Fuzzy Control of Solar Tracker for Photovoltaic Panels

Masoud Jalilian[1*], Hossein Mohammadnezami[2], Younes Amini[3], Mehrdad Boroushaki[4]

[1] Department of Energy Engineering, Sharif University of Technology , Azadi Ave., Tehran, Iran, Phone: +98-21-66166436, Fax: +98-21-66166436,

[2] Department of Chemical and Petroleum Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

[3] Department of Chemical and Petroleum Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

[4] Department of Energy Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

[*]Jalilian@energy.sharif.edu

Abstract

In this paper modeling and control of a solar tracker to receive maximum available output power of a PV panel is studied. This system (tracker and fuzzy controllers) first finds set point (direction of solar beam radiation), then controller moves the panel toward this point. Two controllers are applied to control θ and φ (coordination of normal vector of panel) which are degrees of freedom of system. Inputs of these controllers are error and derivative of error of θ and φ. Outputs of these controllers are electrical signals f_θ and f_φ that act on two stepper motors. These motors rotate the panel. Comparing result of simulation of normal vector of panel with direction of solar beam radiation indicates good performance of the system. Furthermore this system is independent of model of panel and geographical location.

Key words: PV panel; Solar tracker; Fuzzy controller; Stepper motor;

1. Introduction

Using solar panels to exploit energy of sun has been considered extremely in recent decades. These panels are used moving and fixed manners. Fixed panels are positioned with face to south (or north) and slopped equal to latitude of location. To receive maximum radiation and increasing efficiency of PV, single axial moving panel (one degree of freedom) and two-axial panel (two degree of freedom) are used. In these systems, the panels move so that their normal vector is close to normal radiation of sun. Generally excitation of these panels is done electrically or mechanically. In electrical trackers, panel is moved by one or two stepper motors connected to optical sensors. Almost all trackers are of this kind. Required energy of these trackers is provided by the panel itself [1, 2]. In mechanical trackers, two same cylinder arranged parallel to axis of panel with same distance. These cylinders are connected through a pipe. Whenever one of cylinders receives more radiation, the fluid in it vaporizes and goes to another cylinder and due to this imbalance, panel rotates. This system is economically better and does not use received energy of radiation but strongly depends on geographical position of panel [3]. Dependency on geographical position and sun motion leads to difficulty in finding real direction of sun, so designing is for specified location and panel.

1.1. Solar Panel

Solar panel is made of some semiconductors (solar cells) and converts solar energy to electrical energy. Structure of solar cell is like diode, but electrical field in depletion region makes a negative electrical current (inverse bios) from electrons and holes that generated in N and P regions of cell by radiation. The amount of generated electron and hole and in conclusion the output power of cell depends on received normal beam radiation by cell. In other words output power of cell depends on angel between solar beam radiation and normal of panel [4]. Since solar radiation is electromagnetic wave, its power is carried by Poynting vector of wave. Normal element of Poynting vector indicates amount of normal beam radiation.

1.2. Mathematic Equations

Mathematical equations of model are as follow:

$$\vec{N}_{sun} = Sin(\theta_{sun})Cos(\varphi_{sun})\vec{i} + Sin(\theta_{sun})Sin(\varphi_{sun})\vec{j} + Cos(\theta_{sun})\vec{k} \tag{1}$$

$$\vec{N}_{panel} = Sin(\theta_{panel})Cos(\varphi_{panel})\vec{i} + Sin(\theta_{panel})Sin(\varphi_{panel})\vec{j} + Cos(\theta_{panel})\vec{k} \tag{2}$$

$$S_N(panel) = \vec{S}.\vec{N}_{panel} \quad \Rightarrow \tag{3}$$

$$I_N(panel) = I_0 \vec{N}_{sun}.\vec{N}_{panel} = I_0 Cos(\gamma) \tag{4}$$

Where $\vec{S}$, $\vec{N}_{panel}$, I_0, I_N , $\vec{N}_{sun}$ and γ are Poynting vector, normal vector of panel, maximum available radiation, normal component of solar beam radiation, direction of solar beam radiation (normalized vector) and angle between solar beam radiation and normal vector of panel respectively [5]. Each solar panel has a set of characterized curves which each curve is for a specific normal radiation. In other words for a specific normal radiation, panel has infinite working points but just one of them gives maximum output power of panel. This point depends on electrical circuit of panel. In this study it assumes that panel is set at maximum power for specific solar beam radiation [6]. Physical characteristics of used in simulation and also characteristic curves for different normal beam radiation is presented in table 1 and 2 and Fig 1.

Table 1. Physical characteristics of 45[1]/36[2] solar panel [7]

Cell type	Polycrystalline silicone
Cell dimension	10×10×1.1 cm^3
Panel dimension	97.7×46.2×1.1 cm^3
Mass of panel	7.7 kg

Table 2. Electrical characteristics of 45/36 solar panel under 100 mW/cm^2 radiation [7]

Open-circuit voltage	20.5 V
Short-circuit current	2.98 A
Current & voltage at max. power	2.76A, 16.38 V
Average Efficiency	12%

Marked points on Fig 1, show working points with maximum output power of different normal radiation intensity. The equation of curve that relates these points is as follows:

$$P(W) = 0.458 I_N(panel)(mW/cm^2) - 0.67 \tag{5}$$

As Fig. 2 shows panels is placed on a structure which have two axis and two sensors for measuring θ and φ at coordinate system shown in Fig. 2. θ and φ are changed by two stepper motors.

[1] Maximum power output
[2] Number of cells

2. Methodology

Fig. 3 shows block diagram of tracker and fuzzy controllers. Firstly, the system finds set point i.e. solar beam radiation (φ_{sun} and θ_{sun} in spherical coordinates) by search and then fuzzy controllers take the φ_{panel} and θ_{panel} to φ_{sun} and θ_{sun} respectively using error and derivative of error as fuzzifier inputs. This system operates 30 minutes periodically, not continuously.

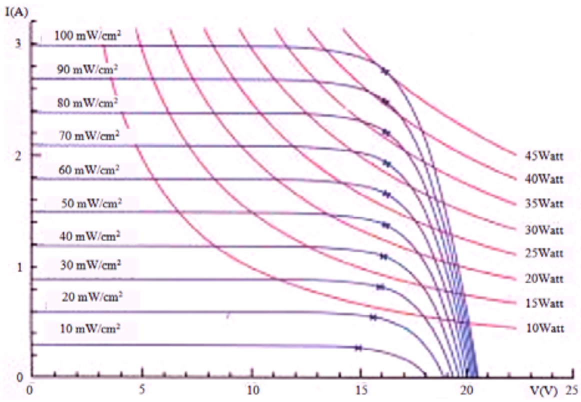

Figure 1. Characteristic curves of 45/36 solar panel under different radiations [7]

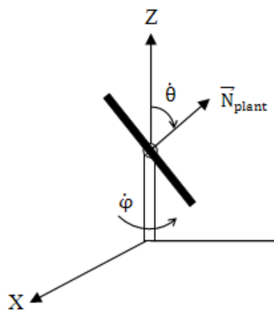

Figure 2. Structure of panel

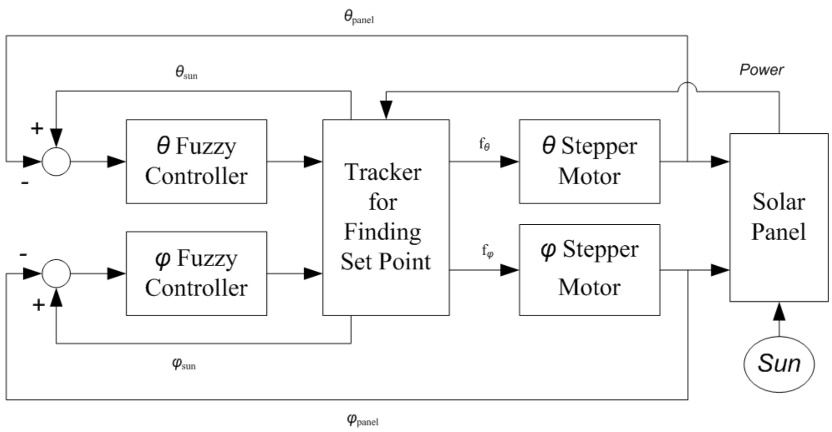

Figure 3. Block diagram of solar tracker and fuzzy controllers

To find set point, first φ_{panel} is set to zero and then tracker find a φ which results maximum power by searching whole domain of φ (0 to 360 degree). Then fuzzy controller begins to control and drive φ_{panel} to φ_{sun}. This point is not global maximum of power because $\partial P/\partial\varphi = 0$(P is output power of panel) but $\partial P/\partial\theta \neq 0$. In next step φ controller is switched off (φ remain fixed) and search for finding θ_{sun} starts. To do this, tracker first brings the θ_{panel} to zero, and then changes θ_{panel} from 0 to 180 until direction of global maximum power is determined. After finding θ_{sun}, θ fuzzy controller plays its role and moves θ_{panel} to θ_{sun}. During tracking, controllers are off. In this type of searching, first φ and then θ tracked and controlled. If first θ be controlled, then tracking do wrong in finding θ_{sun} but if φ tracked this problem never happens. This is because φ is defined in X-Y plane, but θ in a conical plane. Tracking of a special case in which $(\theta_{sun}, \varphi_{sun})=(\pi/4,\pi/2\ )$ and initial position of panel is $(\ \varphi_{0panel},\theta_{0panel})= (0,\pi/2)$ is proceed in 3 steps as illustrated in Fig. 4 and 5. In Fig. 4, θ_{panel} is changed and system reaches to maximum radiation in θ direction but at this point $\theta_{panel} \neq \theta_{sun}$. However, in Fig. 5 first φ is changed and tracker reaches maximum radiation in φ direction at which $\varphi_{sun} = \varphi_{panel}$.

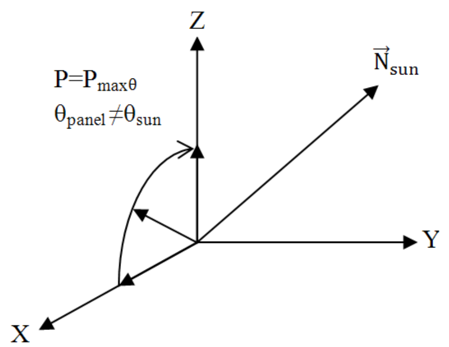

Figure 4. Tracking θ_{sun}

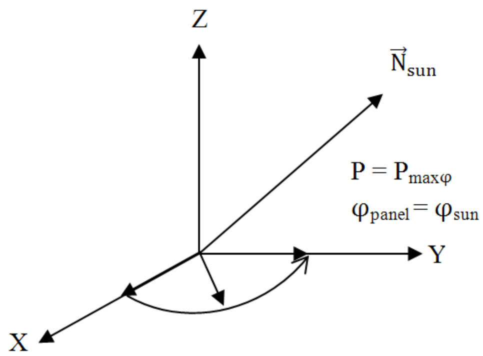

Figure 5. Tracking φ_{sun}

Fuzzy rules which applied for fuzzy controllers of system are presented in Table 3.

Table 3. Fuzzy rules of fuzzy controller

Number	Fuzzy rule
1	**If** error is positive and derivative of error is positive **Then** move panel in positive direction
2	If error is positive and derivative of error is negative **Then** move panel in positive direction
3	**If** error is zero and derivative of error is positive **Then** do not move panel
4	**If** error is zero and derivative of error is negative **Then** do not move panel
5	**If** error is negative and derivative of error is positive **Then** move panel in negative direction
6	**If** error is negative and derivative of error is negative **Then** move panel in negative direction

3. Case Study

In order to study behaviour of simulated system and comparing output power with real data (assuming being in maximum radiation of sun) two case studies are carried out in which two different directions dedicated to sun. Tracking, simulation and control results are compared.

3.1. Case Study 1

Data of this case study is presented in Table 4. In this case study two different direction are assumed for sun and panel, so that initially panel has zero output power. This situation occurs through process sunset and sunrise at next day. Simulation results are given in Table 5 and shown in Figs. 6, 7 and 8.

3.2. Case Study 2

Data of this case study is presented in Table 4. As in case study 1, two different directions are assumed for sun and panel, so that panel has non zero output power. This situation happens during day. Simulation results are given in Table 5 and shown in Figs. 9, 10 and 11.

Table 4. Data for case studies

Parameter	Case study 1	Case study 2
θ_{sun} (Degree)	60	60
φ_{sun} (Degree)	135	90
θ_{0panel} (Degree)	145	30
φ_{0panel} (Degree)	45	45
Initial situation of panel	Back to sun	Font to sun
Initial power (Watt)	0.00	33.20
Radiation amplitude (Watt/cm^2)	100	100

Table 5. Siamulation result of case studies

Parameter	Case study 1		Case study 2	
	Set point	Result of simulation	Set point	Result of simulation
θ (Degree)	60	59-61	60	59-61
φ (Degree)	135	137	90	92
P_{max} (Watt)	45.13	45.12	45.13	45.15

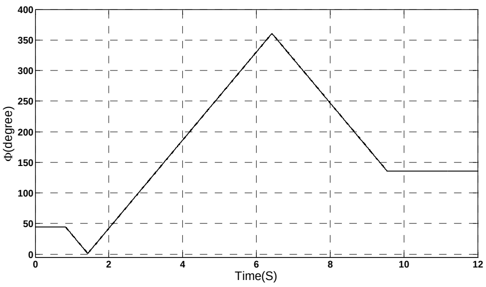

Figure 6. φ angle of panel (Case study 1)

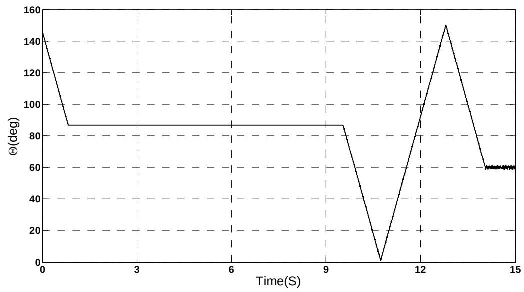

Figure 7. θ angle of panel (Case study 1)

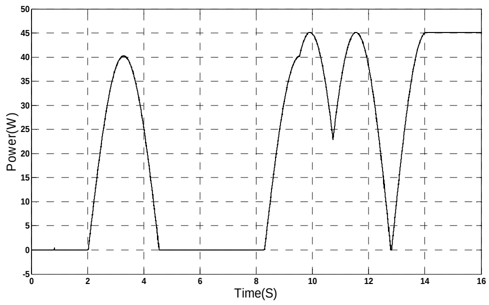

Figure 8. Output power of simulated system (case study 1)

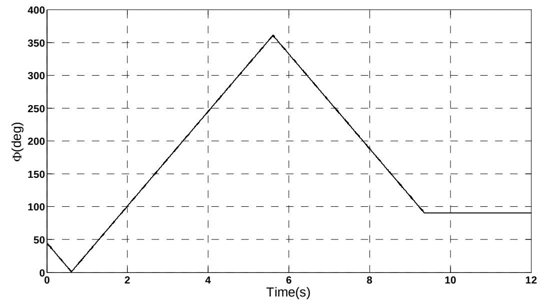

Figure 9. φ angle of panel (Case study 2)

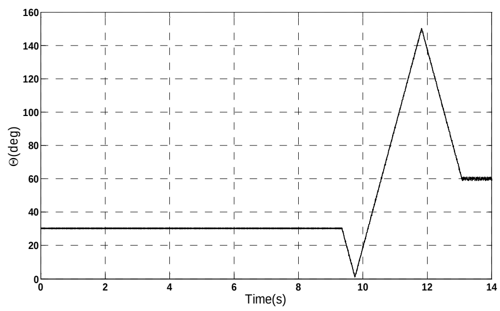

Figure 10. θ angle of panel (Case study 2)

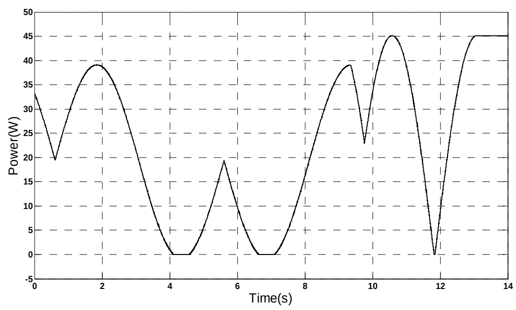

Figure 11. Output power of simulated system (case study 2)

4. Conclusion

As Fig. 6-11 show the tracking and fuzzy control system has good result in achieving maximum power. In both case studies, at first, the system finds maximum power point and then controls panel. Simulation efficiency ($P_{simulation,max} / P_{available,max}$) is 99.9%. For PV power plant, this system can be used to find direction of solar beam radiation by using a small panel and then move all panels to this direction. Main advantage of this system is that it does not depend on model of panel (being small or big) and geographical location of panel.

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