An Empirical Approach towards Solar Energy Harvesting Optimization

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Abstract--To achieve a sustainable future, one of the trends that have been observed to play a crucial role involves renewable energy. In this field, developments have progressed rapidly, with solar energy on particular focus. However, most of the solar energy has failed to fulfill its expected potential due to two main reasons. These reasons include obstacles in the form of efficiency and performance limitations. In this study, the central purpose was to steer improvements in solar panel performance. In particular, the objective of the study was to identify and optimize the affecting parameters. Therefore, a mechanical system was established for holding and controlling the photovoltaic field’s orientation and tilt. To measure and store the system’s performance information, the study relied on an electrical system, as well as a data acquisition system. To determine the impact of the target parameters on output optimization and the yield response, the investigation relied on the Response Surface Methodology and a design of experiments. From the results, the study established that from the horizon, a 600 tilt would attract an optimal result. Also, an optimal result was achieved when the panel condition was clean and that from the south, an azimuth angle was set at 450. Lastly, there was no significant effect posed by the wind factor in the target and specified parameter ranges.

1. Introduction

In developed regions such as the U.S., solar energy has gained increasing application in industries and domestic settings. The new generating capacity of this energy source has seen it surpass that of the coal and wind energy [1, 2]. However, insufficiency continues to be associated with the current state of photovoltaic (PV) panel operation. Imperative to note is that PV panel operations are shaped by various factors. Some of these factors include the PV panel status such as tilting and orientation, environmental factors such as wind and temperature, some of the improvements that are made to the PV panels and the material and manufacturing specifications that involve limiting the maximum theoretical efficiency [3-5].

Hence, several efforts have been made in relation to PV panel optimization. These efforts have targeted or focused on the aforementioned factors from economic and performance perspectives [6, 7]; having strived to steered improvements in panel performance [8], hence, future sustainability [9-12]. In this study, the central focus was on the PV panel status and environmental factors whereby the time or date played a crucial role in shaping PV panel performance, besides the designated location. Therefore, the main aim of the study was to determine some of the factors deemed significant in relation to PV panel improvement. Specific attributes that were investigated relative to the interaction of the target factors included the optimum settings and the range of these factors. Some of the dependent variables that were investigated to discern the extent to which they were likely to play a moderating role or have a predictive impact on PV panel performance included the level of deanliness, wind, azimuth (or orientation), and tilt.

2. Materials and Methods

The infrastructure that was used in the research context included materials such as the PV panel temperature sensor, wires, Ethernet cable, router, power injector, DC current inducer, and the eGauge, which translated into a data acquisition system. In relation to the optimization procedure, the study relied on a Response Surface Methodology (RSM). This technique was selected and deemed appropriate for...
utilization because of the study’s objective, which involved the establishment, refinement, and optimization of a system. Also, the RSM technique was utilized due to its capability to aid in new product design and creation while steering improvements on the existing systems [8, 9]. On the one hand, independent variables constituted the RSM inputs. On the other hand, the yield response constituted the RSM output. The yield response was, in turn, used to determine the selected system’s performance measure. It is also notable that a second-order model was used to determine the interactions and main effects between the selected factors under investigation. The second-order model was in the form:

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i<j}^{k} \beta_{ij} x_i x_j$$

The figure below illustrates the experimental setup of the study.

**Figure 1: An illustration of the experimental infrastructure and factor interactions in the setup**

It is also notable that response optimization was determined by using Minitab. This software aided in the generation of optimum settings through which factors were established and a level at which the yield response would be maximized determined. Regarding the two PV panels that were utilized, they were identical in nature. Whereas one of the panels was flat on the ground, the other was placed on a mechanical system’s dual axis. It is also notable that the study relied on identical rheostats loads applied to the electrical system. For the two PV panels’ initial output power and the potentiality of minor discrepancy, it was overcome through the application of a small calibration. To determine the flat PV panel’s state of irradiance, the process input was considered. To measure the parameter, the study relied
on an irradiance sensor that had been placed flat beside the panel. Lastly, interactions on the yield response and the level of significance of the selected factors were determined through ANOVA, which aided in calculating $P$ values.

3. Results and Discussion

A factor that was not accounted for in relation to the study’s optimization process was the changing position of the sun – as the experiment ran and data collected. For the specific results, the study established that when the PV pointed exactly or directly toward the sun, there was the optimum position for azimuth and tilt, hence continuous tracking of the sun. For the case of the experimental setting that involved fixed level settings, with the study taking some hours, it remains notable that the assumption that the sun had a fixed position was inaccurate.

Despite the limitation above, one of the study’s insightful findings was that when the time of the day changes, there is a change in the optimum point for the tilt angle. This effect was confirmed or demonstrated by conducting the experiment during two consecutive days. For the two days, around 12:28 PM was perceived to be the midday. The eventuality is that the experimental runs were conducted in two sessions, which involved the period before midday and the period after midday. Whereas 22 runs were conducted before midday, 59 runs occurred after midday. For each group, Minitab aided in the generation of the main effect plots. From the plots, it was evident that when the PV panel orientation was toward the east, the runs before midday achieved the maximum power differences. On the other hand, it was after the PV panel oriented toward the west that the period after midday achieved the maximum power differences. Overall, the results pointed to the criticality of sun tracking for PV panels’ outcome optimization.

4. Conclusion

In summary, this experimental study relied on the RSM methodology toward the planning, analyzing, and optimizing the experiments. In particular, the study targeted factors through which the PV panels’ [performance could be optimized. Also, the study aimed at determining the degree to which PV panel location shapes their performance. Other variables that were investigated included the date or time, as well as the PV panel location – in relation to their impact on panel performance. Indeed, objective of the study was to identify and optimize the affecting parameters. Therefore, a mechanical system was established for holding and controlling the photovoltaic field’s orientation and tilt. To measure and store the system’s performance information, the study relied on an electrical system, as well as a data acquisition system. To determine the impact of the target parameters on output optimization and the yield response, the investigation relied on the Response Surface Methodology and a design of experiments. From the results, the study established that from the horizon, a 60° tilt would attract an optimal result. Also, an optimal result was achieved when the panel condition was clean and that from the south, an azimuth angle was set at 45°. Lastly, there was no significant effect posed by the wind factor in the target and specified parameter ranges. As such, the study proved contributory to industrial settings in such a way that it increased the understanding of interactions among several parameters that shape the PV panel performance and how they could be adjusted to yield optimal performance, with the long-term effect of the latter beneficial outcome projected to accrue in the form of future sustainability.

5. References

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