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Study of Shading Photovoltaic Module and Fabrication of Solar Data Logger

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Abstract— Solar photovoltaic (PV) systems are essential for renewable energy production, yet their performance is greatly influenced by shading. The performance of photovoltaic (PV) modules is highly influenced by environmental conditions, with shading being one of the most critical factors causing significant power losses. To investigate this effect, nine different shading strategies were designed based on real-case scenarios commonly encountered in rooftop and field installations, such as partial obstruction by buildings, trees, and nearby structures. This research examines the influence of shading on photovoltaic systems through MATLAB/Simulink simulations and practical experiments. A solar data logger was created to track essential performance metrics, such as voltage, current, temperature, and irradiance. The research confirms the issue of power loss in PV modules due to shading, which results in decreased energy production and efficiency. The main objective is to investigate the impact of various shading strategies, assess their effect on the I-V and P-V characteristics of PV modules, and fabricate a solar data logger system. This system records and analyses real-time data to facilitate performance evaluation and predictive maintenance of PV modules. The findings indicate that shading significantly reduces the output of PV modules, with some shading patterns causing power losses of up to 100%. The hardware results closely match the simulation, confirming the accuracy of the analysis. Additionally, the fabricated solar data logger effectively captures essential PV parameters, providing a reliable tool for long-term system monitoring. This study highlights the impact of shading on PV modules and emphasizes the role of real-time data logging in performance evaluation and predictive maintenance.

Keywords — Photovoltaic, Shading Effect, MATLAB Simulation, Solar Data Logger, Renewable Energy

Introduction

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The demand of energy has been growing continuously all over the world as population rise and industrial activities continue to expand. At the same time, concerns over the fossil fuel depletion and environmental impact, conventional energy generation have increased. These challenges have stimulated a shift to renewable energy sources. Among those alternatives, solar photovoltaic (PV) technology was one of the most promising solutions. It is clean, accessible, and requires relatively very low maintenance once installed [6].

In spite of its advantages, the performance of PV technology is also influenced by external conditions, such as temperature of surroundings, amount of solar irradiance, dust accumulation on PV, and especially shading play a crucial role in determining the PV output. Shading is considered one of the most concerns in PV operation. Small shadow falling on PV module can cause a significant power to drop due to current mismatch between the series-connected cells. In most cases, partial shading helps to form hotspots that can cause permanent damage to the PV module [11].

It is important to conduct experimentations and simulations to understand the shading effects. Simulation tools such as MATLAB/Simulink can simulate PV cells in an equivalent electrical circuit layout and enable testing of different shading outcomes in a controlled environment. However, experimental validation is equally significant. Furthermore, continuous monitoring of PV systems is important for ensuring efficiency, performance and fault detection of PV module. Developed solar data logger system helps to measure & record real time data for solar irradiation, temperature, voltage, current and power of PV module. Analyze the logged data, provide information about the performance of the PV module.

This research mainly focused on two objectives. The first is to investigate the effects of different shading patterns on a 36-cell PV module through MATLAB/Simulink simulations and experimental setup. The second is to design and fabricate a solar data logger using locally available equipment's to record essential parameters PV module at regular time intervals. The findings from this study contribute to a better understanding of shading effects and demonstrate the significant of solar data logger system.

I. Methodology

T he methodology of this study consists of two main sections: (1) examination of the different shading strategies on a photovoltaic module. Both simulation and experimental techniques were used to validate the shading analysis of PV module. and (2) design and fabrication of a solar datalogger for real-time PV performance monitoring.

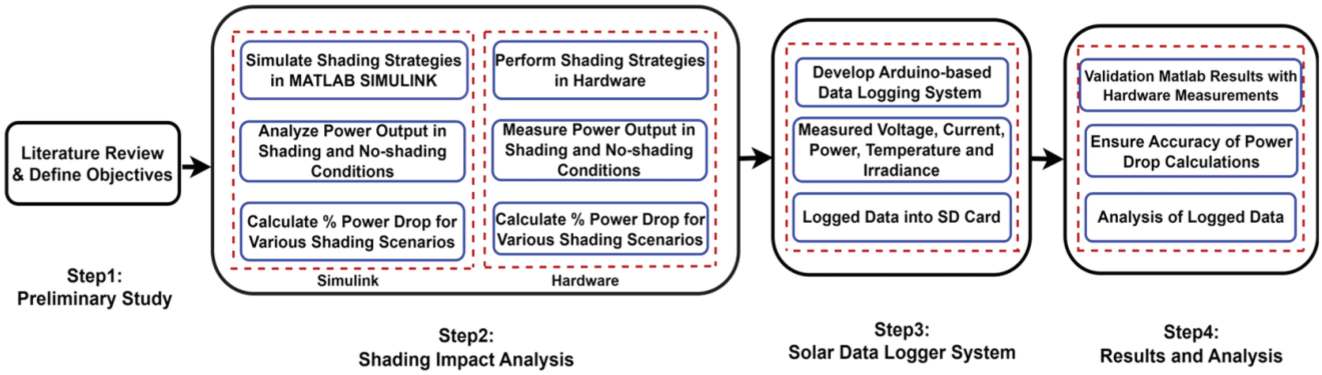

Fig. 1Overall Methodology Block Diagram

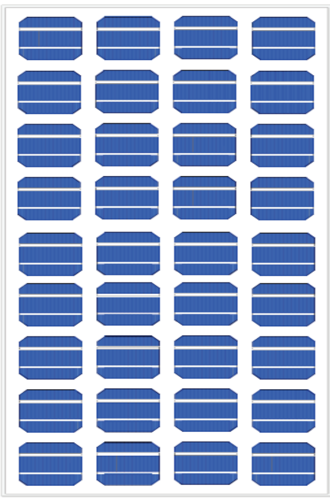
Fig. 2 Without Shading

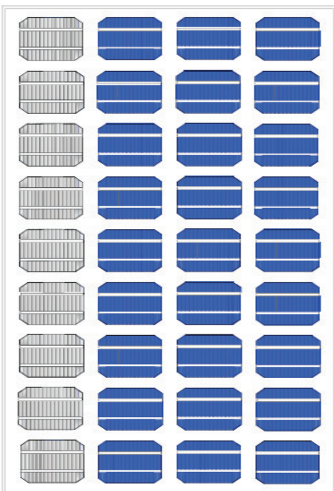
Fig. 3 Long Column Shading

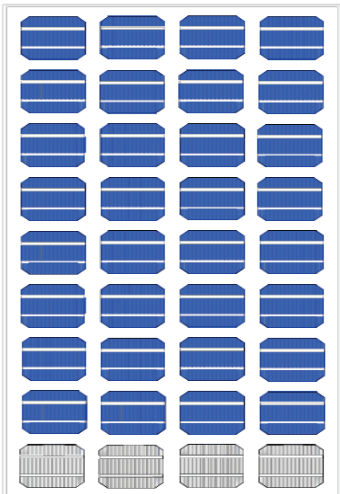
Fig. 4 Long Narrow Sahding

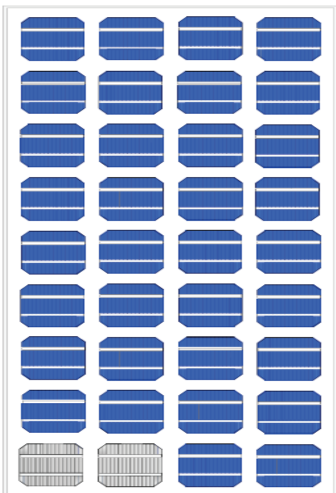
Fig. 5 Partial Narrow Shading

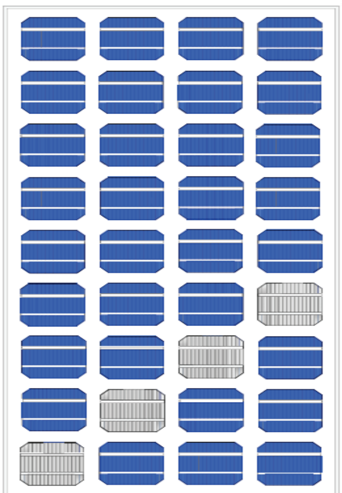
Fig. 6 Short Diagonal Shading

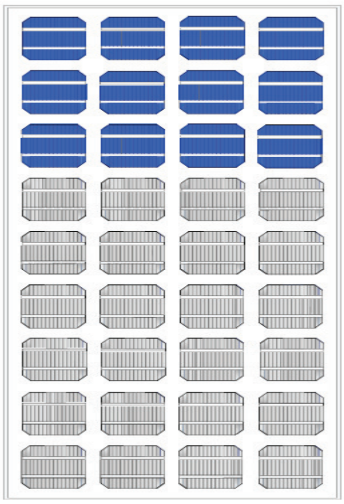
Fig. 7 Long Wide Sahding

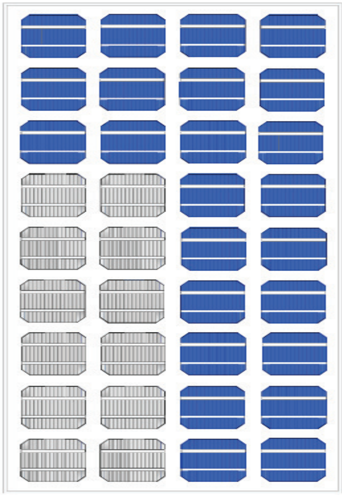

Fig. 8 Short Wide Shading

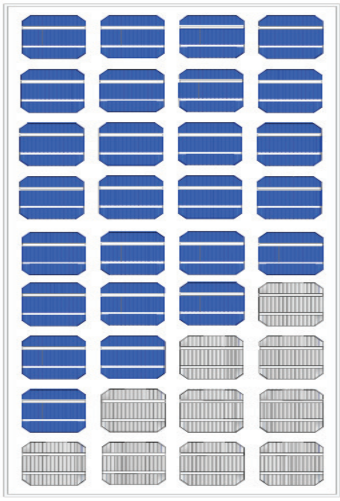

Fig. 9 Long Corner Shading

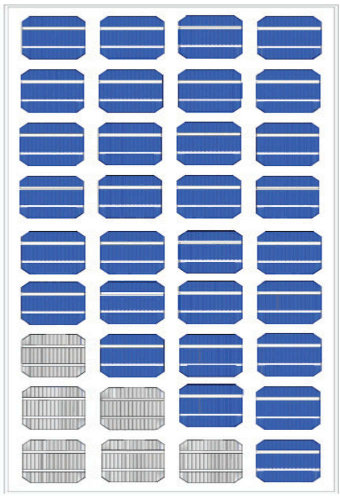

Fig. 10 Medium Corner Sahding

B. *Shading Strategy Analysis*

To examining the shading effect, a 60 W, 36-cell solar module was subjected to different shading conditions and different shading strategies were examined: short diagonal, long column, partial narrow, long narrow, long wide, long corner, medium corner, short wide, and short corner. Using opaque materials on the module surface, each shading pattern was applied in a structured manner to shelter the sunlight from selected areas of its surface. A solar analyser was used to measure the I-V and P-V characteristic curves under each of the shading conditions. The key parameters measured include short-circuit current (I_{sc}), maximum power point (Pmax), open-circuit voltage (Voc), current at maximum power and (Imp) voltage at maximum power (V_{mp}).

C. *Simulation Model in MATLAB/Simulink*

The same experimental shading strategies were done again using MATLAB/Simulink to model the PV module under similar conditions. The solar PV model was set up based on the standard diode equivalent model with parameters calculated from manufacturer specifications for the module. Under all scenarios for shading, irradiance was taken as zero in the shaded portion; meanwhile, the unshaded cells were maintained at standard irradiance according to the experimental findings. Such co-simulation approach ensured accurate validation of shading effects.

D. *Validation of Results*

The comparison of simulation and experiment results was carried out by analysing the percentage power drop (P_{drop}) for each shading condition. The deviation between the experimental results and the simulation results was calculated as follows:

$$\text{Deviation (\%)} = \frac{|P_{drop,sim} - P_{drop,exp}|}{P_{drop,sim}} \times 100\ \%$$

A deviation below 5% was considered acceptable, confirming the reliability of the MATLAB model in predicting real-world shading losses.

E. *Solar Data Logger Design and Fabrications*

A solar data logger system was designed to record the key parameters from the PV system in real-time. The data logger system was designed based on Arduino Uno microcontroller with the following sensors incorporated.

- Standard solar cell: for measuring solar irradiance calibrated such that 158 mV corresponds to 1000 W/m^2.
- ACS712-05B current sensor: for measuring output current.
- Voltage divider circuit: for de-scaling PV output voltage to the Arduino input range.
- DS18B20 temperature sensor: for recording PV surface temperature.
- SD card module: for data storage.

The solar data logger was programmed so as to record voltage, current, power, temperature, and irradiance every five-minute interval. The data were saved in a text file on the SD card for further analysis.

F. *Analysis of Recorded Data*

The fabricated solar data logger was connected in solar module, being connected with the PV modules and operating outdoor under real conditions. Data were recorded from 7:00 AM in the morning to 17:00 PM in the evening. The dataset acquired included parameters such as irradiance, module voltage, current, output power, and temperature, which were plotted later for the analysis of module performances.

II. Results

Different nine shading strategies were applied on a 36-cell PV module to investigate their impact on electrical performance. Both hardware measurements and MATLAB simulations were carried out.

A. Shading Impact Analysis from Experimental Setup

The I-V curve and P-V curve for an operating temperature of 26 ° C under different shading patterns of irradiation levels (0 W/m2) and without shading irradiation of (943 W/m2) are illustrated in the following subsection.

Table I

Graph Scaling for Different Shading Strategies

S.N.	Shading Strategies	Current(Y-axis)	Power(Y-axis)	Voltage(X-axis)
1	Without	1box = 1A	1box = 10W	1box = 3.60V
2	Long Column	1box = 1.8A	1box = 4.76W	1box = 1.7V
3	Long Narrow	1box = 16mA	1box = 114mW	1box = 5V
4	Partial Narrow & Short Wide	1box = 1.86A	1box = 4.6W	1box = 1.73V
5	Short Diagonal	1box = 15.24mA	1box = 192mW	1box = 10.57V
6	Long Wide	1box = 18.9mA	1box = 0.30W	1box = 7.9V
7	Long Corner	1box = 53.84mA	1box = 69.7mW	1box = 1.35V
8	Medium Corner	1box = 30.41mA	1box = 133mW	1box = 4.13V
9	Short Corner	1box = 1.76A	1box = 5.16W	1box = 1.65V

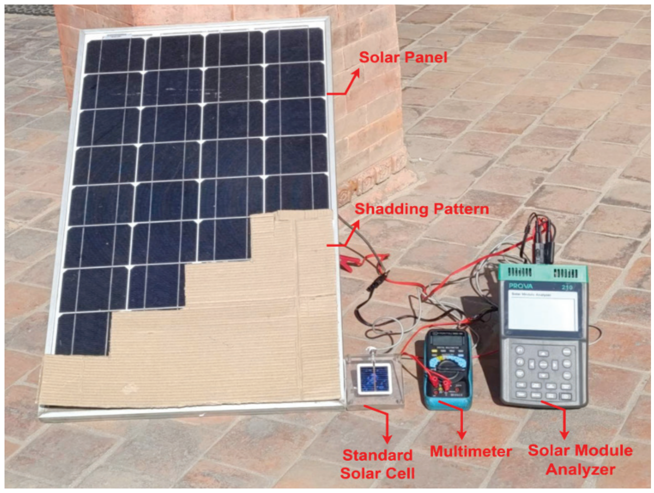

Fig. 11 Experimental Setup of shading Strategies Analysis

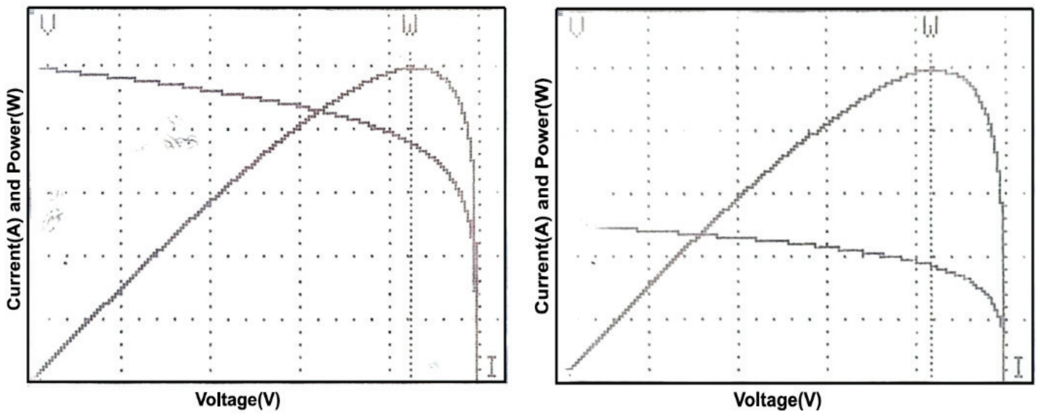

Fig.12 Experimental PV and IV Curve of Without Shading and Long Column Shading

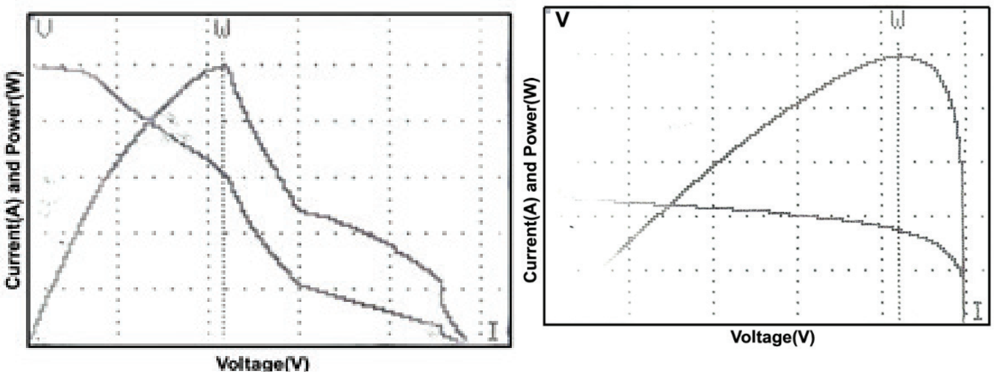

Fig.13 Experimental PV and IV Curve of Long Narrow Shading and Partial Narrow Shading

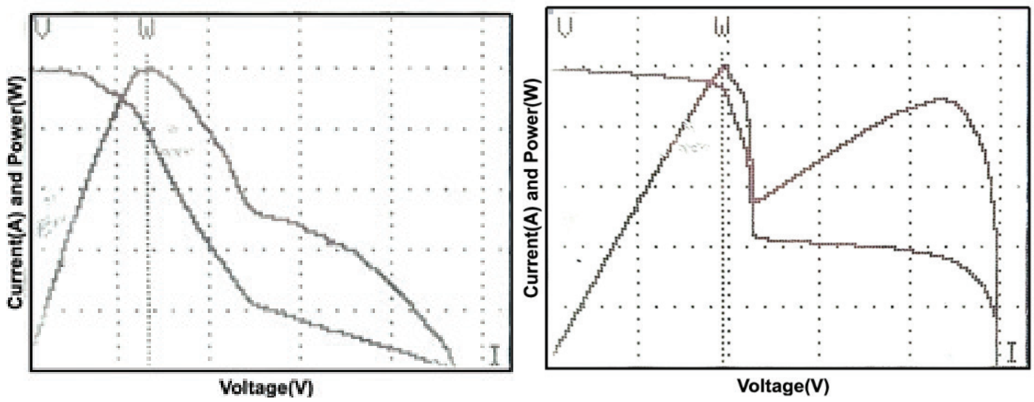

Fig.14 Experimental PV and IV Curve of Short Diagonal Shading and Short Wide Shading

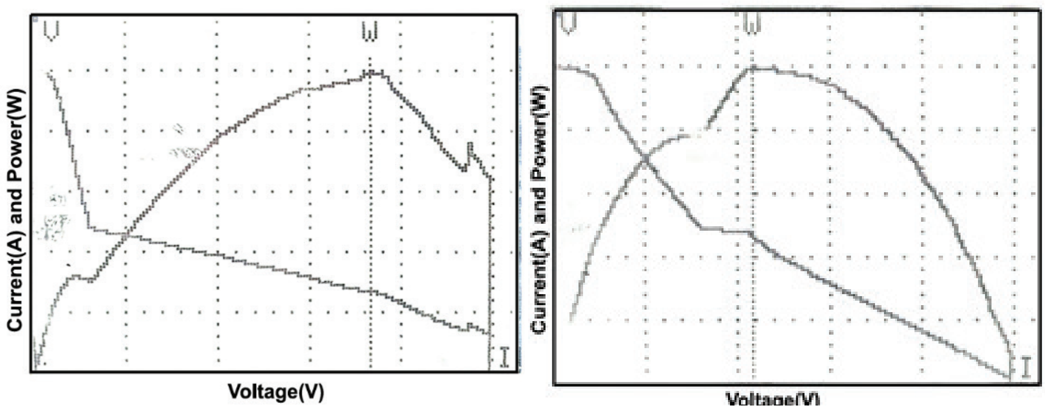

Fig.15 Experimental PV and IV Curve of Long Corner Shading and Medium Corner Shading

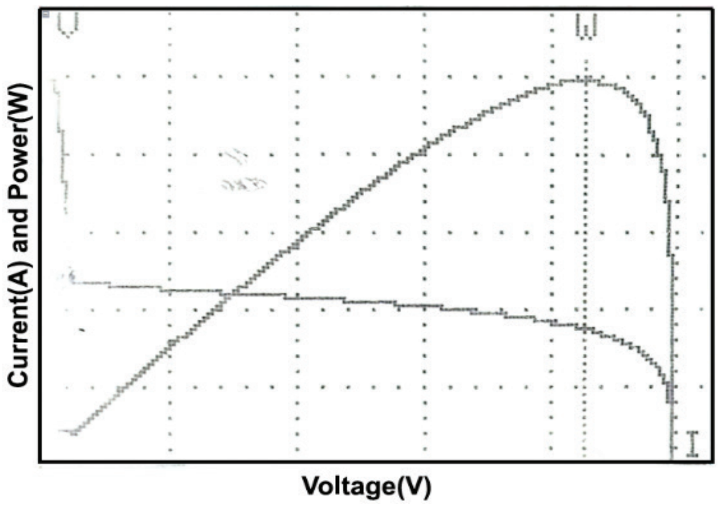

Fig.16 Experimental PV and IV Curve of Short Corner Shading

Table II

Effect of Shading Strategies on PV System Performance

S.N.	Shading Strategies	Without Shading			Without Shading			P_{drop}(%)
		P_{max} (W)	V_{mp} (V)	I_{mp} (A)	P_{max} (W)	V_{mp} (V)	I_{mp} (A)	
1	Long Column	53.35	15.21	3.50	23.81	6.93	3.44	55.37
2	Long Narrow	53.35	15.21	3.50	0.537	11.87	0.04	98.92
3	Partial Narrow	53.35	15.21	3.50	23.25	6.93	3.35	56.41
4	Short Diagonal	53.35	15.21	3.50	0.962	15.86	0.06	98.19
5	Long Wide	53.35	15.21	3.50	1.515	16.15	0.09	97.16
6	Short Wide	53.35	15.21	3.50	22.64	6.96	3.25	57.56
7	Long Corner	53.35	15.21	3.50	0.348	5.01	0.07	99.34
8	Medium Corner	53.35	15.21	3.50	0.665	9.09	0.07	98.75
9	Short Corner	53.35	15.21	3.50	23.83	7.11	3.35	55.33

A. *Shading Impact Analysis Using SIMULINK*

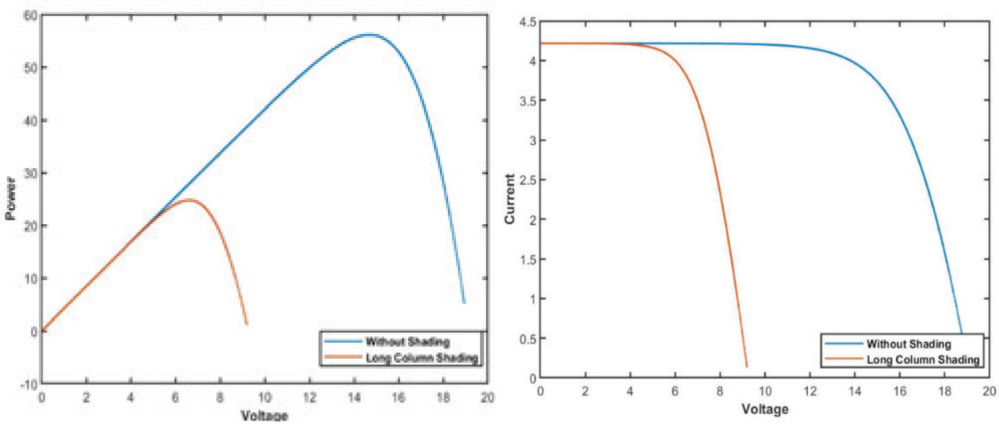

Fig. 17 P-V& IV Characteristic Curve of Without Shading & Long Column Shading

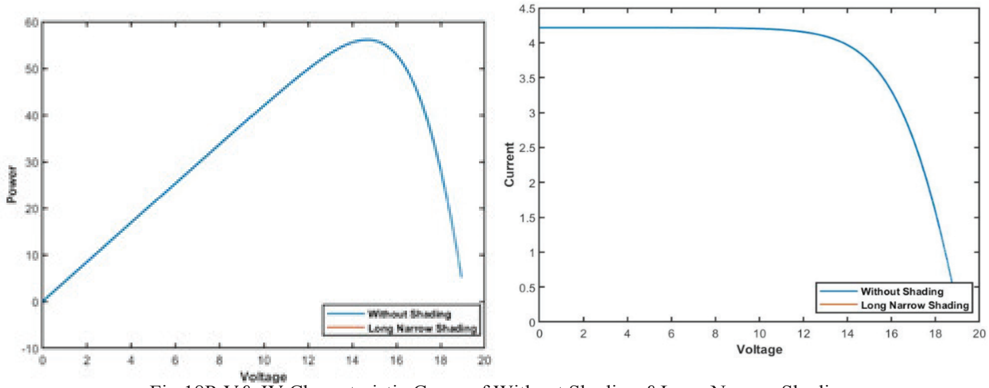

Fig.18P-V& IV Characteristic Curve of Without Shading &Long Narrow Shading

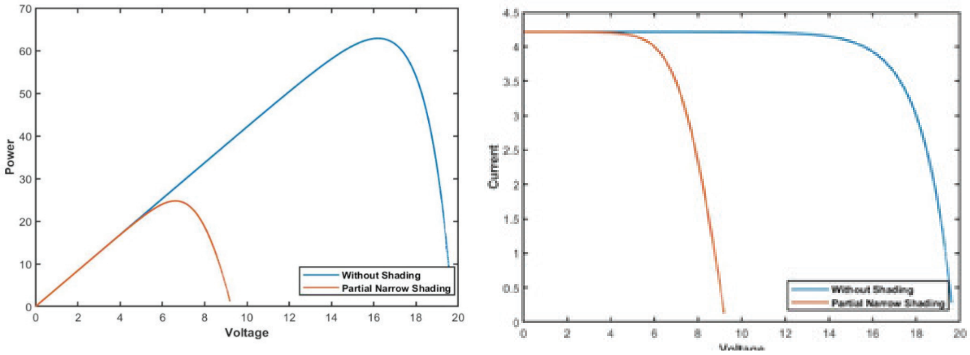

Fig.19 P-V& IV Characteristic Curve of Without Shading &Partial Narrow Shading

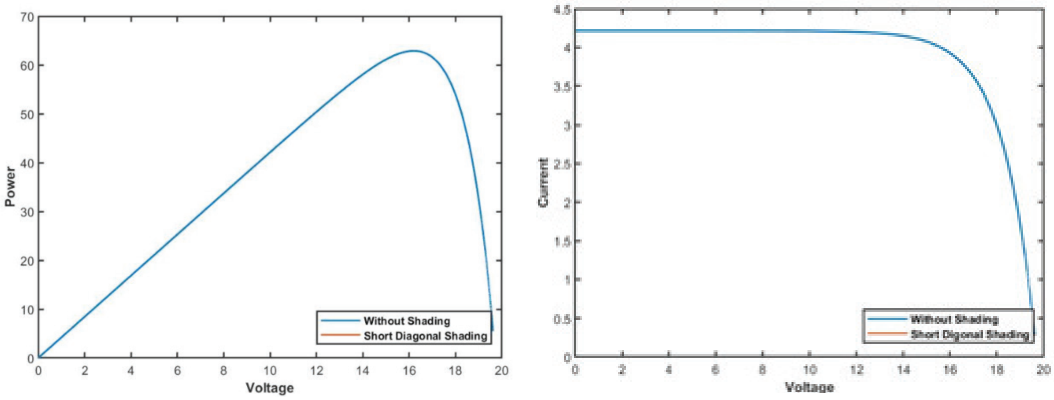

Fig.20 P-V& IV Characteristic Curve of Without Shading &Short Diagonal Shading

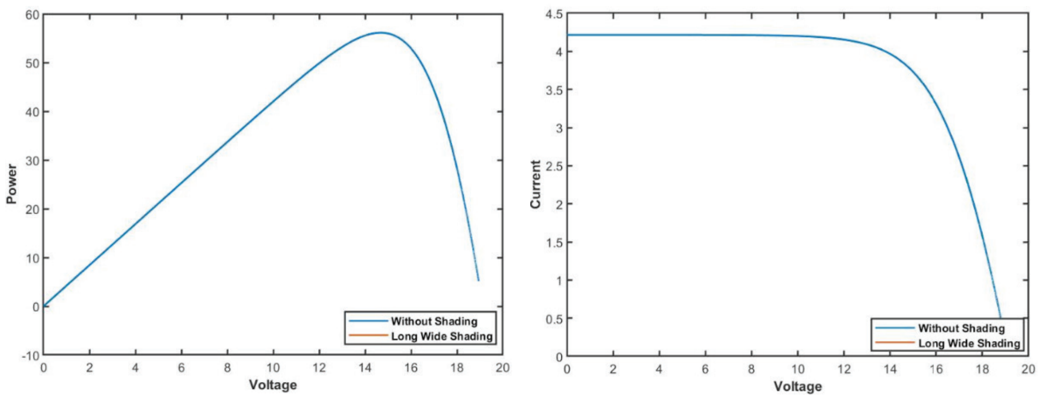

Fig.21 P-V& IV Characteristic Curve of Without Shading &Long Wide Shading

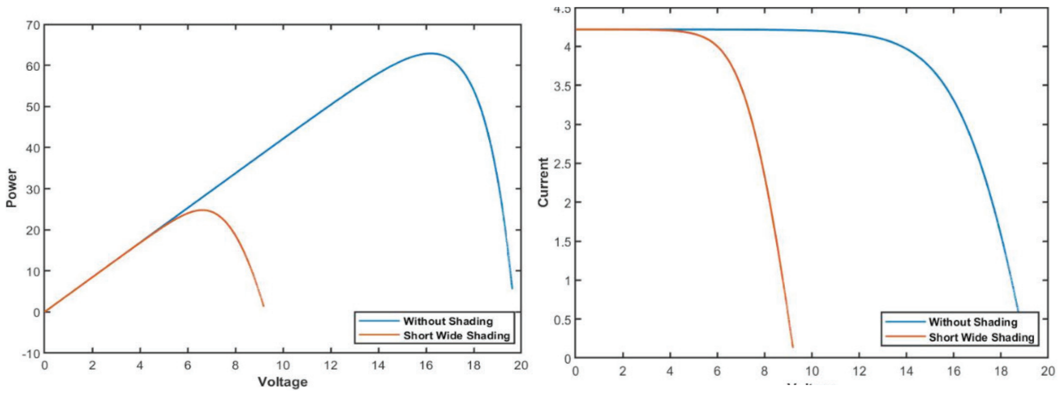

Fig.22 P-V& IV Characteristic Curve of Without Shading &Short Wide Shading

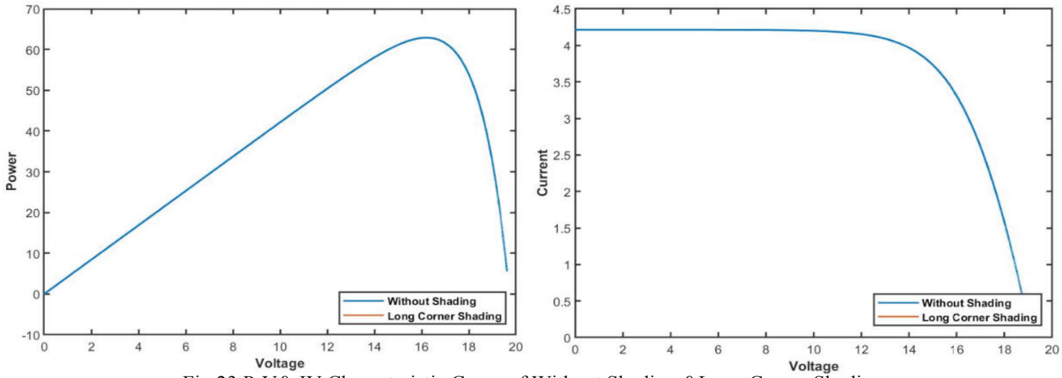

Fig.23 P-V& IV Characteristic Curve of Without Shading &Long Corner Shading

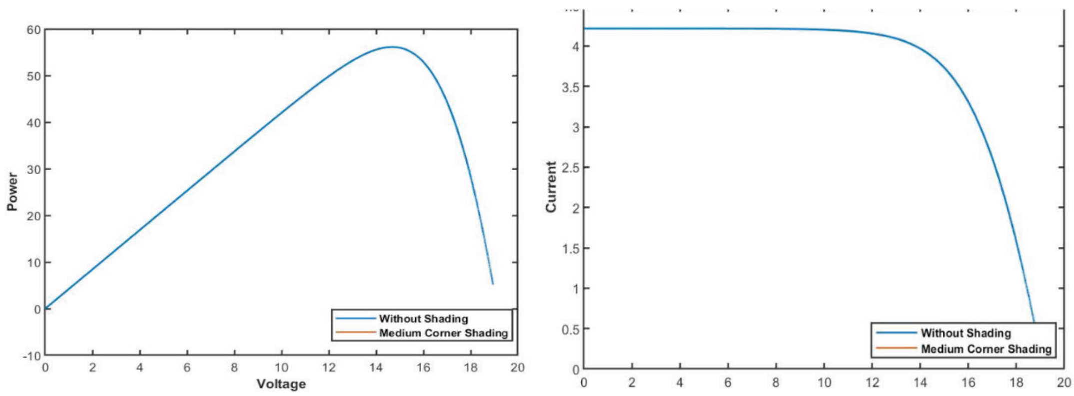

Fig.24 P-V& IV Characteristic Curve of Without Shading &Medium Corner Shading

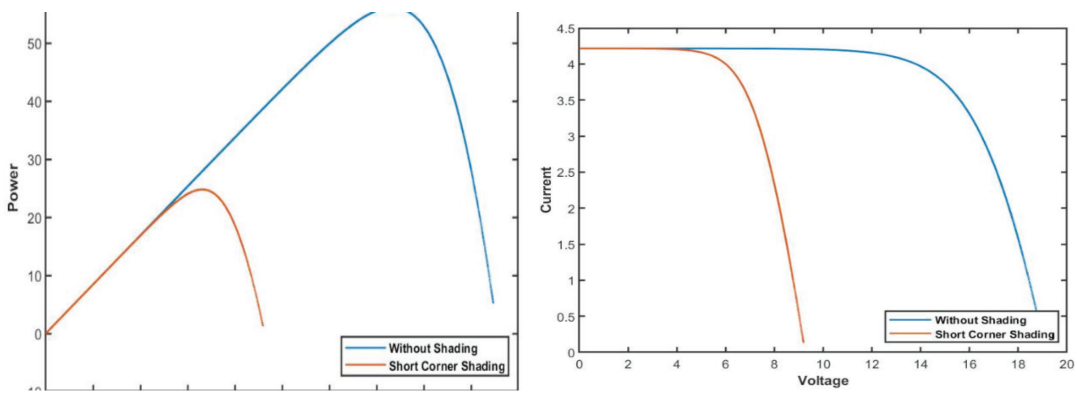

Fig.25 P-V& IV Characteristic Curve of Without Shading &Short Corner Shading

TABLE III

Effect of Shading Strategies on PV System Performance

S.N.	Shading Strategies	Without Shading			Without Shading			P_{drop}(%)
		P_{max} (W)	V_{mp} (V)	I_{mp} (A)	P_{max} (W)	V_{mp} (V)	I_{mp} (A)	
1	Long Column	56.11	14.60	3.84	24.77	6.64	3.73	55.85
2	Long Narrow	56.11	14.60	3.84	0.00	0.00	0.00	100
3	Partial Narrow	56.11	14.60	3.84	24.77	6.64	3.73	55.85
4	Short Diagonal	56.11	14.60	3.84	0.00	0.00	0.00	100
5	Long Wide	56.11	14.60	3.84	0.00	0.00	0.00	100
6	Short Wide	56.11	14.60	3.84	24.77	6.64	3.73	55.85
7	Long Corner	56.11	14.60	3.84	0.00	0.00	0.00	100
8	Medium Corner	56.11	14.60	3.84	0.00	0.00	0.00	100
9	Short Corner	56.11	14.60	3.84	24.77	6.64	3.73	55.85

B. *Comparison of Experimental and Simulation Results*

The experimental and simulation results were compared, and deviations were below 2% for most shading strategies, confirming the accuracy of the MATLAB/Simulink model.

TABLE IV

Validation of Shading Strategies By Comparison of Percentage Power Drop

S.N.	Shading Strategies	Experimental P_{drop}(%)	Simulated P_{drop}(%)	Deviation (%)
1	Long Column	55.37	55.85	0.48
2	Long Narrow	98.92	100	1.08
3	Partial Narrow	56.41	55.85	0.56
4	Short Diagonal	98.19	100	1.81
5	Long Wide	97.16	100	2.84
6	Short Wide	57.56	55.85	1.71
7	Long Corner	99.34	100	0.66
8	Medium Corner	98.75	100	1.25
9	Short Corner	55.33	55.85	0.52

C. *Data Logger Performance*

The Arduino-based solar data logger successfully measured voltage, current, power, temperature, and irradiance in real-time. Data was recorded every five minutes throughout the day. Experimental setup of data logger is shown below.

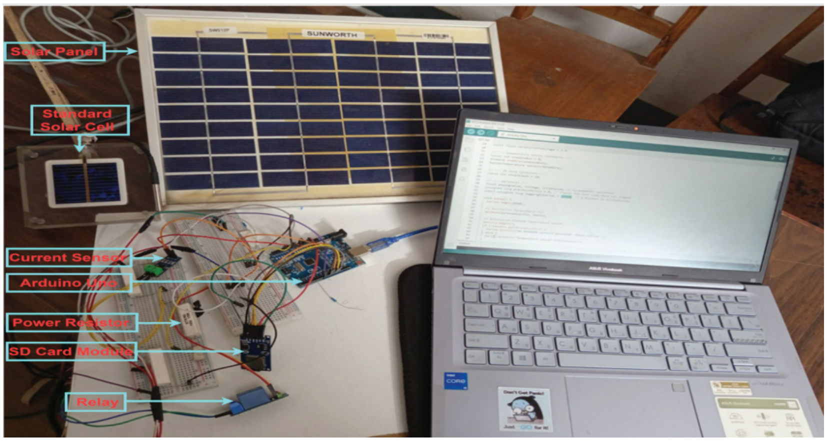

Fig.26 Experimental Setup of Data Logger System

TABLE V

Collected Data From the Fabricated Solar Data Logger

SN	Time	Voltage (V)	Current (A)	Power (W)	Temp (°C)	Irradiance (W/m^2)
1	07:00PM	7.21	0.198	1.43	8.68	278.41
2	08:00PM	9.16	0.277	2.54	22.62	402.14
3	09:00PM	12.70	0.436	5.53	33.68	592.75
4	10:00PM	14.75	0.489	7.21	31.50	680.55
5	11:00PM	15.66	0.515	8.06	38.43	804.29
6	12:00AM	15.26	0.489	7.46	37.43	742.42
7	01:00AM	15.01	0.436	6.54	36.43	711.48
8	02:00AM	15.08	0.383	5.77	32.25	680.55
9	03:00AM	15.01	0.357	4.05	33.87	600.55
10	04:00AM	12.48	0.172	2.14	33.06	523.45
11	05:00AM	2.05	0.256	0.41	23.18	216.54

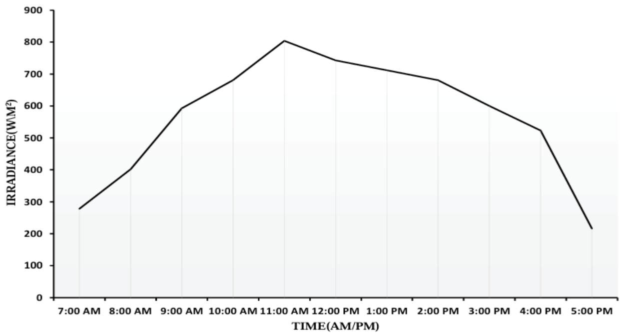

Fig.27 Graph of Irradiance with Change in Time

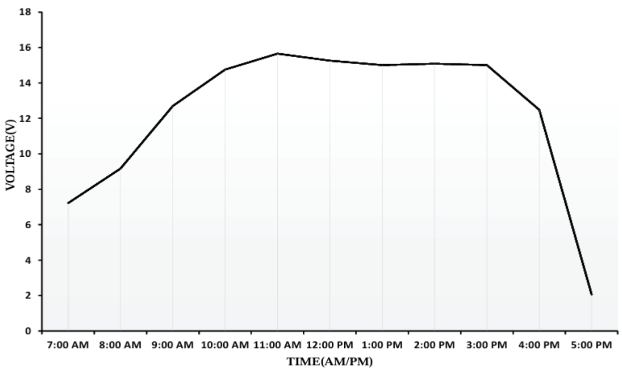

Fig.28 Graph of Voltage with Change in Time

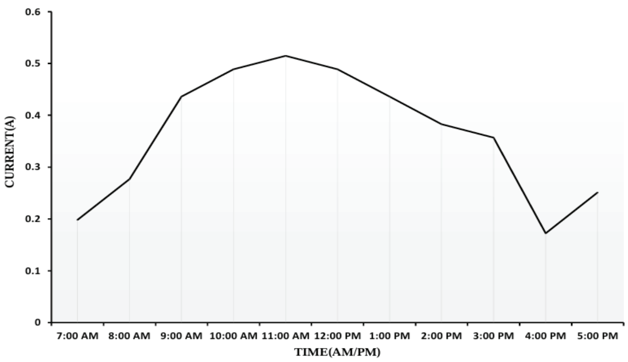

Fig.29 Graph of Current with Change in Time

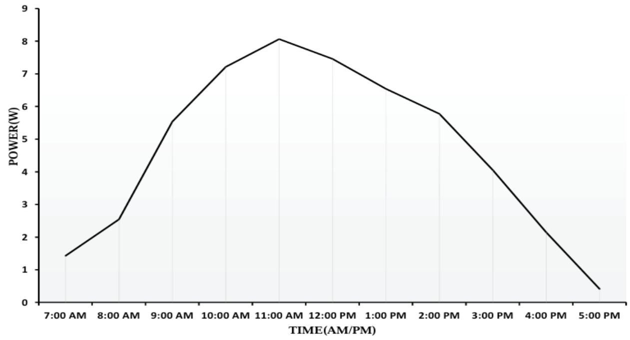

Fig.30 Graph of Power with Change in Time

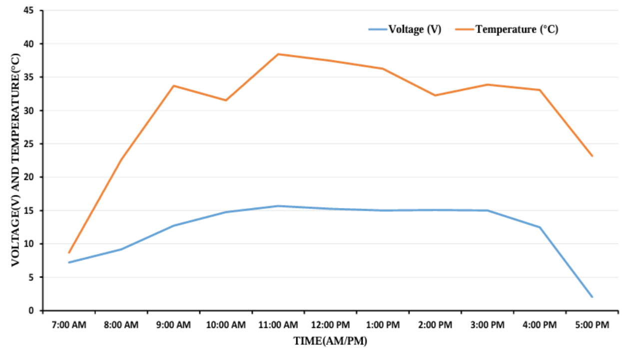

Fig.31 Graph of Voltage & Temperature with Change in Time

Discussion

This work mainly focused on analysing the shading effect of PV panel as well as designing and fabricating of solar data logger system monitoring real-time performance of PV panels. Project was performed to make different shading strategies, validating shading effects through simulation and hardware testing, and fabricating a solar data logger for data collection and analysis. To assess how different shading systems affect PV module performance, several shading patterns have been designed-namely, long column, long narrow, short narrow, short corner, medium corner, long corner, short wide, long wide. These different patterns of shading were applied to a 36-cell PV panel, and real-time data were collected from a solar analyser. To validate this real-time data, the co-simulation approach was used with MATLAB/Simulink to replicate the same shading patterns in simulation. The results obtained in the hardware testing were then compared with the MATLAB results to ensure that the analysis of different shading was done accurately. The validation process showed a significant reduction in power output due to shading. It was observed that shading a single column or corner had a moderate impact on power generation, while full coverage shading scenarios (such as long wide shading) resulted in a nearly complete power loss. From the above results we confirmed the importance of bypass diode in PV modules to mitigate power losses. A solar data logging system was design and developed to allow for real-time monitoring of photovoltaic (PV) system parameters. The data logger, made with Arduino Uno, an ACS712-05B current sensor, a DS18B20 temperature sensor, a standard solar cell, and an SD card module, was utilized to collect data in 5 minutes interval and recording parameters such as voltage, current, power output, temperature, and irradiance for an entire day. The collected data was used to analyse the power output of PV modules throughout the day. This study demonstrated different shading strategies, validated results through hardware testing and MATLAB simulation, and developed a solar data logger for real-time monitoring of solar panels parameters. The data analysis confirmed power variation throughout the day and highlighted the need for efficient PV monitoring and maintenance.

III. Conclusions

Following conclusions have been drawn from the study:

- The study successfully validated different shading strategies by comparing hardware experimental results with MATLAB simulations, ensuring accuracy in analysing shading effects on PV performance.
- The comparison between hardware and software simulation results showed minimum deviation confirming the reliability of the MATLAB model in predicting power losses due to shading.
- A solar data logger system was designed and fabricated to collect real-time data, providing insights in power generation variations alongside temperature and irradiance changes.
- The analysis of logged data for a whole day revealed significant fluctuations in power output due to environmental factors, showing the need for continuous monitoring for optimal PV performance.

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