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Fuzzy Logic Based Solar Tracking System by Estimation of Solar Radiation

Anita Kumari
ME Student, Electrical Engineering
National Institute of Technical Teachers Training and Research
Chandigarh, India

Shimi S. L.
Assistant Professor, Electrical Engineering
National Institute of Technical Teachers Training and Research
Chandigarh, India

Dr. S. Chatterji
Professor & H.O.D., Electrical Engineering
National Institute of Technical Teachers Training and Research
Chandigarh, India

Amita Kumari
M. Tech Student, Electrical Engineering
National Institute of Technology Patna
Patna, India

Abstract

Energy is one of the most important inputs for all sectors of a country's economy. The living standard of the people living in different parts of the globe is related to per capita energy consumption. In India 66.44% of electricity generation is from thermal power plants, 19.13 %from hydro, 2.32% from nuclear and 12.09% from rest. Out of 66.44%, 56.65% share is of coal. These days the demand of energy is increasing rapidly in rural areas. This energy demand can be fulfilled effectively by using the available solar energy. Photo-voltaic system exhibits a right degree of compatibility. In this paper a program is written in C++ to estimate the solar radiation in different areas and calculate the total power which can be generated through the solar energy. It also calculate the angle at which the solar panel is fixed to trap maximum solar radiation. Then a fuzzy logic based C++ program is written to track the solar panel by sensing the voltage and temperature of the panel. This paper also includes the concept of cooling system which cools the panel when its temperature exceeds above its limit at which its efficiency becomes low. Then the input is given to energy efficient motor to start the cooling system to maintain the temperature of the panel. For computing the solar radiation different inputs such as monthly average global radiation, regression constant, extraterrestrial solar radiation, declination angle, latitude angle etc. were noted. When these inputs are given to the written program then it will automatically give the total possible energy production through the solar radiation.

Keywords-photo-voltaic; solar radiation; C++ programming; regression constan;, declination angle; latitude

1. Introduction

Energy is a vital factor influencing the economic growth and development of countries. At present the energy crisis has led the entire world almost to reach the last line of defense of survival and to find out the effective alternatives on priority basis. Diminishing natural reserves of the commercial energy sources a major challenge of today. So that men will have to increasingly depend upon renewable sources of energy. Non-conventional source of energy is one of the areas of emerging technology which have higher priority with reference to national needs.

All fossil fuels will get exhausted eventually in the next century. Therefore other systems based on renewable sources are being tried by many countries. With continuous research all over the world and fear of depleting fossil fuels reserves have compelled the researchers to develop better photo voltaic energy conversion systems. The present work attempts to solve a few problems related to photovoltaic based energy systems. Since PV arrays are precious and energy conversion efficiency is not very high, the user of such an expensive system naturally wants to use maximum of the available output power.

Solar energy can be a major source of power, its potential is 178 billion MW. It shows that we have sufficient amount of solar energy to fulfill our energy needs but actually the problem is that the devices we have are costly as well as less efficient. We have to improve them for better efficiency and optimum utilization of solar energy.

There are various methods for getting maximum radiation of sun light. Many investigators have used Modified Perturb and Observe (MPO) method and was proposed to achieve maximum power point tracking (MPPT) for a PV (photovoltaic) system [1]. This is the Constant Voltage method (CVT). Although the CVT method is very simple, however, the constant Voltage can't track maximum power point (MPP) when temperature changes, so the constant Voltage method is not often used in the true MPPT strategy from the characteristic curves of PV Cell, it can be seen that incrementing (decrementing) the Voltage increases (decreases) the power when operating on the left of the MPP and decreases (increase) the power when on the right of the MPP. Therefore, if there is an increase in power, the subsequent perturbation should be kept the same to reach the MPP and if there's a decrease in power, the perturbation should be reversed [2]. Small perturbations are introduced in the system in order to vary the operating point such that the MPP is achieved. However, this method has several drawbacks such as slow tracking speed and oscillations about MPP, making it less favorable for rapidly changing environmental conditions and this method can appear fallacious tracking when there is a sudden change in irradiance [3]. Others used fuzzy logic, a Genetic Algorithm (GA) and many other methods utilizing sun tracking approaches to maximize the performance of PV panels [4][5].

Fuzzy control has adaptive characteristic in nature, and can achieve robust response of a system with uncertainty, parameter variation and load disturbance. It has been broadly used to control ill-defined, non-linear (or) imprecise system. Fuzzy logic controllerhave the advantages of working with imprecise inputs, not needing on accurate mathematical model, and handling nonlinearly. Fuzzy control has been successfully applied in many fields. Fuzzy control does not require accurate models of control object to overcome the limitation of the above conventional tracking methods, fuzzy control is applied to deal with MPPT of PV generation system in this paper, with this technique, not only can the real MPP be readily tracked but also fast dynamic responses can be achieved.

2. Solar Radiation

In solar radiation analysis, the following angles are useful:

Φ = latitude of location

δ = declination

ω = hour angle

n = monthly average of duration of actual sunshine hours (h) [6]

N = monthly average of duration of a maximum possible sunshine hours (h)

The latitude Φ of a point or location is the angle made by the radial line joining the location to the center of the earth with the projection of the line on the equatorial plane. It is the angular distance north or south of the equator measured from center of the earth.

The declination δ is the angular distance of the sun's rays north (or south) of the equator.

$$\delta(\text{in degree}) = 23.45\sin\left[\frac{360}{365} * (284 + M)\right] \quad (1)$$

where,

M is the day of the year

The hour angle ω is equivalent to15° per hour. It is measured from noon based on the local solar time (LST) or local apparent time, being positive in the morning and negative in the afternoon. Hour angle ω can be expressed mathematically as:

$$\cos\omega = \sin\Phi\sin\delta / \cos\Phi\cos\delta$$

$$= \tan\Phi\tan\delta$$

$$\omega = \cos^{-1}(\tan\Phi \tan\delta) \quad (2)$$

Since 15° of the hour angle are equivalent to 1 hour, the day length (in hours)

$$N = \frac{2}{15}\omega$$

$$= \frac{2}{15}\cos^{-1}(\tan\Phi \tan\delta) \quad (3)$$

Therefore, the length of the day N is a function of latitude and solar declination. The hour angle at sunrise or sunset on an inclined surface ω_{st} will be lesser than the value obtained, if the corresponding incidence angle comes out to be more than 90°. Thus for inclined surface having slope β has hour angle as

$$\omega_{st} = \cos^{-1}(\tan(\Phi - \beta) \tan\delta) \quad (4)$$

The corresponding day length (in hours) is then given by

$$N = \frac{2}{15}\cos^{-1}(\tan(\Phi - \beta) \tan\delta) \quad (5)$$

3. Proposed Work

The proposed work includes the estimation of solar radiation of different areas by knowing its position on earth latitude and longitude. The work also includes the

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calculation of angle at which solar panel receives maximum radiation.

The objective of this proposed work is to develop a working prototype for a solar array peak power tracker. Each solar array is a non-linear device which contains a maximum power point. Tracking this point for a solar array allows an increase in the reliability of the power supply during the sunlight and the achievement of maximum power in order to charge a back-up battery. The tracking is done using fuzzy logic by implementing it into C programming [7]. The investigators have taken voltage and temperature as input and the angle of deviation of the solar panel as output for fuzzy logic.

Figure 1 shows the modeling design of solar panel tracker. In the design of tracking system there is avoltage sensor which senses the voltage of solar panel and a temperature sensor which senses the temperature of surrounding of panel. These two inputs are analog which converted into digital by analog to digital converter (ADC). These two parameters are the input for fuzzy logic based C programing and the output is the angle of deviation of the panel which is fed to the input of stepper motor. Then motor track the solar panel. A cooling system is placed to cool the solar panel when its temperature exceeds the limit to improve the efficiency of the solar system.

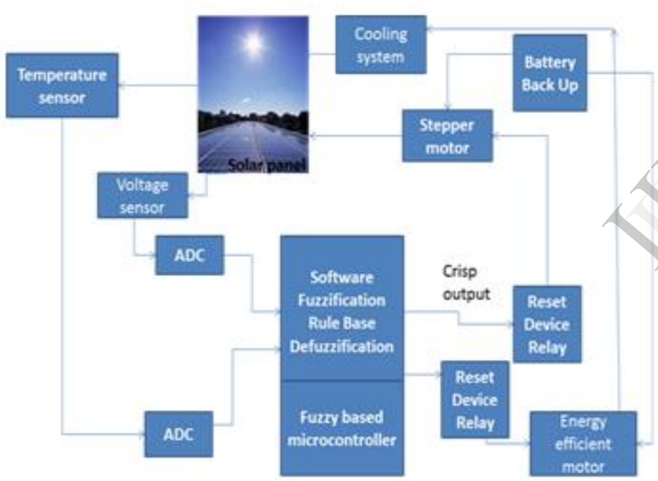


Fig. 1 Block diagram of solar panel control using fuzzy logic

4. Methodology

Solar energy application for thermal environment design the global radiation on a tilted surface is essential. The Liu and Jordan method is used in the present work [8]. The solar collector must be placed in tilted position with respect to the horizontal plane so that it collects maximum energy during the complete year. The tilt angle of the collector β is the angle between the horizontal plane and the plate collector surface.

Liu and Jordan method have been used to estimate the total radiation both on horizontal and tilted surface [8][9]. It contains all the formula being used for the estimation. A linear relation was proposed by Angstrom's for computation of the average daily global radiation on horizontal surface[10][11][12].

$$H = H_o \left[a + b * \left(\frac{n}{N}\right)\right] \quad (6)$$

Where,

H = Total average daily global Radiation at horizontal surface

Ho = Extra-terrestrial solar radiation

a, b = Regression Constant

H_t = total average daily global radiation at tilted (β) surface

$$H_t = (H_b R_b + H_d R_d + H R_r) \text{KW/m}^2 \quad (7)$$

Where,

Hb = Average daily direct radiation

Hd = Average daily diffuse radiation

Rb = ratio of radiation on tilted Surface to radiationon horizontal surface

Rd = Conversion factor for diffuse radiation

Rr = conversion factor for ground reflected radiation

The solar panel is fixed at angle β and employ the tracking mechanism to the base of the solar panel. This tracking results in increase in the average duration of hours for which we are getting sunlight. Thus as the position of sun changes the solar panel also has to be rotated so that it always faces the sun. The tracking is done by using fuzzy logic [13][14]. The variables being used for fuzzy logic control are shown below:

TABLE 1. Fuzzy variables

Name	**Input/Output**	**Minimum Value**	**Maximum Value**
Voltage	Input	0	20

Temperature	Input	0	55ºC
Degree of rotation	Output	0	180º

The membership functions for the variable voltage can be shown as below:

TABLE 2. Fuzzy variable range for voltage

Crisp Input range (in V)	**Fuzzy variables**
0-5	No voltage(NV)
3-8	Less voltage(LV)
6-15	More voltage(MV)
14-20	High voltage(HV)

The membership functions for the variable temperature is as follows:

TABLE 3. Fuzzy variable ranges for temperatures

Crisp Input Range (˚C)	**Fuzzy Variables**
0-10	Very cold(VC)
8-25	Cold(C)
20-32	Moderate(M)
30-55	Hot(H)

The membership functions for the variable rotation is as follows:

TABLE 4. Fuzzy variable range for rotation

Crisp Input Range in Degree	**Fuzzy Variables**
0-8	No deviation(ND)
5-17	Very less deviation(VLD)
15-45	Less deviation(LD)
35-75	More deviation(MD)
70-125	High deviation(HD)
120-180	Very high deviation(VHD)

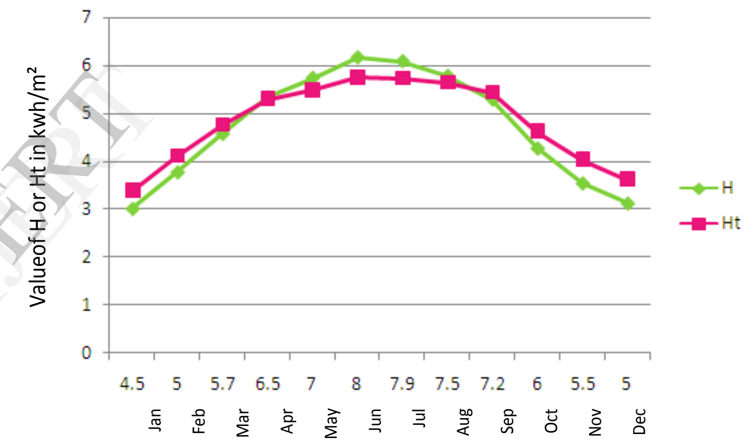
The fuzzy logic control strategy is employed by the following rule base. The interfacing is being done by using C++ Programming.

TABLE 5. Rule base

Temperature /Voltage	**Very Cold**	**Cold**	**Moderate**	**Hot**
No voltage	LD	MD	HD	HD
Less voltage	VLD	LD	MD	VHD
Moderate voltage	ND	ND	LD	MD
High voltage	ND	ND	ND	ND

5. Results and Discussion

From the estimation we get the graph as shown below:



Value of n in hours

Fig. 2 Average daily global radiation H &Htvs monthly average sun shine duration (Patna)

From the different estimation results at different angles we get that the average solar radiation is maximum for β = 31˚during September-March. The different values of average solar radiation at different angle can be shown in Table 6.

TABLE 6. Average solar radiation for the period September-March

β (˚)	Average Solar Energy (Ht1avg) in KWh/m²
0	3.952165421
15	4.249241633
21	4.315994993
31	4.35816412
50	4.199006231

We know that when sun is overhead then solar radiations

Month	Value of n (hrs) Without Fuzzy	Solar Energy Ht in KWh/m² Without Fuzzy	Value of n (hrs) With Fuzzy	Solar Radiation Ht in KWh/m² With fuzzy
Sep.	7.2	5.44485	9.2	6.190635
Oct.	6	4.630621	8	5.685141
Nov.	5.5	4.038451	7	5.016565
Dec.	5	3.628196	6	4.368563
Jan.	4.5	3.383978	6.5	4.308636
Feb.	5	4.109712	7	5.184627
Mar.	5.7	4.769386	7.7	5.629922

are perpendicular to the surface hence the maximum energy can be harnessed. So in this case we get the maximum radiation on β = 0˚. The values of radiation at different value of β are shown in Table 7.

TABLE 7. Average solar radiation for the period April-August

β (˚)	Average Solar Energy (Ht2avg) in KWh/m²
0	5.82271
15	5.651597
21	5.513877
31	5.201795
50	4.358071

The primary benefit of a tracking system is to collect solar energy for the longest period of the day. The new value of n for solar tracking system can be found by considering the morning time and afternoon time duration on an average by neglecting the early morning hours and late evening hours as the intensity of light is low at these times.

The tracking results are shown in Table 8.

TABLE 8.Deviation angle for tracking sun

Input 1	Input2	Output
Voltage (v)	Temperature (˚c)	Deviation (˚)
7	22	26
18	20	0
6	15	20
6	23	50

Even though a fixed flat-panel can be set to collect a high proportion of available noon-time energy, significant power is also available in the early mornings and late afternoonswhen the misalignment with a fixed panel becomes excessive to collect a reasonable proportion of the available energy.

TABLE 9.Solar radiation with and without fuzzy logic controller for β = 31°

TABLE 10. Solar radiation with and without fuzzy logic controller for β = 0˚

Month	Value of n (hrs) Without Fuzzy	Solar Energy Ht in KWh/m² Without Fuzzy	Value of n (hrs) With Fuzzy	Solar Radiation Ht in KWh/m² With Fuzzy
April	6.5	5.304025	8.5	6.110776
May	7	5.485401	9	6.525165
June	8	5.761757	10	6.9493
July	7.9	5.73854	9.9	6.869598
August	7.5	5.647961	9.5	6.558841

6. Conclusion

From the estimation of solar radiation we conclude that the radiation on the tilted surface is more than that we get on the horizontal surface for the period when sun is not overhead. The estimation also give the maximum declination tilted angle for which we could get the maximum average solar radiation which is given by $\beta = 31^\circ$ for September-March. The rest of the year we get maximum radiation for $\beta = 0^\circ$ as during this period sun is directly overhead (for India).

There is a significant increase in the output when tracking is done with fuzzy logic controller. The fuzzy logic based tracking results in an increase of about 25% in monthly average solar radiation. During summer season as the Sun is overhead most of the direct radiation is obtained. Thus it is the summer season in which the maximum radiation is trapped during a year.

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