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Condition Monitoring of Fixed and Dual Axis Tracker using Curve Fitting Technique

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Abstract

This paper deals with the condition monitoring of fixed and dual-axis tracking-based solar energy generation. Initially, the system has been developed with a software interface, and the power output of the single- and dual-axis solar trackers is monitored. From the power signatures, curve-fitting technique-based monitoring has been done. The characteristic equations from the current signatures have been extracted depending on the best-fit feature extracted from the analysis in the software domain. Depending on the extracted feature from the developed characteristic equation, an algorithm has been proposed for disintegrating the power outputs from the single and dual axis trackers in due course. Thereafter, a laboratory-based model has been built consisting of single and dual-axis trackers, and the data has been tracked at different intervals on two respective days to calculate the power outputs. The nature of the power output from the trackers has also been assessed using the same curve fitting technique, and it has been observed that the natures are exactly similar to those obtained from software simulation. Both the current signatures obtained from software and practical studies resemble a 5th-degree polynomial. However, the roots are slightly different in the case of practical study.

Keywords: Algorithm, Curve fitting, Feature extraction, Power estimation, Practical Validation, Single and dual axis solar tracker

INTRODUCTION

In the present scenario of population diversity associated with economic development, the problems of the energy crisis and global warming effects have been of immense concern in recent times. Hence, the reliance on renewable energy sources has increased day by day. Solar energy is one of the primary sources of clean, abundant, and inexhaustible energy. Thus, techniques for maximizing the power output of different types of solar trackers are increasing. Analysis has been seen to build a novel dual-axis solar tracking PV system utilizing feedback control theory to provide a robust power generation system with validation from practical data [1]. Proteus software-based single- and dual-axis sun trackers have been seen to be developed for maximum energy extraction from solar irradiation, wherein 2 light-dependent resistors (LDRs) and a motor have been used for single tracking and 4 LDRs and 2 motors have been used for dual-axis trackers [2]. Fuzzy logic controller-based single-axis tracker design and analysis have been seen incorporating LDRs [3]. A cost-effective two-axis solar tracker design and analysis have been seen using a single servomotor. [4]. 60% energy gain has been seen to be obtained from a dual-axis solar tracking system using four LDRs and two servomotors [5]. Sensor- and sensor-less dual solar trackers have been seen to be developed with 0.11% tracking error, where a 28.8%–43.6% increase in solar energy extraction has been seen [6]. A brief review has been seen for maximizing solar power with an improved modern design of solar collectors [7]. A PID controller-based two-axis solar tracker design has been seen for optimizing the power obtained from solar irradiation [8]. Tetrahedron geometry-based effective solar energy extraction has been seen to be done using 2-axis solar trackers [9]. Takagi-Sugeno-Fuzzy-Blended PID controller-based novel dual-axis solar tracker implementation has been seen to be accomplished for extracting maximum soar energy [10]. Microcontroller-based solar tracking has been seen based on solar maps [11]. Spectral responsivity of cells has been seen to be tested in two-axis trackers in vivid field conditions with a standard deviation of ±0.25% under clear sky conditions [12]. Horizontal and bi-axial solar tracking-based intelligent solar energy extraction has been seen, which is able to detect weather conditions and act accordingly to maximize power output with LoRaAS32TTL logic [13]. ESR-based PV panel capacitor condition monitoring has been successful [14]. Embedded web server-based MPPT tracking has been seen for intelligent battery monitoring of solar power lighting systems [15]. A MATLAB-based predictive controller study has been seen for maximizing the power output from the PV panels [16]. An intelligent solar tracker design has been seen to increase the output power of solar panels incorporating temperature, voltage, and current sensors [17]. An MPPT algorithm-based irradiance feedback controller has been seen to avoid converter oscillations and maximize power output [18]. Online health monitoring has been seen for PV panels to comply with the IEC 62446 standard using the wireless MPPT approach [19]. An IoT-based solar tracking system prototype using the STM32 microcontroller and the servo DS3218MG has been seen to maximize power output from PV-generating systems [20]. Solar trackers are mechanisms that adjust the orientation of solar panels to follow the sun's path throughout the day. These trackers can be categorized into different types based on their tracking capabilities. Dual-axis trackers are highlighted as one of the most efficient options. These trackers are designed to move solar panels in two directions: both horizontally (azimuth) and vertically (elevation). This allows them to accurately track the sun's movement in both dimensions. While dual-axis trackers are efficient, they can be more complex and require additional mechanisms. Dual-axis trackers are particularly suitable for locations where the sun's position changes significantly throughout the year due to different seasons. These trackers ensure precise alignment with the sun's changing path, maximizing energy capture. Single-axis trackers are another type of solar tracker. They only move solar panels in one direction, either horizontally (azimuth) or vertically (elevation). These trackers are often used in regions closer to the equator, where the sun's position remains relatively consistent throughout the year. The increase in energy efficiency achieved through solar trackers depends on multiple factors. The effectiveness of the tracking system itself plays a crucial role. Highly efficient trackers can more accurately follow the sun's movement, leading to greater energy capture. Weather conditions also influence the effectiveness of solar trackers. Clear and sunny weather is favorable for solar tracking systems, as they can accurately follow the sun's position. In such conditions, the increase in efficiency can be more pronounced. Numerous condition monitoring techniques have been seen for PV generating systems, but none of the analysis has dealt with the curve fitting technique for effective feature extraction and condition monitoring of solar-powered generating systems.

Thus, the motivation of this paper is to employ a curve fitting technique for the condition monitoring of the PV generating systems. Here, firstly, a single and dual-axis solar tracker have been built into the software interface, and the power outputs have been recorded. The results obtained have been obtained using the curve fitting technique, and the equations have been developed. Depending on the nature obtained, an algorithm has been built to show the characteristic nature of the power outputs from the single and dual axis trackers in due course. Thereafter, two models have been developed in the laboratory, and the power outputs from the same have been recorded. The nature has been seen in software applications to depict the nature of the responses. Both the natures obtained from software and experimentation have been seen to show more or less the same response.

CASE STUDY

A single- or dual-axis solar tracking model based on stepper motors has been built into the software interface, as shown in Figure 1.

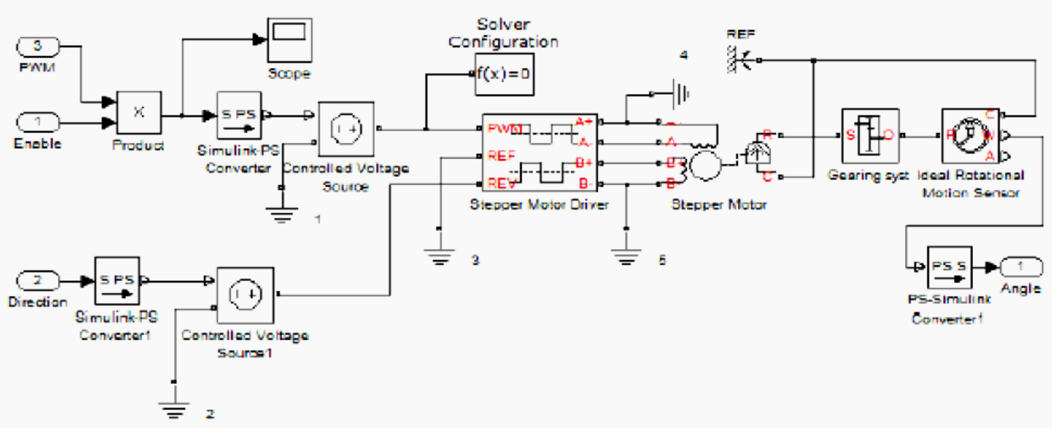

Figure 1. Stepper motor used in software interface

Based on the stepper model, a single- or dual-axis solar tracking system has been developed in simulation, as shown in Figure 2.

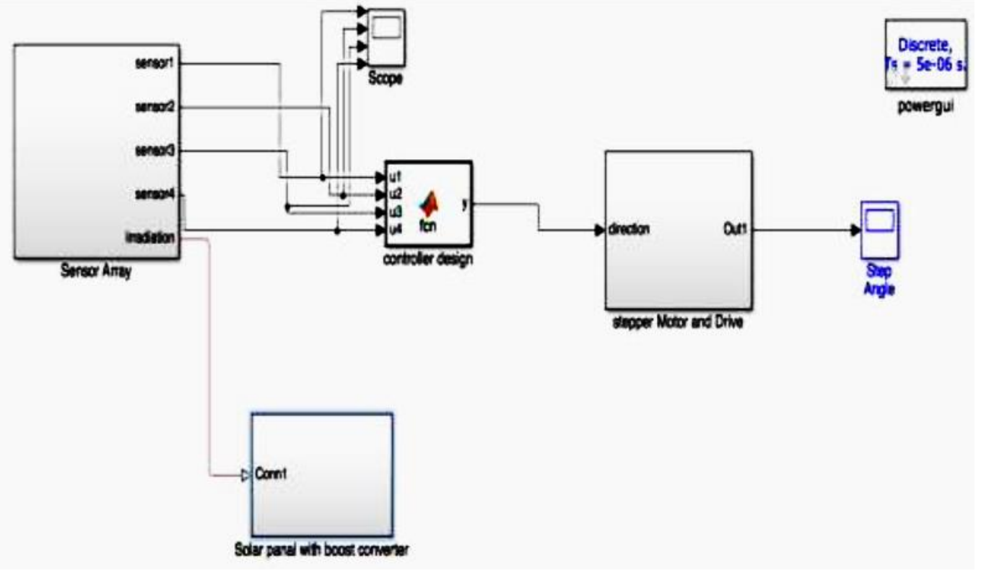

Figure 2. Solar tracker built in software interface

RESULTS AND ANALYSIS FROM SIMULATION

The voltage and current outputs from the PV panel have been provided in Figure 3. The nature has been seen to comply with the MPPT pattern.

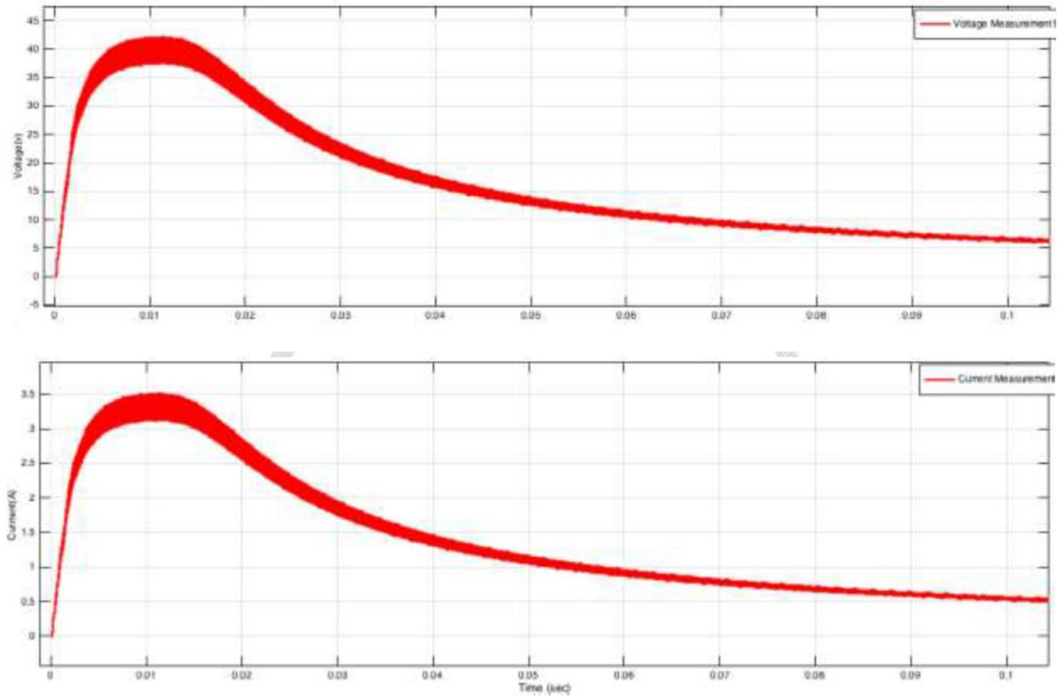

Figure 3. Voltage and current response obtained from solar tracker in simulation

The response obtained has been assessed using the curve fitting technique, and the analysis is provided in Table 1.

Table 1. Curve fitting technique-based estimation

Response	Equation	Remarks
PV panel voltage	$y = x^5 + 5x^4 + 5x^3 + 3x^2 - 6x - 1$	**5th degree polynomial equation**
PV panel current	$y = x^5 + 4x^4 + 3.5x^3 + 3x^2 - 5.12x - 1$	

Also, it has been observed that the power output degrades with decreasing solar irradiance in a smooth manner. Hence, if the nature of the responses can be monitored, powers can be well predicted from the solar trackers effectively. Thus, depending on the above analysis, as shown in Table 1, an algorithm has been proposed for estimating power from the panels.

Algorithm:

- Step 1: Acquire panel voltage and current.
- Step 2: Assess using the curve-fitting technique
- Step 3: Extract the feature as in Table 1.
- Step 4: Predict power output at a particular time.

PRACTICAL VALIDATION OF THE ANALYSIS

To authenticate the approach, a fixed and dual-axis tracker has been built in the laboratory, as shown in Figures 4 and 5. The equipment specifications have been provided in Table 2.

Table 2: Equipment specifications

Single axis solar tracker		Dual axis solar tracker	
Equipment	**Specifications**	**Equipment**	**Specifications**
Solar panel	Sova Solar, 10Wp, 17.71V, 0.6A	**Solar panel**	10Wp, 17.71V, 0.6A
Multi-meter	Metravi, 0-10A AC/DC, 0-600V, 50Hz	**LDR**	Lighting condition-100Ω, Dark condition-1024Ω, Dimension-5mm
Connecting wires	----------	**Arduino**	ATMEGA 328, i/p voltage-5V, i/p voltage recommended-7-12V, i/P voltage limitation 6-12V, digital i/opins-14, analog i/p pins-6, clock speed 16MHz, EEPROM-1KB
		Servomotor	MG995, 55gm, operating voltage-4.8-7.2V, servo plug- JR, stall torque- @4.8V-10kg-cm, stall torque@ 6.6V-12kg-cm
		Resistor	10kΩ, 1/4W
		Bread board and connecting wires	-------------------

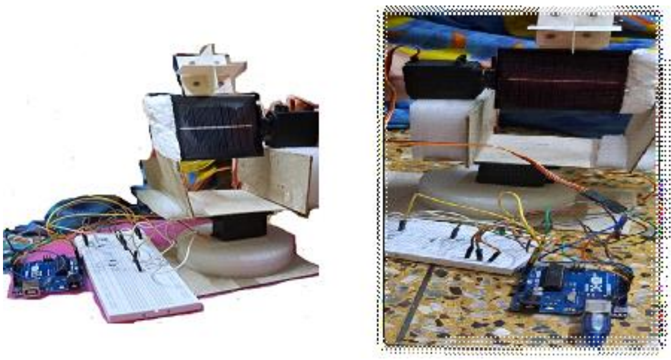

Figure 4. Single axis solar tracker

Figure 5. Dual axis solar tracker

The power outputs from the single and dual axis trackers have been measured on January 9 and 14, 2023, as presented in Tables 3–4.

Table 3. Single axis solar tracker power output

Sl. No.	Time	Voltage (in volts)	Current (in Ampere)	Power (in VA)
1	11:00 am	21.20	0.40	8.48
2	11:30 am	20.90	0.464	9.6976
3	12:00 pm	20.65	0.483	9.9739
4	12:30 pm	20.62	0.466	9.6089
5	01:00 pm	20.53	0.398	8.1709
6	01:30 pm	20.45	0.333	6.8098
7	02:00 pm	20.38	0.245	4.9931
8	02:30 pm	20.35	0.225	4.5787
9	03:00 pm	20.25	0.162	3.2805
10	03:30 pm	20.03	0.113	2.2634

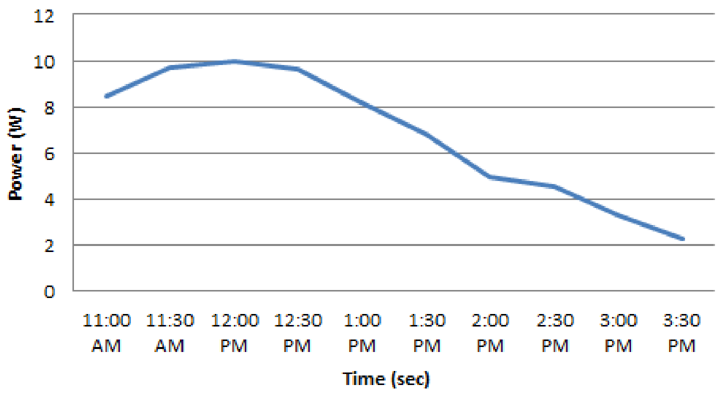

Figure 6. 5th degree polynomial response based on Table 3
($y = -0.0015x^5 + 0.0378x^4 - 0.3005x^3 + 0.5871x^2 + 1.0169x + 7.141$)

Monitoring the responses in Figures 6 and 7, it is clear that the practical responses are similar to those obtained from the simulation study. Thus, it can be inferred that, by using this technique, power prediction can be effectively done for single- and dual-axis tracker-based solar energy extraction in power systems. In addition to this, the energy obtained from fixed and dual-axis trackers has been compared, as depicted in Table 5.

Table 4. Dual axis solar tracker power output

Sl. No.	Time	Voltage (in volts)	Current (in Ampere)	Power (in VA)
1	11:00 am	21.2	0.40	8.48
2	11:30 am	21.03	0.483	10.157
3	12:00 pm	20.77	0.536	11.132
4	12:30 pm	20.65	0.550	11.357

5	01:00 pm	20.45	0.375	7.668
6	01:30 pm	20.75	0.364	7.553
7	02:00 pm	20.80	0.381	7.924
8	02:30 pm	20.75	0.330	6.847
9	03:00 pm	20.68	0.250	5.170
10	03:30 pm	20.45	0.170	3.476

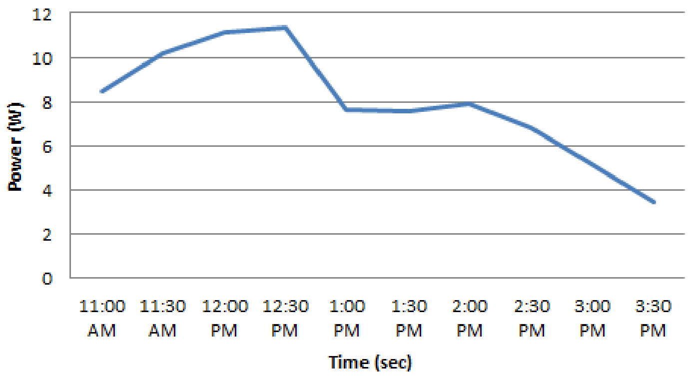

Figure 7. 5th degree polynomial response based on Table 4
$(y = -0.0004x^5 - 0.0036x^4 + 0.2255x^3 - 2.2865x^2 + 7.74x + 2.6351)$

Table 5. Comparison in energy extraction from fixed and dual axis trackers

Time	**Energy consumed (Wh)**		**Remarks**
	Dual axis solar tracker	**Single axis solar tracker**	
11:00 am	0.5029788	0.529783	*Dual axis tracker energy consumed response:* y = -3e-6x5 - 0.0009x4 + 0.0216x3 - 0.1839x2 + 0.5879x + 0.0681 *Single axis tracker energy consumed response:* y = -1 e-4x5 + 0.0024x4 - 0.0202x3 + 0.0478x2 + 0.0298x + 0.4718 *Conclusion:* 5th degree polynomial
11:30 am	0.634558575	0.605820075	
12:00 pm	0.6954717	0.6020091	
12:30 pm	0.709528575	0.6020091	
01:00 pm	0.4790583	0.51042075	
01:30 pm	0.471873675	0.42414277	
02:00 pm	0.4950519	0.31190767	
02:30 pm	0.427766325	0.2860105	
03:00 pm	0.32299575	0.204918	
03:30 pm	0.2171631	0.141380925	

CONCLUSION

Renewable energy conversion systems have been of immense use in recent days, concerning the chances of a possible future threat due to the depletion of coal and fossil fuels. In this regard, the present work has been advanced, wherein a curve-fitting technique-based energy prediction has been done for single and dual-axis solar trackers. Firstly, a model has been built into a software interface, and the power has been recorded. Depending on the nature of the response, a curve-fitting tool has been applied to extract features. Depending on the extracted feature, an algorithm has been proposed for effective energy prediction. Furthermore, a real model has been developed for single- and dual-axis trackers, wherein the responses obtained have been seen to more or less match those obtained from a software study. Thus, it can be concluded that the technique can be well used for energy prediction in solar power extraction systems.

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CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interests associated with this publication.

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