired value. these oscillations are translated into the amount of energy required by the electric motor which aims to move the system to the position determined by the sensor. System behaviour with proportional and integrative control is shown in Fig. 9. in this graph it can be seen that after some fluctuations around the determined position, the system approaches a stable state, while this stability becomes faster and more precise when applying the PID control, the behaviour of the system in this control is shown in Fig. 10.

5 EXPERIMENTAL RESULTS

To confirm the results of the simulation, we have built an experimental panel made up of the electric steper motor, the electronic signal processing circuit made up of ArduinoUno, motor drive L298N, PCmio interface and National instruments and motion sensor. as shown in the figure below.

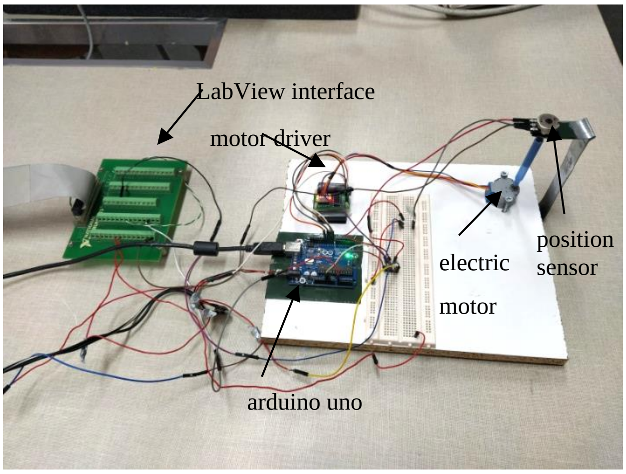

Figure 11 Experimental pane build.

Table II - System behaviour for the three analyzed cases

PID Coefficients	**Rise-Time [ms]**	**Overshoot**	**Steady-State Err**
K_P	40	1.7	1.7
K_P =10, K_D=0.001	25	9	0.9
K_P =10, K_D=0.001, K_I=10	18	0	0

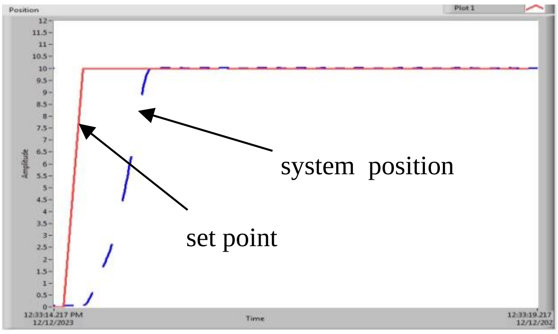

Figure 12 Experimental measurement of positioning.

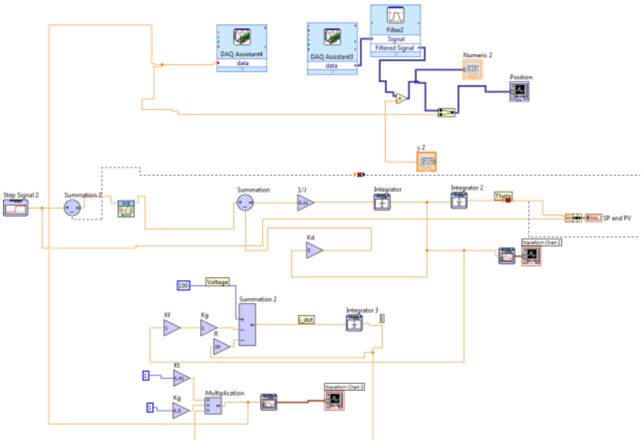
Figure 7 The program built in LabVIEW for experimental measurement.

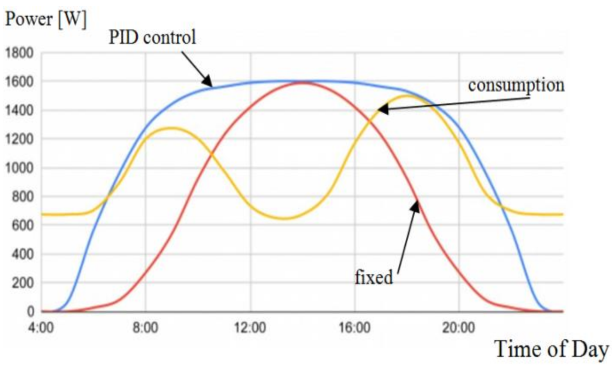

Figure 8 Blue line - the production of panel with PID control; Red - fixed mounted panel in roof; Yellow - family consumption

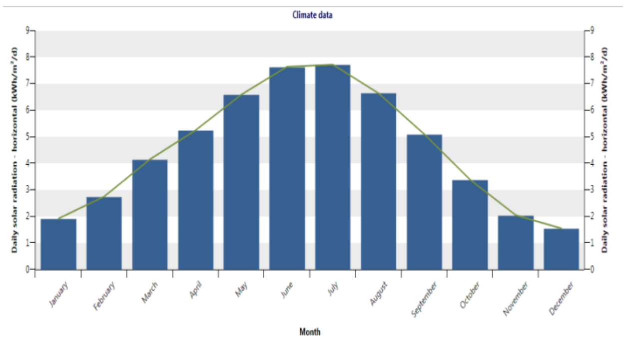

Figure 9 Daily solar radiation for Tirana City in one year, from RETsrcreen expert software

Table III - Daily solar radiation for Tirana City in one year, from RETsrcreen expert software

Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal
Cel. Degree	%	mm	kWh/m2/d
7.8	16.2%	121.78	1.92
78.0	71.0%	114.62	275
10.2	68.11	114.02	415
13.9	72.6	98.22	5.25
18.3	69.8	68.43	6.59
21.6	67.6	62.02	7.64
24.8	63.1	42.46	7.72
24,2	65.7	43.62	6.64
20.8	70.5	111.7	5.1
16.1	74.2	125.54	3.39
10.6	77.7	157.77	2.05
7.60	79.5	178.8	1.55
15.3	71.3	1238.9	4.57
Ground	Ground	NASA	NASA

5 CONCLUSIONS

1. The use of the mathematical model in the construction of the PID control is one of the most efficient ways for the precise control of dynamic processes.
2. Regarding what we described above, as well as referring to the results of the simulation with the program built in LabView, it seems clear that the proportional control reduces the time to reach the target, significantly increases the deceleration above the set value, and reduces the stabilization time to minimum values. Derivative control also reduces the time to reach the objectives increases the value of the delay above the predetermined value and eliminates the steady state errors. Integrative control affects very little in reducing the time to reach the target, reduces the jump over the set value, and affects very little in reducing the time to reach the steady state. Combined with each other, these controls give optimal results.
3. The use of solar tracking systems equipped with the PID control system makes possible an increase of 80% in the yield of the plant realizing an almost 100% coverage of the daily demand for energy from the consumer as shown in Figure 8. The use of solar energy for the production of electricity or hot water is one of the most efficient ways of producing energy, especially in countries with the highest number of sunny hours, such as Albania, as shown in Figure 12, which shows daily solar radiation for Tirana City in one year.
4. The use of PID control also significantly reduces the amount of energy consumed by the electric motor, compared to simple proportional control, since this control eliminates system fluctuations around the desired position.

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