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Control Motion of Solar Panels

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Abstract – In present work, we simulate designing a tracking system to keep the solar panel aligned with the sun. We demonstrate this system as motion according to sun position in the sky all day. This motion was presented by some ordinary differential equation that represent the trajectory of variables (theta, d_theta and etc.), by implementing an electric motor to drive the solar panel. A PI controller was applied to track the actual path of the sun, it gave us a good response in real time from sun rising (22 deg.) to sunset (322 deg.) for Azimuth at USA and from (0 deg.) sunshine, (60 deg.) mid-day to sunset (0 deg.).

Keywords – Solar Panels, Azimuth, PI Controller

I. Introduction

In the last decades, the human was increased demands by the clean energy to decrease the environment contamination. The solar panel is one of most popular form of these energy, it's generating the electricity by converting the solar energy to direct current (DC). These panels are face south and fixed in place that means they produce more electricity when the sun is shining directly on them in the middle of the day and less power when the sun is to east or west early and late in the day. What if you had a solar panel to rotated to track the sun so that you could produce as much electricity as. For this reason, they innovated some mechanism to rotate the solar panel according to sun position in the sky to obtain the maximum useful energy as soon as possible. The physical system consists of a panel and a motor will model those a first and then we will add a controller to track the sun position.

II. Design Procedure

A. *Model the physical system (solar panel and motor).*

B. *Design the controller by Simulink-block (PID, PI, ...).*

C. *Test design*

A. Modelling the physical system

The physical system has two components: the panel and motor that shown in Figure. 1. The governing formula for a solar panel is represented by 2nd order differential equation that demonstrates the panel's motion toward the sun and as the following.

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Fig. 1 the solar panel with electric motor

$$\Sigma T = J\frac{d^2\theta}{dt^2}$$

$$T - k_d\frac{d\theta}{dt} = J\frac{d^2\theta}{dt^2}$$

$$J\frac{d^2\theta}{dt^2} + k_d\frac{d\theta}{dt} - T = 0$$

Then;

$$\ddot{\theta} = \frac{1}{J}(T - k_d\dot{\theta}) \quad (1)$$

The electric circuit for the motor is governing by the following equation:

$$L\frac{di}{dt} + k_g k_f\frac{d\theta}{dt} + Ri = E$$

$$\frac{di}{dt} = \frac{1}{L}\left(E - k_g k_f\frac{d\theta}{dt} - Ri\right) \quad (2)$$

Where;

$$T = k_g k_t i \quad (3)$$

We simulate the above equations by using Simulink-MATLAB. This is the first step to modelling the physical system.

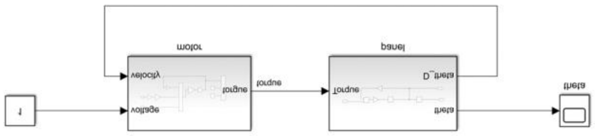


Fig. 2 Simulation of the physical system

B. Design the Controller via PID Simulink-block

One of the most popular controllers is PID controller, we design the PI controller only to track the sun-position.

$$u_{(t)} = k_p * e_{(t)} + k_I * \int_0^t e_{(t)}dt \quad (4)$$

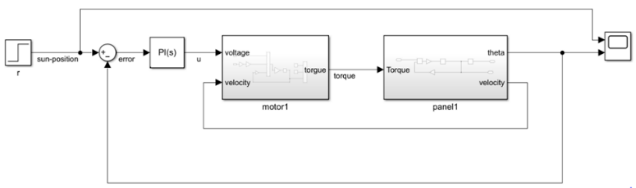


Fig. 3 Simulation of a physical system with PI controller and step-input

It's useful to see the performance of PI controller with default step-input to evaluate the amount of error between the setpoints and the response.

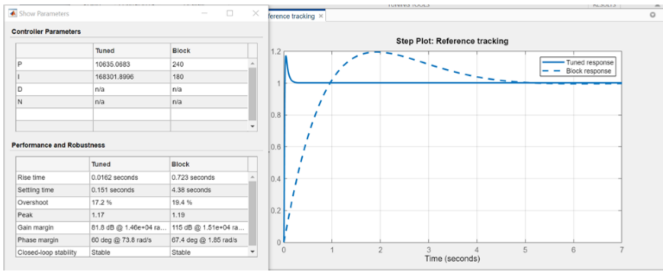


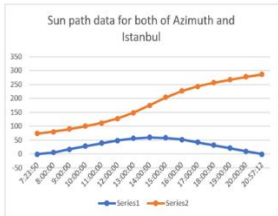
Fig. 4 Tunning a PI controller for the system.

After this test, we are getting the actual sun path data in Table 1 as listed below:

Table 1. sun path data table for two different cities.

Date: 20/04/2022
coordinates: 41.6934271, 27.2005039
location: 40.76000000,-73.98400000

hour	Elevation, deg. For Istanbul-Turkey	Elevation, deg. For Azimuth-USA
7:23:50	-0.833	73.75
8:00:00	5.74	79.7
9:00:00	16.89	89.49
10:00:00	28.05	99.87
11:00:00	38.82	111.89
12:00:00	48.59	127.18
13:00:00	56.19	147.95
14:00:00	59.81	175.05
15:00:00	57.99	203.5
16:00:00	51.52	226.56
17:00:00	42.34	243.47
18:00:00	31.84	256.41
19:00:00	20.77	267.22
20:00:00	9.6	277.13
20:57:12	-0.833	286.51



After that, we get some real data to the sun path instead of step-input to get the desired response as shown in Figure 5.

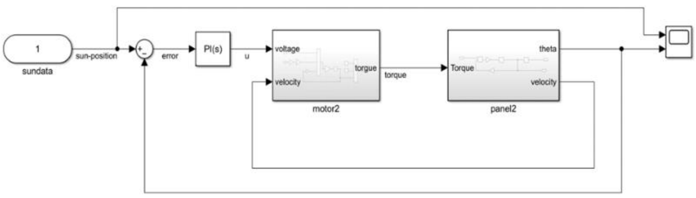


Fig. 5. Simulation of a physical system with PI controller and some real sun-position data.

III. Results and Discussion

The simulation results from Fig. 2 to Fig. 5 can be achieved. The plot from Fig.6 represents the direction of solar-panel (θ=10 deg.North-East) effected by the torque produced (T=0.03562 N.m) from an electric motor with source voltage E = 1 volt.

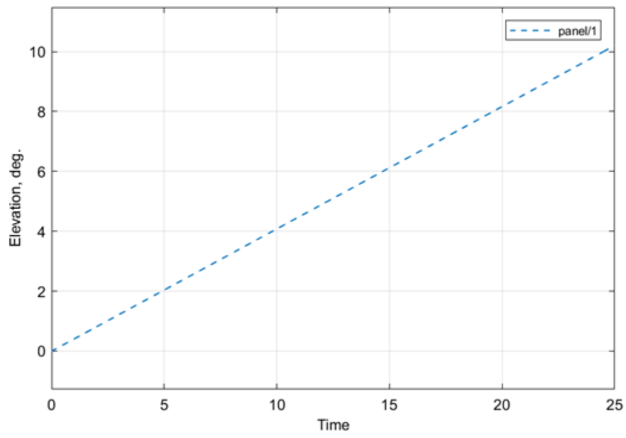


Fig. 6 Solar-panel direction due to source voltage E = 1 volt.

The step-input and PI controller were applied with the system to design the response. Fig. 7 show us the performance of PI controller with step-input. The torque produced by this case (T= -0.7205 N.m) is driving the system to follow the default input. Although PI controller was implemented, the response appears delay time by 1.5 hour and Max. peak over shoot 20%.

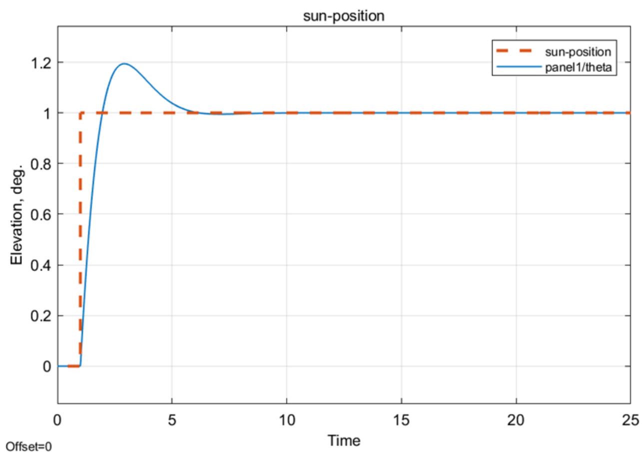


Fig. 7. System response due to PI gains and step-input.

Figure.8, a good comparison between Azimuth city at USA and Istanbul city in Turkey. These differ between the two data cites will test the ability of PI controller to track the actual position with different cases. Fig. 7. Shows us sun rise and sun set for Azimuth (73.75 deg., 288.77 deg .) and Istanbul (-0.83 deg., -0.83 deg.) respectively.

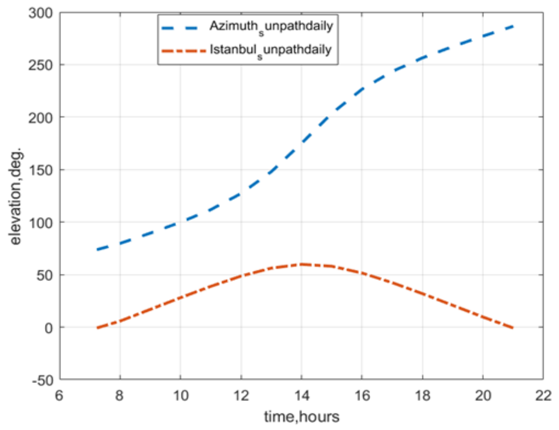


Fig. 8 Sun rise-set for two different time zone cities.

Figure.9 And Figure. 10, Represent ability of PI controller to drive the response through the actual sun-path, so the residual error is equal to $2.333 * 10^{-6}$.

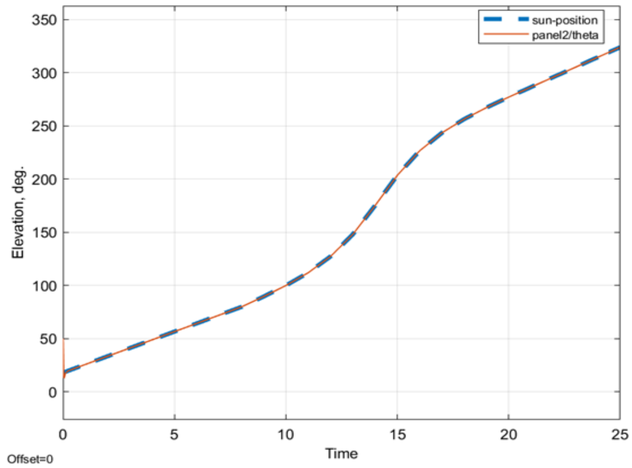


Fig. 9. Response of the system due to PI controller for Azimuth city-USA.

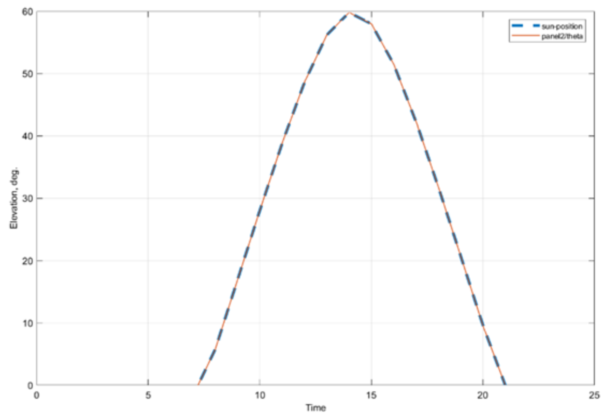


Fig. 10. Response of the system due to PI controller for Istanbul city-Turkey.

Figure. 11 Describe the amount and behavior of PI action from $-3.4 * 10^{5}\, N$ to Max. over-shoot

$0.2 * 10^5\ N$. Theses various values are driving the response through the actual sun position.

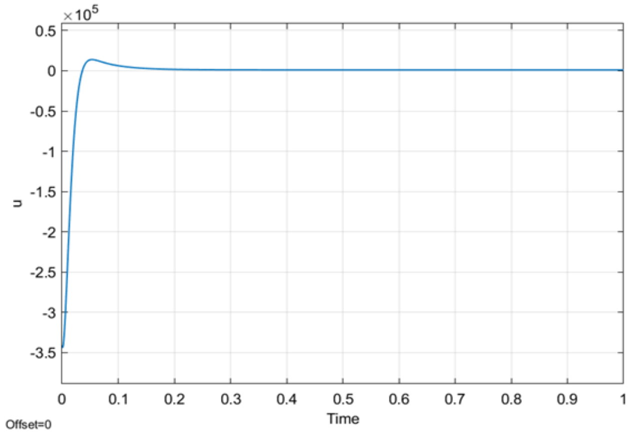


Fig. 11. PI action behavior.

IV. CONCLUSION

1-It's very useful to modelling and simulate any the physical system to know the behavior. The knowledge of the system gives us the clear indication to assign the precise design (i.e., reduce and store the cost and time when we trying to design any system).

2-For starting, it's good to simulate PI controller with default input (step-input) to see the response (just for checking) but this not the desired values (not our main goal).

3-It's very important to get the actual sun path data for the desired city. This validation is very necessary to the modelling and simulation to support our output data.

4-Finally, we got validation and verification between actual sun path data and panel response from this side, and other side a very good comparison between Azimuth city at USA and Istanbul city in Turkey.CONCLUSION

The main conclusions of the study should be summarized in a short Conclusions section.

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ABBREVIATIONS

T: is the torque applied to the panel, N.m.

J=8.6, polar moment of inertia, m4.

L=1.000e-5 Ω,is inductor

V: is the volt providing to motor, volt.

i: is the current supply, Amper

R=10: the resistance, Ohm.

k_p: gain proportional to error.

k_I: gain integral to error.

e_((t)): the error.

u_((t)): is control action.

SYMBOLS

θ: is the incline panel angle

$k_d = 5\ N./s^{-1}, k_g = 2000, k_f = 0.07, k_t = 0.07$: are parameter of solar panel and motor.