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The Efficiency of MPPT in Mitigating the Effects of Partial Shading on Power Stability through the MPNO Method

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A B S T R A C T

An electric vehicle charging station (EV charging station) is an infrastructure designed to charge electricity for electric vehicles. However, most EV charging stations still rely on fossil energy sources. Innovation is needed to overcome this problem. One of them is through the use of solar panels. Using solar panels on the CBMS turns it into a clean and environmentally friendly energy source. However, environmental factors such as weather significantly affect the energy conversion produced by solar panels. Panels that are covered by trees and tall buildings cause partial shading conditions. Partial shading conditions can result in a direct decrease in PV output power. To overcome this, output power optimization using a DC-DC converter is required. The MPPT boost converter system with a modified Perturb and Observe (P&O) method is designed to maximize the output power of solar panels when partial shading occurs. The test results show that the developed system can maximize the output power of solar panels in partial shading conditions with an average power increase of 8.13 and an efficiency of 91%. This method can reduce the negative impact of changes in light intensity, keep the system close to the maximum power point, and improve the efficiency of charging electric vehicles at SPKL during unstable weather conditions. However, the modified P&O method is less effective in maximizing the output power in standard solar panels. This research does not address the effectiveness of solar panels concerning temperature, humidity, and dust.

INTRODUCTION

The demand for electricity increases every year as the need increases. The continuous use of fossil energy can cause fossil energy reserves to deplete, and exhaust emissions from burning fossil fuels trigger environmental pollution and global warming. The compounds in exhaust emissions are carbon monoxide (CO) and carbon dioxide (CO_2). Therefore, transitioning from fossil energy to new renewable energy sources is vital. [1], [2]. The World Health Organization (WHO) has drawn attention to the effects of air pollution worldwide, which has aided in the expansion of environmentally friendly and emission-free transportation options like electric cars (EVs) [3]–[5] .

Electric vehicles require electric energy charging stations just like public fuel stations for conventional cars. However, most energy sources for EV charging stations are fossil fuels, potentially contributing to the greenhouse gas effect. [6], [7]. Conversely, EVs have disadvantages like pricey batteries, short lifespans, a lack of dependability, a small driving range, and lengthy charging times. [8], [9]

Renewable energy sources (RESs) like biomass, solar, and wind power are becoming progressively more popular when integrated with EV charging infrastructures. Benefits of PV solar-powered EV charging include lower fuel costs, more straightforward installation, reduced pressure on the power grid, and financial savings [10]–[13].

A monitoring system based on solar panels was created in earlier studies that evaluated the energy efficiency of electric vehicle charging stations. In addition to measuring weather conditions like temperature, humidity, and sunshine intensity on the solar panels, this system can also monitor the voltage and current coming from the panels, the voltage and current flowing to the battery, and the current during the charging process [14], [15]. However, this research indicates no special processing for partially covered solar panels if trees, buildings, or other objects cover them. Even so, manually changing the electric vehicle charging system's design is possible. Nevertheless, this is regarded as less successful because it will take much time and work.

A partial shading condition refers to a solar panel's surface partially covered by shading. This is due to environmental factors

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such as trees, towering buildings, clouds, and weather fluctuations [16]. According to the PV curve, partial shade situations might directly decrease PV output power[10]. To address this issue, output power must be optimized utilizing a DC-DC converter with MPPT control [17]–[20]. Given this issue, this study will develop a system for optimizing PV output power during partial shade situations at a solar panel-based electric vehicle charging station using a DC boost converter and the Modified Perturb and Observe (P&O) method [21]–[23].

The objective of this research is to clarify the design and construction of a boost converter connected to a solar panel to produce optimal output power from the PV to the battery, to determine the power generated by the PV under partial shading conditions using the modified P&O method, and to develop an automated system that can integrate with a relay to perform the switching process from MPPT to the boost converter during partial shading conditions. Carrying out this research as planned hopes to provide solutions to address the impact of partial shading on the output power of solar panels, contribute to reducing reliance on fossil fuel sources, and promote environmental sustainability while strengthening the infrastructure for electric vehicles.

METHODS

This research is a vast collaborative project that begins with identifying difficulties and generating ideas for using solar power as an alternative energy source. It is followed by a literature review focussing on constructing boost converters using the modified P&O approach. After developing and installing the components, the researchers tested and repaired the converter to guarantee it worked adequately. Hardware planning and production refer to the system block diagram, which will be used as follows.

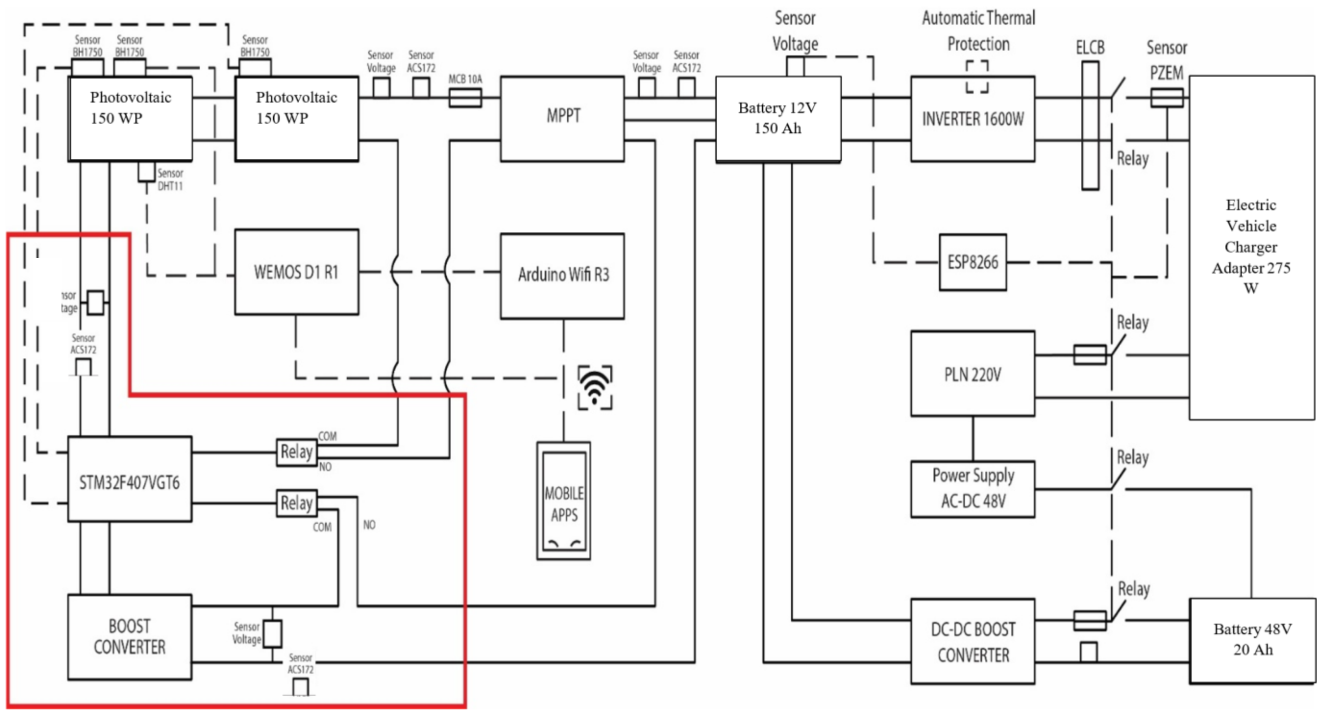

Figure 1. Schematic of Solar PV-Powered EV Charging Station

Figure 1 depicts the overall system block diagram. This general block diagram describes the processes and components added to the SPKL system for partial shading conditions using solar panels. The block diagram above shows distinctions between the system under consideration in this study and the EV charging station system, which is essentially connected.

The solar-powered EV charging station was constructed on the site of Jakarta Global University's main campus, Indonesia, at a Latitude of -6.4184713° E, a longitude of 106.82798° N. Design of electric vehicle charging station equipment created by previous researchers. as given in figure 2.

Figure 2. Solar PV-Powered EV Charging Station at the Jakarta Global University

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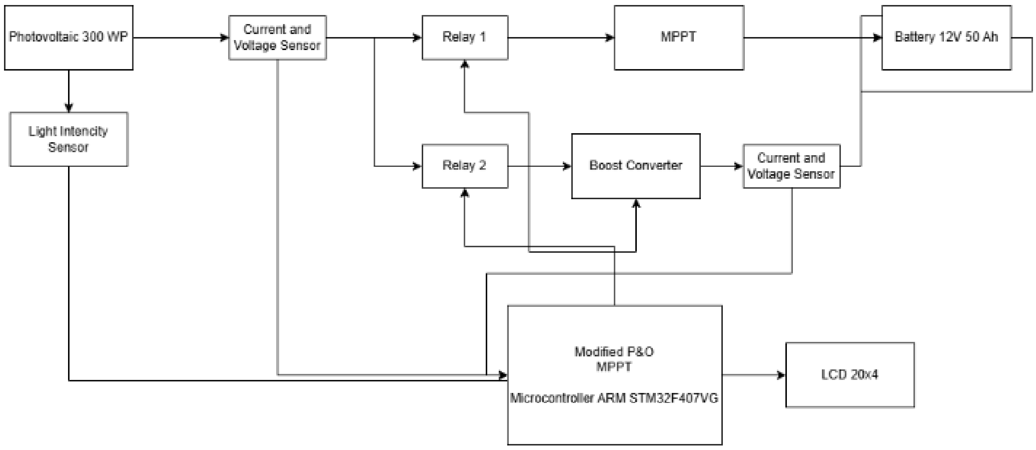

Figure 3. Solar PV-Powered EV Charging Station Partial Shading Condition Schematic

The instrument employed in this research was designed to demonstrate how solar cells can maximize output energy at charging stations for electric vehicles. The system's overarching idea is: The system consists of 2 solar panel modules, each with a capacity of 150-watt peak. These solar panels transform energy into electrical power. A relay acts as a switching system When the PV is normal and changes to a partial shading condition. The voltage sensor and ACS712 sensor monitor the boost converter's output and measure the voltage and output current from the solar cell. The STM32F407VG microcontroller uses the voltage sensor and ACS712 sensor, which are situated on the input side of the converter from the solar panel output, for sensing purposes as part of the MPPT control. The current and voltage on the output side of the converter will be observed using the ACS712 sensor and voltage sensor on the side linked to the battery. The microcontroller continually adjusts the duty cycle to attain the highest PV output power using a modified P&O approach that uses voltage and ACS712 sensors' sensing. Using this maximum PV output power as the input, a 12 V 50 Ah battery is charged using the boost converter.

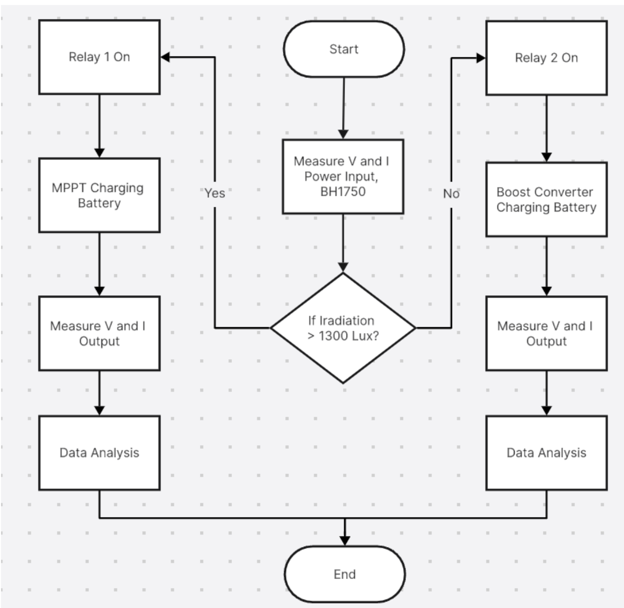

Figure 4. Diagram Illustrating The Operation System

Figure 4 depicts a flowchart of the process sequence for the planned system that will operate. According to the aforementioned operating principle, when this system is turned on or started, two solar panels with a capacity of 150 Wp each will absorb solar energy and convert it into electrical energy. The voltage sensor will then read the input from the solar panel. The A712 and BH1750 sensors provide readings for irradiance parameters, indicating whether the irradiance value matches the set point or is in a normal state as determined. The system will direct to relays 1 and 2 in the off position.

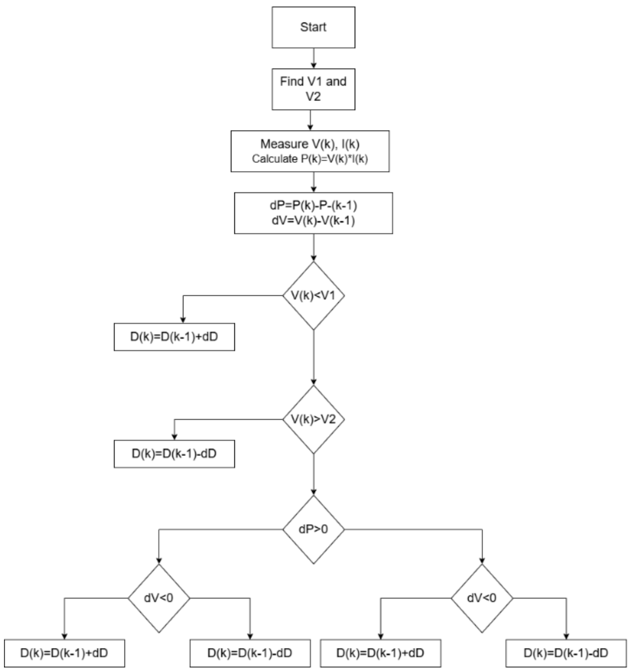

Figure 5. Flowchart of Modified P&O Algorithm

Conversely, if the system reads input from the solar panel during partial shadowing conditions, the irradiance will drop and will not match the set point indicated by the BH1750 sensor. The automatic system will then switch relay 1 off and relay 2 on. The boost converter then charges the battery using a control method known as modified perturb and observe, which aims to identify and optimize the power trapped during partial shading situations. This is explained in Figure 5, which shows the flowchart for the MPNO approach. Then, the boost converter's output measurements will be collected using the voltage and current sensors. Finally, data will be analyzed.

RESULTS AND DISCUSSION

Design and Layout of Boost Converter

The 3D design representation of the boost converter will be designed in this research project. Several components employed in this study were selected based on previous design outcomes. The inductor has a value of 100 µH, while the capacitor is rated at 1000 µF. The selection of these component parameter values ensures that the boost converter operates safely and efficiently, following the specifications of the intended application. The MOSFET used is the IRFZ44N, as are the other primary components in the architecture of the boost converter.

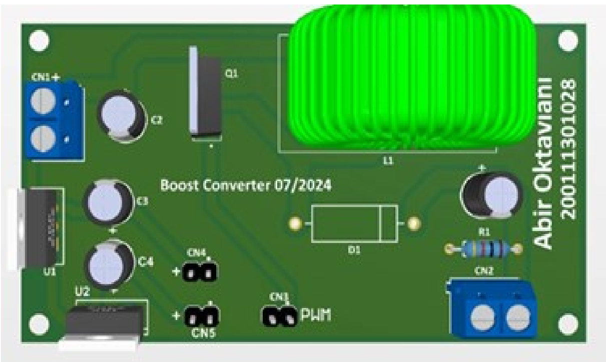

Figure 6. Design 3D Boost Converter

Implementing Systems for Partial Shading at EV Charging Station

Additional designs for new tools and systems, such as microcontrollers, relays, and sensors, were created for the system's implementation at the Solar-Powered Electric Vehicle Charging Station.

Figure 7. Solar PV-powered EV charging Station.

The image above has been updated with several components, including one STM32F407VG microcontroller, a two-channel relay module, a boost converter, an ACS712 sensor, a voltage sensor, a BH1750 sensor, and a 20x4-character LCD.

Assessing the Characteristics of Solar Panels

The objective of solar panel analysis is to collect the characteristics of the solar panels, which will then be utilized as a reference to define the system design. The testing was conducted by connecting two 150 Wp solar panels in concert from 9:00 AM to 3:00 PM, every 30 minutes. The solar panels were tested on August 4, 2024, during partly overcast conditions.

Figure 8 depicts the measurement procedure involving collecting current and voltage data. This situation will be separated into two, specifically measuring the solar panel in normal conditions and measuring the solar panel in partial shade. Data collection is carried out simultaneously and in location to minimize differences in light intensity, as variations in light intensity can significantly affect the output power. This is important because solar panels rely heavily on consistent irradiation to generate stable electrical energy. Even slight changes in light intensity can lead to fluctuations in the voltage, current, and power produced. By conducting the data collection simultaneously in the same location, the influence of external factors, such as shading, cloud cover, or varying sunlight angles, can be reduced, thereby ensuring that the data obtained accurately reflects the system's performance under consistent environmental conditions.

Figure 8. Assessing the characteristics of solar panel

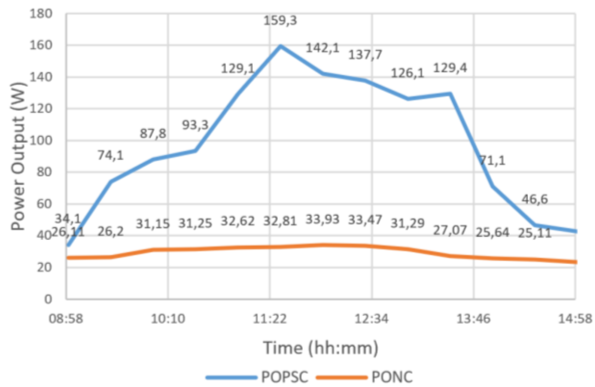

Figure 9. PV power line characteristics

The testing results of solar panel characteristics under normal conditions indicate that light intensity increases during the daytime and gradually decreases in the evening. The peak irradiance was recorded at 11:30 AM, measuring 140600 lux, and subsequently decreased to 35970 lux by 2:00 PM. Testing with a resistive load recorded an initial voltage of 12.7 V and a current of 2.7 A at 9:00 AM, reaching a maximum voltage of 19.2 V and 8.3 A at 11:30 AM. The power calculation yielded a peak value of 159.3 W at 11:30 AM. Thus, it can be concluded that the voltage, current, and power generated by the solar panels tend to decrease as irradiance diminishes, highlighting the influence of weather conditions and sunlight intensity.

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Table 1. Testing the Modified P&O Control System

Duty Cycle (%)		Input			Output					
					BC with MPNO			BC without MPNO		
DC MPNO	DC without MPNO	V_{in} (Volt)	In (A)	P_{in} (Watt)	V_{out} (Volt)	I_{out} (A)	P_{out} (Watt)	V_{out} (Volt)	About (A)	P_{out} (Watt)
24	55	11,5	4,8	55,35	14	3,58	50,12	13,1	3,54	46,37
23	55	10,2	4,5	45,53	13,8	3,03	41,81	13,1	2,79	36,55
22	55	10,1	4,3	43,41	13,3	2,91	38,7	13,2	2,68	35,38
24	55	10,2	4,5	45,62	13,2	3,25	42,9	12,9	2,66	34,31
22	55	11,8	5	59,31	13,8	3,86	53,27	13,1	3,69	48,34
20	55	11,1	4,5	50,14	13,3	3,47	46,15	13	3,13	40,69
21	55	11,6	4,6	53,86	13,5	3,8	51,3	13	3,24	42,12
22	55	11,1	4,5	50,26	13,3	3,43	45,62	13,2	3,28	43,3
20	55	11,4	4,6	52,11	13,4	3,6	48,24	13,5	3,27	44,15
22	`55	10	4	39,62	13	2,62	34,06	12,4	2,44	30,26
22	55	10,9	4,4	48,31	13,2	3,24	42,77	12,8	3,07	39,3
23	55	10,2	4,2	42,85	13,1	2,91	38,12	12,5	2,74	34,25
22	55	11,3	4,1	46,54	13,2	3,2	42,24	12,6	3	39,54

In partial shading conditions, the test results revealed a generally lower light intensity. Although light intensity increased during the daytime, the values remained lower compared to conditions without shading, with a peak irradiance of 1,259 lux at noon, gradually decreasing to 986 lux by 1:30 PM. Testing with a resistive load indicated an initial voltage of 12.1 V and a current of 2.2 A at 9:00 AM, which increased to 12.7 V and 2.7 A at noon. The power curve recorded a peak power output of 33.93 W at noon. Therefore, it can be concluded that under partial shading conditions, the voltage, current, and power generated by the solar panels also tend to decrease as irradiance levels drop, underscoring that the characteristics of solar panels are significantly affected by partial shading and variations in sunlight intensity throughout the day.

Testing the Modified P&O Control System

This testing obtained the input voltage and current from the solar panel. In contrast, the output voltage and current were measured through the boost converter without any method, maintaining a constant duty cycle of 55%. Conversely, testing the boost converter using the modified Perturb and Observe (P&O) method resulted in a variable duty cycle governed by the modified PNO algorithm itself.

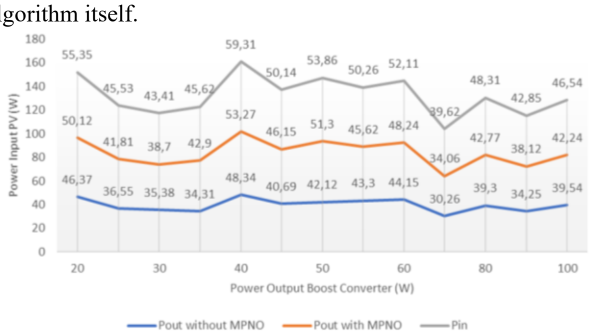

Figure 10. Boost Converter Output Testing Curve

Figure 10 depicts the curve of the boost converter output power test results after comparing three conditions: input power (Pin), output power without control (Pout Without Control), and output power with control (Pout with MPNO). The input power depicted by the blue curve appears stable, ranging from 41 to 55 watts, indicating that the input to the boost converter system remains constant during the test. The orange curve depicts the output power without control, which varies significantly between a maximum of roughly 59 watts and a minimum of about 30 watts. This demonstrates that the output power provided by the boost converter is unsteady when it is not controlled. In contrast, the grey curve's output power with MPNO control appears more consistent, ranging from 38 to 53 watts. Despite minor oscillations, the MPNO control appears to be effective in preserving the stability of output power production. In conclusion, applying MPNO control to the boost converter improved the stability of the output power compared to the control-free condition. However, the input power stayed constant during the test.

System Integration Testing

Data collection will be continuous throughout the observation period, showing variations in the recorded values over time. This provides insights into how light intensity and battery conditions affect the performance of the photovoltaic system. Such analysis is crucial for understanding the system's operational patterns under different environmental conditions.

Table 2. Power Increase Percentage of System Integration

Condition	Test Time	Weather Irradiation (Lux)	Voltage		Current		MPPT Power (W)	MPNO Power (W)	MPNO Power Increase	
			PV (V)	Battery (V)	PV (A)	Battery (A)			Watt	%
Normal Condition	09:00	39421	12,7	13,9	4,9	3,35	62,23	46,57	-15,67	-34%
	09:30	45850	14,5	15,3	5,1	3,4	73,95	52,02	-21,93	-42%
	10:00	49770	16,4	17,2	5,4	3,4	88,56	58,48	-30,08	-51%
	10:30	68400	16,6	17,3	5,6	3,66	92,96	63,32	-29,64	-47%
	11:00	82640	16,9	17,5	7,6	4,79	128,44	83,83	-44,62	-53%
	11:30	140600	19,2	20,1	8,3	5,13	159,36	103,11	-56,25	-55%
	12:00	119400	17,5	18,3	8,1	5,04	141,75	92,23	-49,52	-54%
	12:30	110300	17,2	18,2	8	4,98	137,6	90,64	-46,96	-52%
	13:00	73060	16,7	17,4	7,6	4,81	126,92	83,69	-43,23	-52%
	13:30	80340	16,7	17,4	7,5	4,62	125,25	80,39	-44,86	-56%
	14:00	35970	14,8	15,6	4,8	3,07	71,04	47,89	-23,15	-48%
	14:30	7376	13,5	14,3	3,5	2,8	47,25	40,04	-7,21	-18%
	15:00	4194	13,3	14,2	3,2	2,8	42,56	39,76	-2,8	-7%
Average Power Increase									-31,99	-44%
Partial Shading Condition	09:00	908	11,5	14	4,4	4,2	50,13	58,35	8,22	16%
	09:30	923	10,2	13,8	4,1	3,7	41,78	50,53	8,75	21%
	10:00	1019	10,1	13,5	3,9	3,6	39,25	48,41	9,16	23%
	10:30	1025	10,2	12,2	4	4,1	40,48	49,62	9,14	23%
	11:00	1113	11,8	12,8	4.8	4.5	55,2	64,31	9,11	17%
	11:30	1158	11,1	13,3	4,2	4,1	46,14	56,14	10	22%
	12:00	1259	11,6	12,5	4,3	4.2	50,21	59,86	9,65	19%
	12:30	1206	11,1	13,8	4,3	3,9	47,35	53,26	5,91	12%
	13:00	1037	11,4	12,1	4,4	4.2	49,82	57,34	7,52	15%
	13:30	986	10	13,9	3,4	3	33,51	41,62	8,11	24%
	14:00	857	10,9	12,4	3,7	3.5	40,22	48,31	8,09	20%
	14:30	814	10,2	13,3	3,6	3,4	36,73	44,85	8,12	22%
	15:00	792	11,3	13	3,4	3.0	38,2	45,54	7,34	19%
Average Power Increase									8,39	20%

Table 3 presents data from the system integration testing of the electric vehicle charging station under both normal and partial shading conditions, recorded from 09:00 to 15:00. The data, collected at 30-minute intervals, include parameters such as solar irradiance, PV panel voltage,e and current, and battery voltage and current, providing insight into the system's performance under varying weather conditions and sunlight intensity. At 09:00, under normal conditions, the solar panel recorded an irradiance of 39,421 lux, generating 12.7 V and 4.9 A, while the battery registered 13.9 V and 3.3 A. In partial shading conditions simultaneously, sunlight intensity dropped to 908 lux, and the panel voltage decreased to 11.5 V. However, the MPNO method boost converter raised the output voltage to 14.0 V and 4.4 A, optimizing power output despite the shading. These variations throughout the observation period provide valuable insight into how sunlight intensity and battery conditions impact the performance of the photovoltaic system.

Discussion

The Modified Perturb and Observe (MPNO) method offers several advantages over other Maximum Power Point Tracking (MPPT) methods. One of its main advantages is simplicity, as MPNO retains the basic principles of the traditional P&O method, making its implementation easier and less dependent on complex algorithms. Additionally, MPNO provides improved tracking efficiency by enhancing its ability to avoid being trapped at local Maximum Power Points (local MPP) and more effectively locating the global MPP (GMPP) under partial shading conditions. Another advantage is its reduced computational burden compared to optimization methods such as Perturb & Observe [24], Particle Swarm Optimization (PSO) [25], Modified Swarm Optimization (MPSO) [26], [27], and Hybrid Algorithm [28], [29]. This makes MPNO computationally lighter, making it highly suitable for systems with limited power and processing resources.

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CONCLUSIONS

The MPPT boost converter, using the modified PNO approach, maximizes solar panel output under partial shading, with a power gain of 8.13 and 91% efficiency. Without the enhanced MPNO, power fluctuations range from 30 to 59 watts, with 81% efficiency. The modified P&O approach helps reduce the impact of shading and light fluctuations, keeping the system near its maximum power point, though it falls short under normal conditions. This innovation can improve electric vehicle charging efficiency and system reliability, especially in bad weather.

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NOMENCLATURE

RE	Renewable Energy
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
MPPT	Maximum Power Point Tracker
PSC	Partial Shading Condition
MPNO	Modified Perturb and Observe
P&O	Perturb and Observe
PV	Photovoltaic
PO	Power Output
V	Voltage
I_{PV}	Photovoltaic Current
P_{PV}	Photovoltaic Power
V_{PV}	Photovoltaic Voltage

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