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Manipulation of the Sun's Look Angles Using Linear Equation to Develop Fuzzy Logic Rules for Dual-Axes Solar Tracking system

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Abstract: - Increasing the energy production of solar array systems is crucial, but increasing the time duration during which the energy collected is even more critical. As solar energy becomes more mainstream, installers and enthusiasts must find new methods to maximize its potential. Solar tracking systems, along with cutting-edge innovation, increase energy capture and efficiency. Due to its ability to move panels on both horizontal and vertical axes, dual-axes solar tracking systems enable better energy optimization. The purpose of this paper is to present the manipulation of the sun's look (or lookout) angles in order to develop fuzzy logic rules for dual-axes solar tracking system for optimization. The look angles for the summer season were obtained from the solar elevation angle calculator, which is an online application that is used to calculate the solar angles. The linear equation was used to manipulate the look angles of the sun for the day from which the fuzzy logic rule set was derived. Results indicated system's accuracy and more power harvesting for the fuzzy logic look angles-based tracking system. The study was conducted only in the summer season, and since the other seasons have lower levels of solar radiation, it is crucial to test the findings for those times of year.

Keywords: —Look angles, photovoltaic, fuzzy logic, azimuth and elevation angle.

I. Introduction

Global warming and pollution are genuine and important challenges that must be addressed immediately [1]. Using fossil fuels for heat generation in the energy industry significantly contributes to global carbon dioxide emissions [2]. Environmentally friendly options, such as solar energy, are crucial for protecting the environment [3]. The most essential element of this energy source is that it does not harm the environment by producing greenhouse gases into the atmosphere [4]. Using solar power instead of typical power plants, which require large amounts of water in addition to fuel, minimizes pollution and water usage since solar power generates energy without the need for water [5]. Any energy produced by renewable resources, including solar energy is regarded as pollution-free energy [6]. Solar energy is an abundant source of energy that may be utilized to heat, cool down, and illuminate homes and businesses [7]. The earth receives more energy from the sun in an hour than the whole global population uses in a year [8]. Sunlight is converted into useful energy for buildings using a range of methods [8]. The most prevalent solar technologies for houses and businesses include solar photovoltaics (PV) for energy, passive solar design for space heating and cooling, and solar water heating [9]. A PV system is made up of one or more solar panels, an inverter, and other electrical and mechanical components that convert solar energy into electricity [10]. The PV effect occurs when light from the sun, which is composed of packets of energy known as photons, falls on a solar panel and generates an electric current [11]. Each panel generates a modest quantity of electricity, but when joined together, they create more energy as a solar array [12].

Solar energy travels to Earth in numerous ways, including heat and light [13]. However, a significant percentage of this energy is lost during transit due to cloud absorption, reflection, and dispersion [14]. Subsequently, promoting the development of innovative solar energy harvesting technologies [15]. Several approaches have been used to maximize the energy gained from solar electricity [16]. Of these, solar-tracking is one of the most often used technique [17]. Solar tracking systems provide significant benefits in solar energy applications, including increased power and efficiency relative to fixed systems, as well as economic assessments for large-scale applications [18]. The systems are positioned with ideal azimuth and elevation angles towards the equator from the horizon to optimize solar radiation on collectors and panels [19]. Tracking angles vary based on latitude and climate conditions [20]. Solar tracking systems are classified as single axis or dual axes, based on their degree of freedom of movement [21].

The purpose of this paper is to present the results for the manipulation of the sun's look (lookout) angles using linear equation to develop fuzzy logic rules for dual-axes solar tracking system for optimization purposes.

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II. LITERATURE REVIEW

Simulation models are becoming more and more common to solve problems and help with decision making [22]. Decision makers who use information acquired from empirical results, as well as those affected by decisions based on such models, are all legitimately interested in whether a model and its outcomes are valid [23]. Through model validation and verification (simulation), this issue is resolved [24]. Model verification is sometimes characterized as assuring that the computer program of the computerized model and its implementation are correct [25] [26]. A computer simulation model can be a valuable tool for testing theories, subsequently offering easily verifiable and understandable analysis [27]. Real world challenges like the sun's look angles calculations can be solved safely and efficiently by simulation models [28]. Look angles are usually noted as azimuth and elevation angles in satellite communication [29]. Antenna look angles of a geostationary communications satellite give the necessary information to guarantee that the control station antenna is pointed in the direction of the satellite; more precisely, to guarantee that the antenna's main lobe is aligned with the main lobe of the satellite and that the maximum amount of energy is extracted from the satellite [30]. Just as an Earth station can track a satellite in outer space using the look angles, so as a PV module can track the movement of the sun using similar proposed look angles, which can translate to appropriate azimuth and elevation angles [31]. However, establishing the station of the sun at a particular geographical location and time, mathematical formula or algorithm should be engaged [32]. An artificial intelligence (AI) algorithm is needed in order to rotate the PV module for optimization in a solar tracking system hence the application of fuzzy logic algorithm (FLA) [33] [34].

By definition, fuzzy logic (FL) is a type of many-value logic that works using approximate reasoning as opposed to fixed and accurate reasoning [35]. FLA is a control approach that mimics the human decision-making process, making random or uncertain decisions between 0 and 1 [36]. The FLA application improves the solar tracking system's performance by processing input variables towards the position of the highest irradiance, resulting in better output optimization and system efficiency [37]. The primary responsibility of the algorithm involves establishing rules based on analysis of the system's behavior and language input factors [38]. The input variables provided to the FLA must go through three basic stages of fuzzification, decision-making, and defuzzification before generating the output [39]. During the fuzzification stage, predetermined membership functions (MFs) are used to convert the input variables into a linguistic variable [40]. The fuzzified output is subsequently produced using the fuzzification stage's output in accordance with the established guidelines. Ultimately, the fuzzified output is converted into the necessary output needed for system control at the defuzzification stage [41]. A fuzzy logic controller has the benefits of working with imprecise inputs, not requiring a correct mathematical model, and handling nonlinearly [42].

III. RESEARCH METHODOLOGY

The methodology and research techniques used for the investigation are described in this section. One PV module (representing the direct-tracking system) was moving between 90° in the morning, 0° at 12 noon and 90° in the afternoon (this is for the tilt angle). The orientation angle was limited to +180° at 06:00 am and -180° at 06:00 pm. In this study, the orientation angle relates to the azimuth angle, while the tilt angle relates to the elevation angle. Linear regression equation (equation 1) was used to determine proposed lookout angles for the solar-tracking system.

$$Y = a + bx \qquad (1)$$

where: Y = Linear regression function (dependent variable), a = Y-intercept, b = Slope and x = X-axis value (independent variable). In this current study the equation is used as follows: Y = Simulated lookout angles, a = First lookout angle of the day, which equates to 103.65°, b = Multiplying constant (0.0039) and x = Accumulated power total from direct-tracking system. The application of equation 1 yields the following look angle for a given direct power measurement:

$$Y = (103, 648) + (3.993 \times 10^{-3})\,(41, 42) = 103, 8 \qquad (2)$$

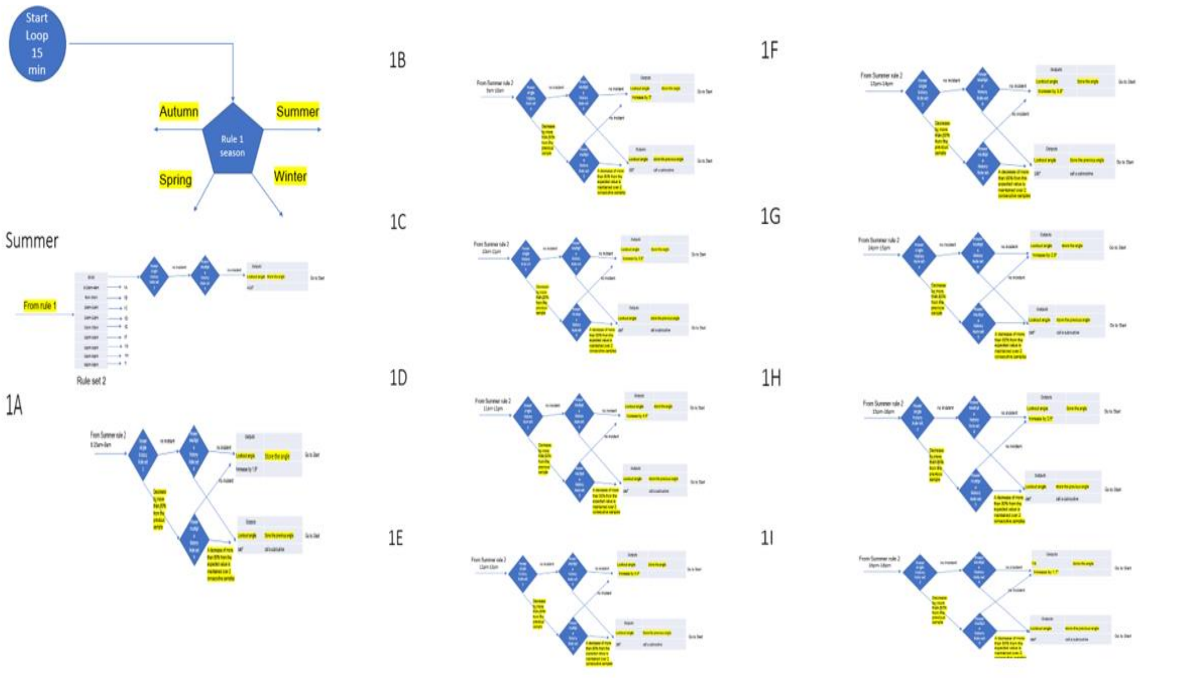
Table 1 lists the methods that were engaged to develop the fuzzy set rules. The output power profile of the tracking system was used to determine the amount of power reduction due to cloud movement. Linear equation was used to manipulate the look angles of the sun for the day from which the fuzzy logic rule set was derived. Both tilt and orientation angles were varied throughout the day. LabVIEW was used to simulate the output power of the system by applying a linear regression algorithm and a fuzzy logic algorithm.

TABLE I: The development of fuzzy rules

Step	Description	Reason
1	Obtain the look angles for the summer solstice for the research site. These are derived from the azimuth and elevation angles obtained from Keisan.com website	Used to determine the amount of change required for the orientation and tilt angle for various seasons so as to account for different solar radiation values. A translation table can be used to calculate the tilt and orientation angles using the look-out angles
2	Obtain an output profile of a fixed solar module for the research site	Used to determine the amount of power reduction for cloud movement to be used as one of the fuzzy rule inputs derived from historical values
3	Obtain an output profile of a direct-tracking system for the research site	Used to determine the rate of change required for the orientation and tilt angle over a 12-hour day so as to prevent oscillations and reduce power consumption (value per movement)
4	Sketch an anticipated output profile of a solar tracking system for the research site and indicate various times of importance	Used to determine the amount of change and rate of change for the solar module
5	Develop a concise generic rule set based on the information of the preceding steps	To be used in the programming of the algorithm in LabView

IV. Results and Discussion

Fig. 1 (a-c) illustrates the flowchart on how the fuzzy decisions were made. At 6:00 am, the system moves to the starting point and checks the season of the year (only the summer season being considered for the current study) and then stipulates a look angle of 110° It is essential to state that the tilt angle of the PV module is limited to maximum of 90°. During a sunny day, the motion is kept according to the sun's angles for the day with intervals of 15 minutes while recording and saving the readings. The same condition is maintained even when there is a single cloud based on the condition that the cloud does not last for more than 15 minutes.



(a) The fuzzy logic flowchart showing start-loop, season of the year and time of the day (1A)

(b) The fuzzy logic flowchart showing season of the year and time of the day (1B-1E)

(c) The fuzzy logic flowchart showing season of the year and time of the day (1F-1I)

Fig. 1. Fuzzy development flowcharts.

Since the sun behaves differently in different seasons, it is essential to state that there should be a slight deviation on the fuzzy rules depending on the season of the year. Fig. 1 (b and c) depicts the fuzzy logic flowchart rules for the summer season and for different times of the day (1B-1E and 1F-1I). At the beginning, the system determines the season of the year (summer), then the time of the day and applies the relevant rule set. The flowchart shows 1A (fi.1), which represents 6:15am-9am, 1B (9am-10am), 1C (10am-11am), 1D (11am-12pm), 1E (12pm-13pm), 1F (13pm-14pm), 1G (14pm-15pm), 1H (15 pm-16pm) and 1I representing 16 am -18 pm. The system also makes use of the power history values for decision-making purposes. If the output power falls by more than 80 % over two consecutive readings, then a subroutine is called as it is assumed that multiple clouds are present. According to [43], a threshold dip range is considered to be 80 % of full load. The system proposes look angles as outputs with necessary adjustments (increments of 2.5° at 3 pm and 1.7° at 4 pm). The adjustments are determined by the difference between four consecutive look angles in an interval of 15 minutes, then the difference is utilized to determine the hourly average change (increase). That means the system will assume a look angle of 110° at 6 am and automatically adjusts (increases) the look angle by 1.9° between 6:15 am and 9 am and by 3° between 9 am and 10 am. Table 2 lists the daily look angles from the website and the daily average look angles increase calculated for the fuzzy logic algorithm. Fig.2 depicts the daily profile for the simulated power for fuzzy logic. It is evident that the algorithm is capable of tracking the sun accurately from the sunrise to the sunset. The algorithm starts at higher power values when the sun rises due to its perpendicular alignment to the sun.

TABLE II: The daily look angles from the website and the daily average lookout angles increase calculated for the fuzzy logic algorithm

Time of the day (hours)	**Look angles from the Keisan website (°)**	**Average increase calculated (°)**
6:15 am	112,1	1,9
7:00 am	116,8	1,9
8:00 am	124,3	1,9
9:00 am	133,6	1,9
10:00 am	149,1	3
11:00 am	160,7	3,8
12:00 pm	178,1	4,4
13:00 pm	195,9	4,4
14:00 pm	211,5	3,9
15:00 pm	211,9	328
16:00 pm	232,7	2,5
17:00 pm	240	1,8
18:00 pm	246,6	1,7

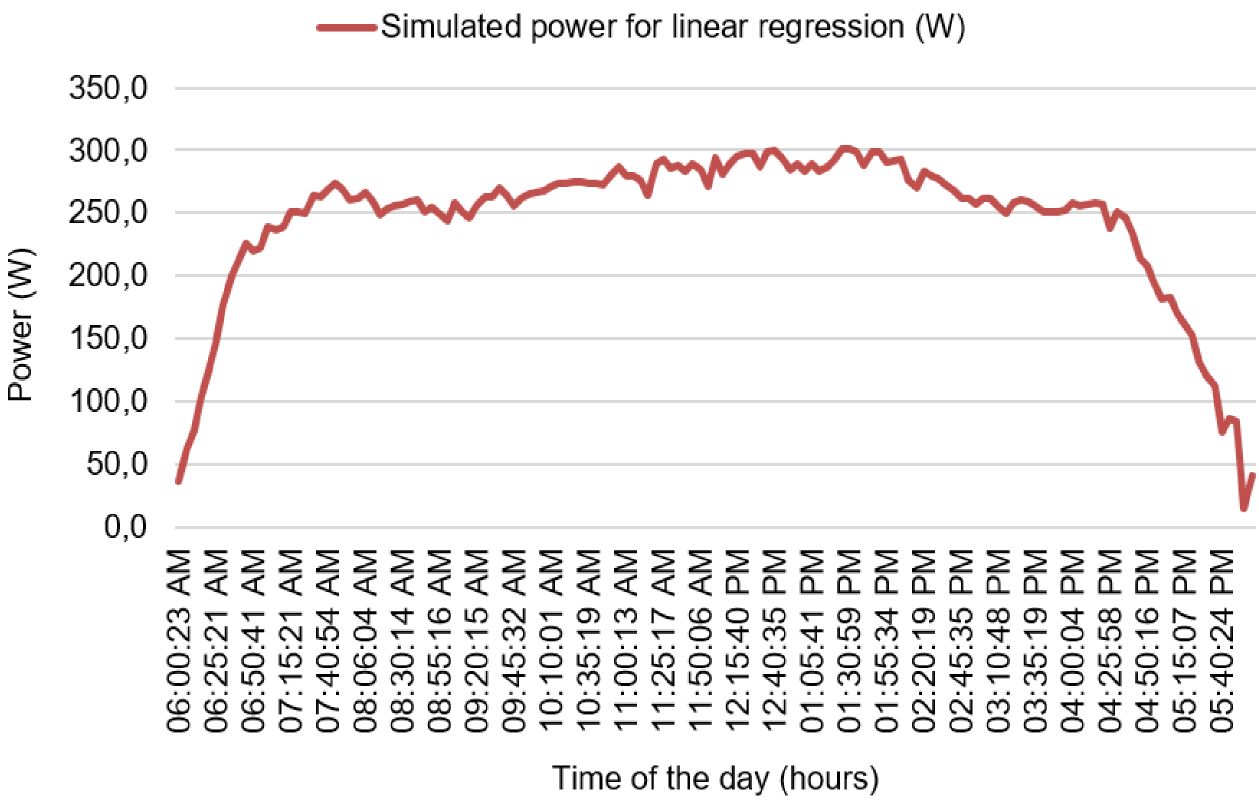


Fig. 2: The fuzzy logic algorithm sunny day simulated power.

V. CONCLUSION

The fuzzy logic algorithm development involved an automatic adjustment (increases) of the lookout angle by 1.9° between 6:15 am and 9 am and by 3° between 9 am and 10 am (fig. 1-2). The adjustments were determined by the difference between four consecutive look angles at intervals of 15 minutes, then the difference was utilized to determine the hourly average change (increase). These average based adjustments resulted in more power harvesting for the algorithm. It is important to state that the fuzzy logic rules for the other seasons (autumn, winter and spring) should also be established and then be validated using an experimental setup.

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