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DVOOSNO USMJERAVANJE FOTONAPONSKOG MODULA KORIŠTENJEM PID REGULACIJE

DUAL-AXIS DIRECTING FOR PHOTOVOLTAIC MODULE USING PID CONTROL

Josip Krejči, Igor Petrović, Zoran Vrhovski

Stručni članak

Sažetak: *U ovom članku prikazano je konfiguriranje PID regulatora na primjeru pozicioniranja usmjerenja prototipne mjerne stanice sa fotonaponskim sustavom i dvoosnim usmjerivačem. S obzirom da je prototipna mjerna stanica predviđena za istraživanjepmogućnosti proizvodnje električne energije fotonaposnkim modulima, uz teorijsku podlogu na Liu-Jordan-Klein modelu, cijeli sustav je prilagođen nazivlju odabranog modela. Za prototipnu mjernu stanicu programiran je, parametriran i pušten u rad PID regulator za pozicioniranje azimuta, te isti postupak ponovljen za pozicioniranje nagiba. Tako dobiveni PID regulatori mogu se koristiti istovremeno.*

Ključne riječi: *fotonaponski sustav, dvoosno usmjeravanje, upravljački sustav, PID, PLC*

Professional paper

Abstract: *The configuration of a PID controller is presented in this paper on the example of a positioning system for a prototype measurement station with photovoltaic system and dual-axis directing. Since the prototype measurement station is supposed to be used for research possibilities of electrical energy production using photovoltaic modules, and based on the conventional Liu-Jordan-Klein analytical model, the whole nomenclature is adjusted to the selected model. For the described prototype measurement station the PID controller for azimuth positioning was programmed, parameterized and run in test mode, after which the same procedure was provided for slope positioning. Such PID controllers can be used simultaneously.*

Key words: *photovoltaic system, dual-axis directing, control system, PID, PLC*

1. INTRODUCTION

The prototype measurement station has been designed for the purpose of collecting data which are important for electrical energy production using a photovoltaic system. It has been designed using dual-axis directing and a control system which is at the same time an acquisition system for the measured electrical and non-electrical quantities. The whole prototype measurement station is described in [1]. The measured data are a continuation of a research according to a prototype measurement station that has already been installed in Zagreb, which is described in [2]. The purpose of the measurement station is to upgrade the research that has also been done, among other places, in Bjelovar and the results are shown in [3].

In order that the prototype measurement station might have a higher quality of functionality, it is necessary to integrate a better system of value regulation which is the most important for dual-axis directing and that is azimuth and slope positioning. A PID controller provides the best control system. Considering the structure of the mechanical part of the prototype measurement station, it can be expected that a PI controller would be an optimal solution, but in this case a PID controller was used, which can be later easily transformed into a PI controller by turning off a D component. The basic requirement is a fast response of the rotation position in the azimuth axis as well as the slope axis. The controller will use reference values based on Liu-Jordan-Klein model for calculating the trajectory of the sun in the sky, which is described in [4]. For that reason both the azimuth and slope position are adjusted to the values which are given by the model.

2. PID CONTROL IN THE POSITIONING SYSTEM

A controller is part of the automatic control system which maintains the system in the desired state, as it is described in [5]. Based on the control deviation of the actual value from the desired value of the controlled variable, the role of the controller in the control circuit is to give at its output such a type and value of the signal which will bring the system into the desired state and keep it there. The structure and the parameters of the control system are unchangeable in ideal conditions, but in praxis the parameters of the system are changeable due to the wear and fatigue of materials. Based on the analysis of the control system, the structure and the parameters of the controller are chosen in such a way which helps create the desired performance of the controlled system. There are a lot of ways in which controllers can be parameterised for linear systems. Based on the tracking error of a measuring output value *e(t)* a controller creates a control signal $u_r(t)$ which serves as an instruction to the executing device to bring energy into the system. There are different types of controllers in the field of automatic control, but the most common ones, according to [5], are based on three basic types of actions:

- a proportional (P) action
- an integral (I) action
- a derivative (D) action

There are open-loop and closed-loop automatic control systems. An open-loop automatic control system does not give information about the state of the controlled value, and that can easily create deviation of the actual value from the default value on the controlled system, without any feedback. Since it is important that an error, i.e., a deviation from the default value for the dual-axis directing for a photovoltaic module is known and as small as possible, a closed-loop automatic control system is used. Information from the system is obtained by implementing feedback into the system. A system closed with a negative feedback represents a closed-loop automatic control system as it is shown in Figure 1. The influence of the controller on the control system is achieved through an actuator, while a measuring element, i.e., a sensor gives information about the status of the system. In that way a desired behaviour of the system can be achieved regardless of the action of the disturbance variable.

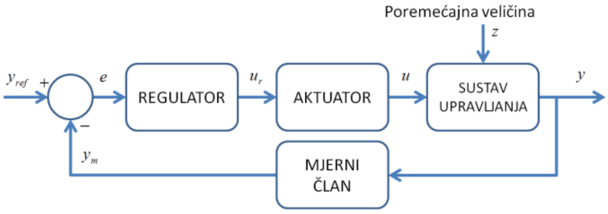


Figure 1 A block diagram of a closed-loop automatic control system [5]

A regulator that includes all three types of actions is called a proportional-integral-derivative-action controller or a PID controller which is described by a differential equation (1).

$$u_r(t) = K_R(t) + \frac{K_R}{T_I}\int_0^t e(\tau)d\tau + K_R T_d \frac{de(t)}{dt} \qquad (1)$$

Where K_R is the coefficient of proportional gain, T_I is the integral time constant expressed in seconds and T_d is the derivative time constant expressed in seconds.

Bode diagram of a real PID controller is shown in Figure 2. It is evident that the amplification of high-frequency signals is removed. Uplifting of phase characteristics enables the system stability. A real PID controller is the best choice for the system control and one of the actions can be turned off. That depends on the type of the system and the demands for the control system. With PID controllers it is practically possible to enable regulation of all kinds of processes, regardless of their characteristics, which depend on the type of their transient characteristics, inertia, accumulation etc.

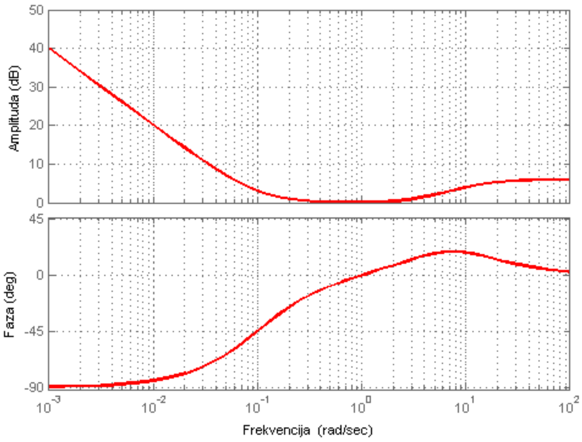


Figure 2 Bode diagram of a real PID controller [5]

3. DEVELOPMENT OF THE PID CONTROLLER FOR THE PROTOTYPE MEASUREMENT STATION SYSTEM

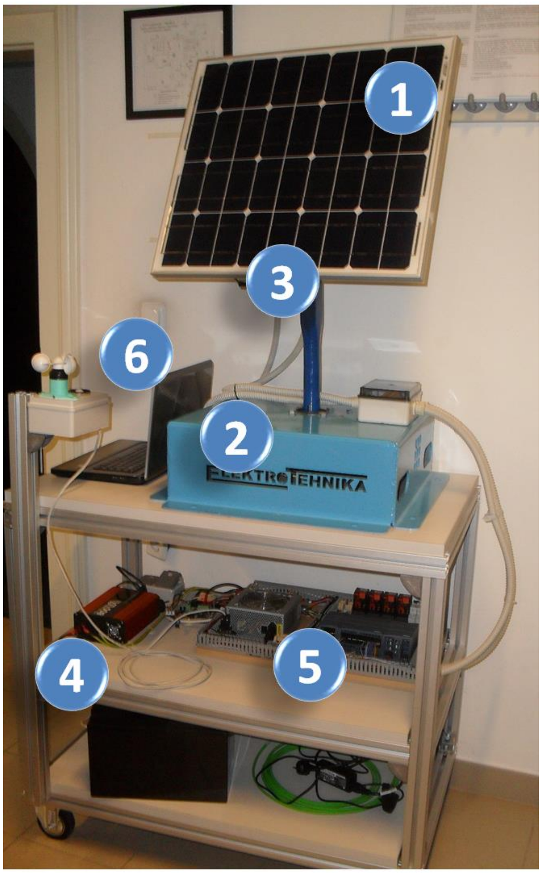


Figure 3 The prototype measurement station of the photovoltaic system with dual-axis directing

The photovoltaic measurement station, shown in Figure 3, consists of:

1 a photovoltaic module
2 an actuator for azimuth positioning
3 an actuator for slope positioning
4 an energy conversion subsystem (a charger, a battery, an exchanger)
5 a control system
6 a laptop (programming / SCADA)

The way the measurement station functions is very simple. Energy which is produced by the photovoltaic module using a battery with a charger and an exchanger supplies the PLC and the SCADA devices which control the whole system. Electrical energy also supplies the motors for rotation of the photovoltaic module, as well as other circuits and devices. The laptop battery is charged through the exchanger. Since the photovoltaic module can produce more or less electrical energy than the system can consume, depending on weather conditions, it is possible to store energy in an accumulator. If the photovoltaic module does not produce enough electrical energy, it can be taken from the accumulator. Exchanger output of 800 W can simply be connected to a NN network and in that way ensure the supply of the control system and the actuator.

The measurement station system is controlled by a Siemens PLC (eng. *Programmable Logic Controller*), Siemens Simatic S7-1200 model. A PLC is a microcomputer system used for automation of industrial plants, mostly for electromechanical processes. The great advantage of a PLC is that it has minimum maintenance requirements and for that reason it is used in industrial environment where dust, humidity and high or low temperatures are common. It is resistant to electrical and electromagnetic interferences, vibrations and changes in temperature. PLCs simplified the control algorithm design which is now a control programme and detecting errors is faster since wiring does not have to be examined. Advantages over a relay technique are numerous and some of them include reliability, flexibility, functionality, communication, velocity and diagnostics. Signal modules (SM) are used for adjustment of different digital and analogue process signals which the S7-1200 is connected to and for the increase in the number of inputs and outputs in the PLC. Their merger does not require additional connectors or cables and they are connected to a CPU using a built-in connector. It is possible to upgrade the CPU using digital and analogue signal modules. An SM 1234 is an analogue input-output extension module used for the prototype measurement station.

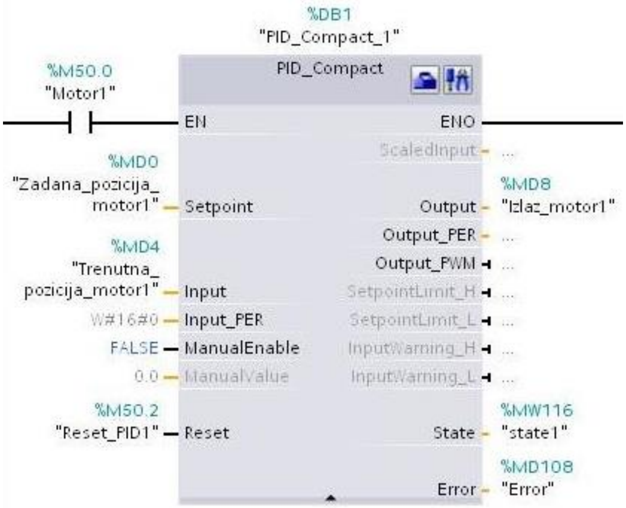


Figure 4 A PID regulator block in LAD, an example of azimuth positioning

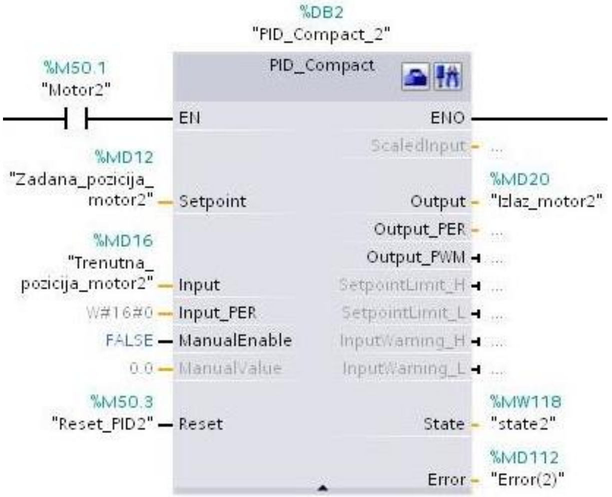


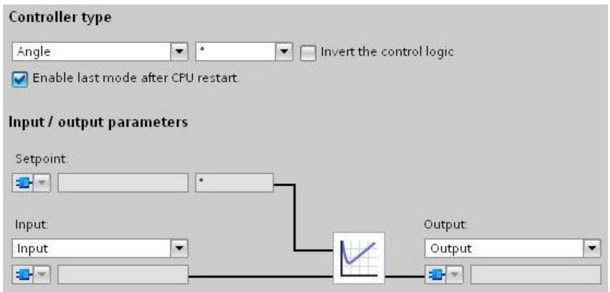
Figure 5 A PID regulator block in LAD, an example of slope positioning

For the control of the azimuth and slope positioning a compact built-in controller was used. A PID controller block for the azimuth is defined in the programming environment which is shown in Figure 4. A PID controller block for the slope is defined in the programming environment which is shown in Figure 5. A PID controller in „PID_Compact“ block uses the equation (2) to calculate the output value.

$$y = K_p\left[(bw - x) + \frac{w-x}{T_I s} + \frac{T_D s(cw-x)}{aT_D s+1}\right] \qquad (2)$$

Where y is the output value, w is the set point, K_p is the coefficient of proportional gain, T_I is the integral time constant, T_D is the derivative time constant, x is the process value, s is the Laplacian operator, a is the derivative delay coefficient and b is the derivative action weighting.

During the start operation, the structured PID controller, according to Figure 5, is inactive. It is necessary to adjust the system in order to get all the parameters. An exception is the case of manual input of previously known parameters. The system itself performs the function of pretuning and fine tuning. After the tuning process has been finished, it is possible to enter the obtained parameters into the PID controller, which can be subsequently changed depending on user preferences. Once the PID controller has been set, it sends information that the control system has been set and it starts working in automatic mode. Each time the PID controller is run up, it starts working in automatic mode.



Controller type

Angle | ° | ☐ Invert the control logic

☑ Enable last mode after CPU restart

Input / output parameters

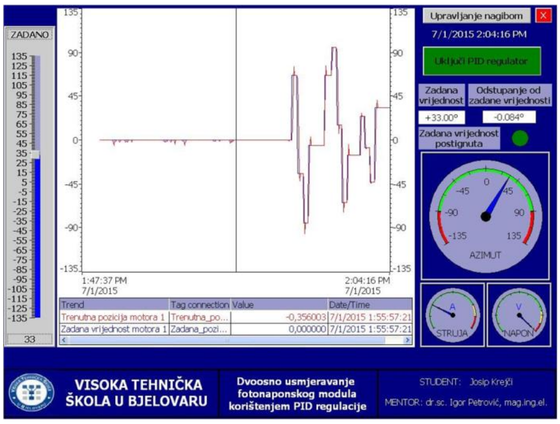
Setpoint: °

Input: Input

Output: Output

Figure 5 Defining the structure of the PID controller parameters

A SCADA application was made for the analysis of the PID controller operation. Separate screens are intended for separate actuators. Figure 6 shows a visualisation for azimuth control.



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STUDENT: Josip Krejči

MENTOR: dr.sc. Igor Petrović, mag.ing.el.

Figure 6 A SCADA part for azimuth control

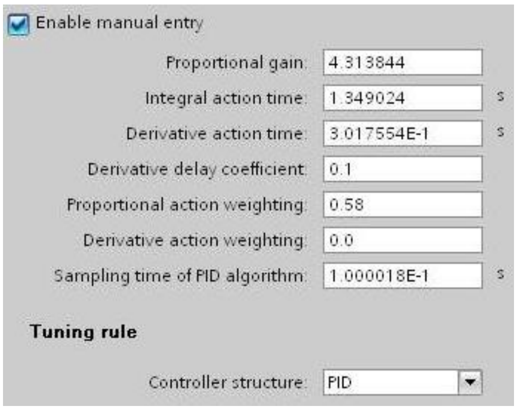
4. THE RESULTS OF COMMISSIONING OF THE PID CONTROLLER FOR THE PROTOTYPE MEASUREMENT STATION

The azimuth and slope position feedback is entered in an integer form. Since it was planned to use Liu-Jordan-Klein model, it is necessary to map the information into the rotation using unit °. The azimuth positioning resulted in the equation (3), where x is the amount of reading from the analogue input of the azimuth feedback. The slope positioning resulted in the equation (4), where x is the amount of reading from the analogue input of the slope feedback.

$$\alpha = 0{,}01826x - 149{,}01632\ [°] \tag{3}$$

$$\beta = -0{,}017x + 196{,}7\ [°] \tag{4}$$

The starting operation of the pretuning function by direct response recording determines the proposals of the PID controller parameters according to the predetermined algorithm. The settings of the PID controller for azimuth are shown in Figure 7, while the settings of the PID controller for slope are shown in Figure 8.



☑ Enable manual entry

Proportional gain: 4.313844

Integral action time: 1.349024 s

Derivative action time: 3.017554E-1 s

Derivative delay coefficient: 0.1

Proportional action weighting: 0.58

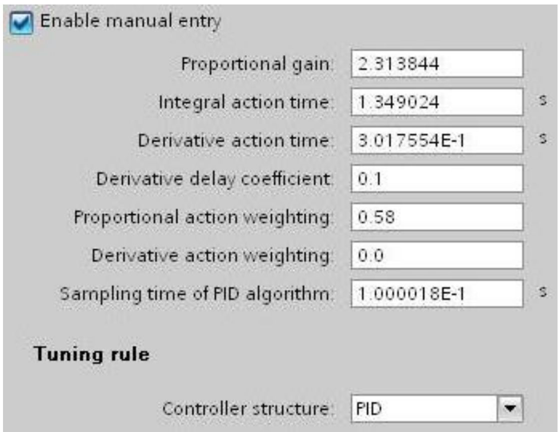
Derivative action weighting: 0.0

Sampling time of PID algorithm: 1.000018E-1 s

Tuning rule

Controller structure: PID

Figure 7 The settings of the PID controller for azimuth, the results of pretuning



☑ Enable manual entry

Proportional gain: 2.313844

Integral action time: 1.349024 s

Derivative action time: 3.017554E-1 s

Derivative delay coefficient: 0.1

Proportional action weighting: 0.58

Derivative action weighting: 0.0

Sampling time of PID algorithm: 1.000018E-1 s

Tuning rule

Controller structure: PID

Figure 8 The settings of the PID controller for slope, the results of pretuning

If we compare the proposed settings of the PID controller, it is evident that all the parameters for the azimuth and the slope are the same, except the proportional part. A computer subprogramme in the TIA software package is used to test the operation of the PID controller. The recordings contain the diagrams of set points in blue, feedback in green and the output analogue signal in red. Figure 9 shows the recording of the PID controller for azimuth in operation, while Figure 10 shows the recording of the PID controller for slope in operation. The deviation of the measured value of the position from the set point in the stationary state of the system is less than 1 ° for both cases, which can be considered negligible.

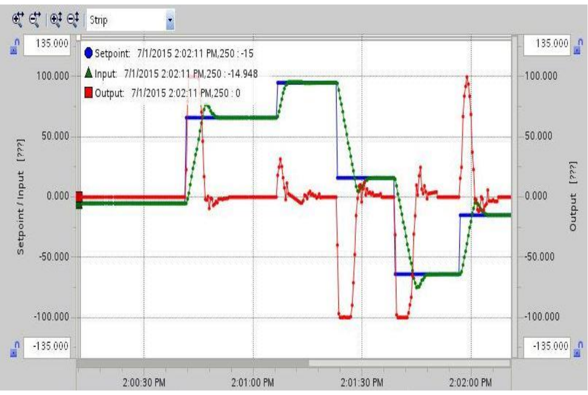


Figure 9 The response of the system with the PID controller for azimuth positioning

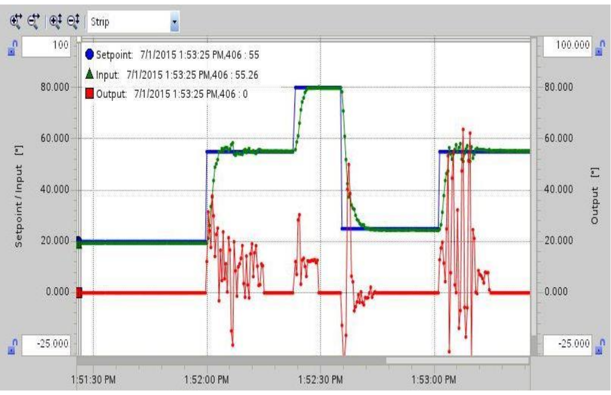


Figure 10 The response of the system with the PID controller for slope positioning

During the regulation of the azimuth position, a camber usually occurs in the linear relationship to the excitation value which the controller quickly corrects. The reason is that the load in the azimuth axis comes down to overcoming friction, while the bearing area bears the construction weight. In case of the regulation of slope positioning, there are different responses, such as stable responses without a camber in the direction of slope descending, i.e., multiple oscillations in the direction of slope steepening. The reason for that is the potential character of the load on the slope axis. In the descending direction the load helps the actuator and less excitation is needed for changing the position. In the direction of the slope steepening the load significantly inhibits the excitation in smaller slope values and pushes the controller to significantly increase the output from the controller, while reaching the slope of 90 ° reduces the load due to a more favourable (horizontal) position of the photovoltaic module. For that reason the controller cannot reduce the output value fast enough, which causes the oscillation of the regulated value.

5. CONCLUSION

The prototype measurement station is equipped with a PID controller in both axes of freedom in movement. The application of the PID controller enables the further research into the usage, advantages, drawbacks and optimal solution of controllers on a real example. The application of a modular block of the controller also enables a simpler devising and doing scientific researches into electrical energy production using photovoltaic technology.

The results of the parameterisation of the PID controller which are determined by pretuning function have shown that the response characteristics of the system are satisfying and also that the accuracy is good enough. The system has a stable response to a stepped excitation. During the regulation of the azimuth position a camber appears regularly, which the controller quickly corrects. During the regulation of the slope position there are stable responses without a camber in the direction of slope descending, as well as multiple oscillations in the direction of slope steepening.

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Kontakt autora:

Josip Krejči, student
Visoka tehnička škola u Bjelovaru
Trg Eugena Kvaternika 4, 43 000 Bjelovar
043 / 241 – 201; josipkrejci@gmail.com

dr. sc. Igor Petrović
Visoka tehnička škola u Bjelovaru
Trg Eugena Kvaternika 4, 43 000 Bjelovar
043 / 241 – 201; ipetrovic@vtsbj.hr

Zoran Vrhovski, mag.ing.el.techn.inf.
Visoka tehnička škola u Bjelovaru
Trg Eugena Kvaternika 4, 43 000 Bjelovar
043 / 241 – 201; zvrhovski@vtsbj.hr