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Energy Management Systems Development in Electric Vehicle Charging Stations Based on Multi-Source Inverters with Utilisation of Renewable Energy Sources

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ABSTRACT

The use of electric vehicles (EVs) is growing rapidly and widely, as they produce no gas emissions, reduce pollution, and do not rely on fossil fuels. Solar energy is a reliable and renewable energy source. Problems arise when charging stations cannot meet demand due to unfavourable weather conditions. This research offers a solution using multi-source energy management to ensure the availability of electrical energy sustainably and economically. The multi-source inverter converts from direct current (DC) to alternating current (AC), stabilising the voltage from solar panels, batteries, and the grid. The proposed energy management ensures an uninterrupted power supply, especially when energy absorption from the sun is reduced due to weather. The research contributes to providing and managing energy for electric vehicle charging, prioritising the exploitation of energy from solar panels and batteries. Sourcing electricity from the grid will be the last resort when the load reaches its peak. With the proposed strategy, the charging station can reduce the use of fossil energy, requiring only 1,795 watt hours (Wh) each week.

Keywords: Charging station, electric energy management system, electric vehicle, solar energy

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INTRODUCTION

Electric vehicles (EVs) offer a sustainable transportation solution that can effectively replace traditional fossil fuel-powered

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vehicles. This transition is crucial since traditional vehicles are known for emitting harmful air pollutants, carbon dioxide (CO_2) emissions, and greenhouse gases, which resulted in the depletion of petroleum resources. These factors collectively present substantial threats to the environment (Narasipuram & Mopidevi, 2021). Currently, numerous countries are supporting the adoption of EVs to mitigate the rising levels of pollutants. However, various challenges must be addressed to facilitate the widespread implementation of electric vehicles, including the limited development of EV infrastructure, identifying optimal locations for EVs, and managing power usage (Ahmad et al., 2022). One critical approach to increasing the accessibility of electric vehicles is through ongoing research and development in battery technology. Advancements in battery technology will enable electric vehicles to achieve a longer range and improved efficiency. Furthermore, the establishment of charging stations distributed evenly across user activity areas is essential. With accessible charging stations, electric vehicle users will not have to worry about running out of power while on the move. These several key factors have a significant impact on the growth and development of electric vehicles in the automotive industry. With robust support for EV infrastructure, it is anticipated that the adoption of electric vehicles will accelerate in the future. This transition will further aid in decreasing greenhouse gas emissions and fostering a cleaner, more sustainable environment. According to a study conducted by Sanguesa et al. (2021), the presence of a supportive EV infrastructure is essential for facilitating the widespread adoption and utilisation of electric vehicles. Therefore, concrete actions must be continually pursued to enhance electric vehicle infrastructure, from increasing the number of charging stations to improving the battery capacity of electric vehicles.

Users of electric vehicles need to predict energy consumption and optimise battery capacity to avoid running out of power. Efficient route planning can also contribute to energy savings. It is essential to ensure the availability of adequate charging infrastructure, allowing users to recharge their batteries with ease. These strategies allow electric vehicle users to extend battery life and enjoy a more comfortable and efficient driving experience (Zhang et al., 2020). The battery capacity of electric vehicles is affected by the weight of the load being carried. On average, the battery will deplete after covering a maximum distance of 25 km at a speed of 25 km/h, with a load of 58–70 kg and a battery capacity of 80 Ah. Selecting the appropriate battery capacity is crucial for the performance and efficiency of electric vehicles (Lestari & Rangkuti, 2023). Various studies have highlighted the importance of the distribution of charging stations to alleviate electric vehicle drivers' concerns regarding power needs and travel range (Pan et al., 2020). Therefore, the installation of charging stations in public areas must be supported by the availability and continuity of power supply.

In recent times, there has been an increasing focus on utilising renewable energy sources to power charging stations. Solar energy is a renewable and environmentally friendly energy source. However, its generation is heavily influenced by climatic and weather conditions. The electricity generation from solar power is most effective in regions with sunny climates and during the summer months, while production becomes severely limited in winter or overcast areas. Solar energy can be harnessed only during daylight hours, as it is not accessible at night. Conversely, the demand for energy to power EVs persists until daily activities cease. The energy stored in batteries serves as a solution to ensure the continuity of the energy supply (Kunj & Pal, 2020). To guarantee sustained energy production, the integration of various sources is essential. Efficient power flow management can positively impact energy savings (Baqar et al., 2022).

The utilisation of Renewable Energy Sources (RES) through a hybrid system that combines solar and wind energy has been analysed using HOMER software. The simulation results indicate that solar energy plays a more dominant role compared to wind energy (Ekren et al., 2021). In the context of energy utilisation for electric vehicle charging stations, it is essential to optimise the scheduling of charging and energy absorption to maintain the stability of the electrical system (Ullah et al., 2023). Furthermore, the placement of solar panels significantly impacts energy absorption efficiency (Reddy et al., 2023). Installing solar panels on rooftops presents a viable solution for enhancing energy absorption while also providing shade for the charging stations (Khan et al., 2023). Inverters are required to convert the direct current (DC) into alternating current (AC) and stabilise the voltage by harnessing solar energy as a power source for charging stations (Ebrahimi et al., 2021). Developing inverters capable of integrating multiple energy sources and filtering the output is necessary to produce cleaner energy and ensure a continuous power supply at the charging stations. This article discusses charging stations that utilise energy from various sources, employing multi-source inverters to integrate solar panels, batteries, and the electrical grid. Power flow management from these three sources will be carefully regulated to minimise fossil fuel usage. The primary goal is to maximise energy production from solar panels by implementing battery storage to address any increase in energy consumption. If necessary, the electrical grid will provide energy as a final option. The contributions and innovations presented in this research provide a framework for energy management at charging stations using multi-source inverter technology, expecting to reduce electricity costs and ensure sustainable electricity supply, even during periods of reduced sunlight intensity.

MATERIALS AND METHODS

The recently installed charging station at Hang Tuah University's parking area has been designed to enhance the infrastructure available to electric vehicle users. This charging station was accessible to the public, given its strategic location near public facilities. The station utilises a hybrid power supply system comprised of solar panels, batteries, and the electrical grid to effectively meet the energy demands of electric vehicles. The efficiency of the solar panels was assessed based on the amount of sunlight converted into electrical energy to the surface area of the solar panels exposed to sunlight, measured in watts. Equation 1 could be employed to calculate the efficiency value of the solar panels exposed to sunlight (Triyanto et al., 2023).

$$\eta_{PV} = \frac{P_{max}}{A_c \text{ X } E_{sw.sy}} \quad [1]$$

Where:
P_{max} = Maximum output power (Watt)
A_c = Cell Surface Area (m^2)
$E_{sw.sy}$ = 1000 W/m^2, coefficient of incident radiation flux in standard test condition (STC) (W/m^2)

The requirements for solar panels are determine in two steps: Assess the available area and evaluate the power requirements. Equation 2 can be used to calculate the necessary solar panels.

$$L_{potential} = L_{total} \, (1 - 0{,}25) \quad [2]$$

With:
$L_{potential}$ = Potential area of PV installation (m^2)
L_{total} = Total area (m^2)

A value of 0.25 indicates an area that was not utilised for the installation of photovoltaic (PV) systems. Once the potential area has been identified, the subsequent step involves calculating the area designated for PV installation, referred to as the PV Area. The PV Area could be determined using Equation 3.

$$PV_{Area} = L_{potential} \times (1 - 0{,}2) \quad [3]$$

Where:
PV_{Area} = PV mounting/installation areas (m^2)
$L_{potential}$ = Potential areas for solar PV installation (m^2)

A value of 0.2 indicates an area designated for maintenance or repair pathways within a Solar Power Generation System. Additionally, the size of the solar panel array or the area covered by the photovoltaic installation could be determined to assess the potential power output of the solar power system. Equation 4 was employed to compute the potential power output.

$$P_{wattpeak} = PV_{Area} \times \text{PSI} \times \eta\text{PV [Watt]} \quad [4]$$

Where:

PV_{Area} = Surface Area of the Solar Panel (m^2)

PSI = *Peak Solar insolasion* (1.000 W/m^2)

ηPV = Efficiency of Solar Panels [%]

Subsequently, a calculation was conducted to determine the number of solar panels required for the planning of the Solar Power Plant construction. This calculation aimed to ascertain the quantity of PV modules that could be installed. This information was crucial for understanding the installation capacity of the modules within the proposed solar power plant plan. Equation 5 could be utilised to compute the number of PV modules that could be installed.

$$\Sigma_{Panel\ surya} = \frac{P_{wattpeak}}{\text{Pmp}} \quad [5]$$

With:

$\Sigma_{Panel\ surya}$ = Number of PV modules (Unit)

$P_{wattpeak}$ = Power generated by PV (Wp)

Pmp = Maximum power output of the solar panel (Watt)

A schematic representation of the charging station is illustrated in Figure 1, while the actual implementation of the charging station can be observed in Figure 2. Solar energy was

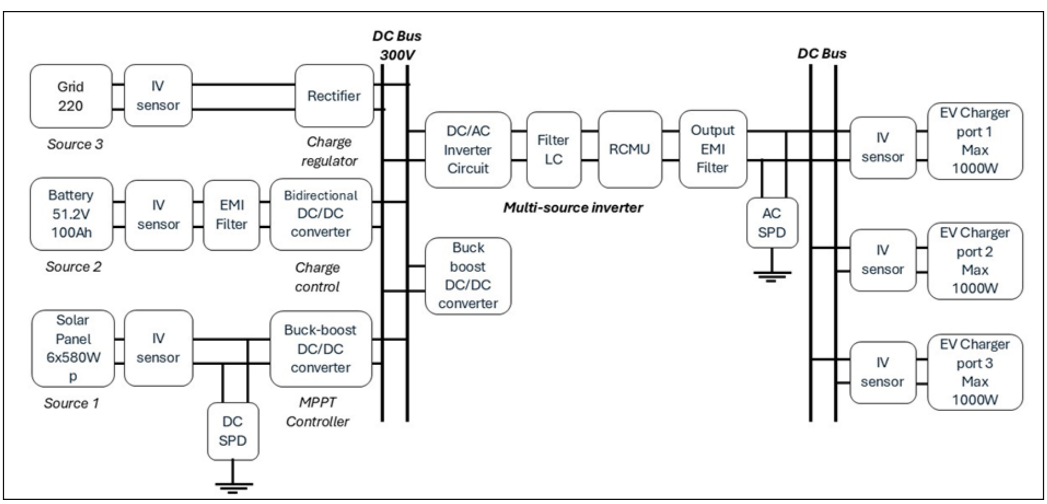


Figure 1. Schematic diagram of multisource inverter-based solar charging station

harnessed through six units of monocrystalline PV panels, each with a capacity of 550 watts peak (WP). The placement of the solar panels followed a rooftop concept. The supporting structure was designed to support the solar panels, protect the panels' enclosure beneath, and provide shade for the electric motor to facilitate the charging process. A multi-source inverter system was employed at this charging station, ensuring a sustainable supply of electrical power. When solar energy absorption peaks, the energy is stored in batteries. The battery capacity needs to be customised to adequately accommodate the daily energy needs of the solar charging system.

Figure 2. Implementation of the solar charging station in the campus area

Depth of Discharge (DOD) was the quantifiable measure of the amount of charge that had been used in relation to the total capacity of a battery. It was expressed as a percentage and indicates the level of discharge the battery has undergone. Instead, the State of Charge (SOC) was a metric that reflects the percentage of battery capacity currently available, indicating the level of energy available for use (Xie et al., 2020). According to existing data, the daily energy requirement for solar charging was 10.78 kWh per day. Consequently, the minimum battery capacity required must be at least equivalent to this daily energy consumption. However, when determining battery capacity, it was crucial to consider the type of battery being used, as each type has a different DOD. In this study, the battery employed was of the lithium variety, which had a DOD of 95%. Therefore, the capacity of the battery that should be selected could be calculated using Equation 6.

$$\text{Battery Capacity} = \frac{Daily\ energy\ consumption}{Depth\ of\ Discharge} \quad [6]$$

Using a DOD of 95%, the required battery capacity was:

$$\text{Battery Capacity} = \frac{10{,}78\ kWh}{0{,}95} = 11{,}33\ \text{kWh}$$

The required battery capacity should be a minimum of 11.33 kWh, equivalent to 11,400 Wh. However, in this study, the researchers would utilise a battery with a capacity of 5.12 kWh. The selection of a smaller-capacity battery was intended to assess the performance of the multisource inverter in managing charging from various sources, such as solar panels, the electrical grid, and the battery itself.

Based on the load profile data, it has been determined that the maximum power requirement reaches 3 kW. This study utilised a solar panel system comprising six units, each with a capacity of 550 WP, resulting in a total solar panel capacity of 3,300 WP. This configuration will enable an assessment of the efficacy of the solar panels in fulfilling the load power demands, especially during times of peak load. Furthermore, it was acknowledged that solar panels produced fluctuating power output depending on solar radiation, indicating that the load power requirements also vary hourly throughout the day. This research aimed to assess how the inverter manages these fluctuations and identify when the solar panels require additional support from the electrical grid and battery systems.

The multi-source inverter comprised a DC/AC inverter circuit designed to convert direct current (DC) from various sources into alternating current (AC) for use by electrical loads. Distortion in the AC output was mitigated by an LC filter, resulting in a waveform that closely resembles a sinusoidal shape. The Residual Current Monitoring Unit (RCMU) was a key component within the inverter system. The term "residual current" refers to leakage current that flows from the electrical system to the ground, often resulting from ground faults. This leakage current poses a risk of flowing through the human body to the ground, potentially leading to electric shocks, injuries, burns, and an increased risk of overheating and fire hazards. Residual Current Devices (RCD) were employed to detect such leakage currents, automatically disconnecting the circuit from the source when the residual current exceeds a predefined threshold. The RCMU serves a purpose similar to the RCD but cannot disconnect the circuit.

Instead, the RCMU was designed solely to monitor residual current and activate an alarm when necessary. Given that the inverter was equipped with highly precise residual current detection devices, installing leakage protection switches within the system was generally not recommended. Should the need arise, such switches should be installed between the inverter's output and the electrical grid. Additionally, a buck-boost converter was utilised to ensure that the input voltage can be maintained at levels either above or below the output voltage. Furthermore, an Alternating Current Surge Protective Device (AC-SPD) was incorporated to safeguard the electrical installation from damage or fire caused by voltage surges resulting from lightning strikes or excessive voltage spikes. Consequently, the multi-source inverter is an energy converter from DC to AC. It protects and filters, ensuring the generated energy is cleaner and the output voltage remains stable. The configuration can be observed in Figure 3.

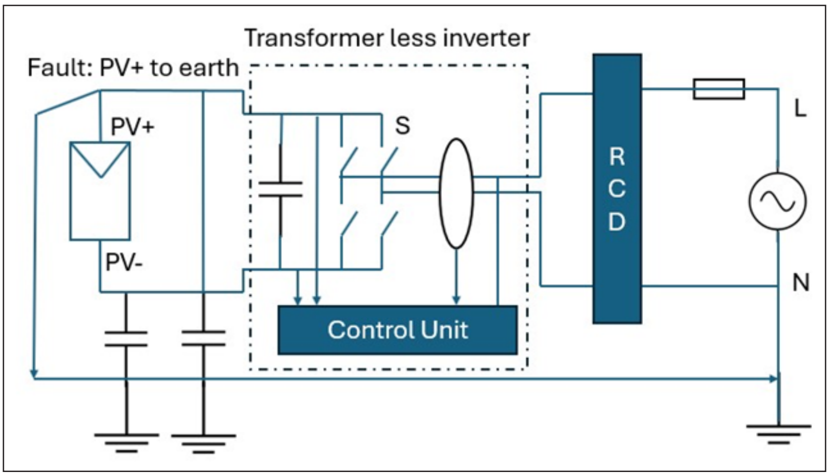


Figure 3. Residual current monitoring unit

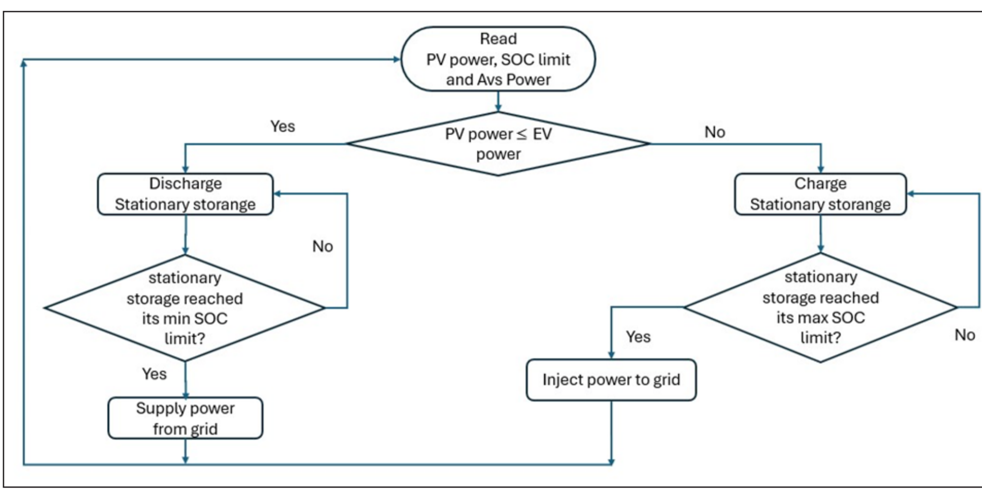


Figure 4. Energy management of solar charging stations

The process algorithm is presented in Figure 4. Energy management regulated by multi-source inverters prioritises the direct use of energy generated from PV panels. When the demand for EVs is lower than the power produced by the PV system, the energy will fully supply the energy, with any excess energy stored in batteries. Conversely, if the demand from EVs exceeds the power generated by the PV system, the charging station will draw power from the batteries. Throughout this process, as long as the energy discharge does not fall below the minimum SOC threshold, the batteries will undergo an energy discharge. However, should the SOC exceed the maximum limit, the batteries would engage in charging from the electrical grid. Charging will commence when the battery capacity drops below 15%, while the discharge process is capped at 85% of capacity.

RESULTS AND DISCUSSION

Solar Energy Potential at the Charging Station Location

The capacity of solar charging stations was determined based on the potential absorption of solar energy at the specific installation site. This potential was derived from solar irradiation data specific to the location of the charging station, as outlined in Table 1. It was observed that solar irradiation tends to increase in correlation with the sun's position throughout the day. The solar irradiation values in Indonesia demonstrate monthly fluctuations due to seasonal changes. Data for September indicates a peak, with an average daily total irradiation reaching 6.157 Wh/m². On the contrary, January had the lowest recorded values, with an average daily total irradiation of 2.776 Wh/m². This decline in irradiation values was likely attributable to the rainy season, which diminishes the amount of sunlight that can be harnessed. Overall, the annual average solar irradiation stands at 4.208 Wh/m².

Table 1
Solar energy potential as a charging station energy source

Hour	Average Solar Irradiation During the Year (Wh/m2)												Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0–1	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1–2	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2–3	0	0	0	0	0	0	0	0	0	0	0	0	**0**
3–4	0	0	0	0	0	0	0	0	0	0	0	0	**0**
4–5	0	0	0	0	0	0	0	0	0	0	0	0	**0**
5–6	0	0	0	0	0	0	0	0	0	0	0	0	**0**
6–7	15	6	7	11	12	8	0	14	40	59	60	23	**21**
7–8	141	126	153	188	211	216	209	264	336	281	218	143	**207**
8–9	225	242	289	310	358	379	417	460	506	428	323	221	**347**
9–10	310	328	363	377	433	457	511	573	616	535	377	290	**431**
10–11	371	368	422	448	504	520	587	657	694	604	447	339	**497**
11–12	382	402	470	510	565	573	651	720	734	633	471	351	**539**
12–13	371	392	467	510	580	607	675	740	734	625	434	330	**539**
13–14	327	364	409	438	539	594	668	725	702	580	353	265	**497**

Table 1 *(continue)*

Hour	Average Solar Irradiation During the Year (Wh/m2)												Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
14–15	258	297	306	340	462	535	615	671	637	472	274	198	**422**
15–16	172	196	205	231	348	429	528	575	530	377	195	122	**326**
16–17	103	126	138	160	245	322	405	439	394	269	140	78	**235**
17–18	77	88	94	102	115	179	232	261	223	136	82	54	**137**
18–19	24	32	14	6	1	3	14	18	11	5	4	6	**12**
19–20	0	0	0	0	0	0	0	0	0	0	0	0	**0**
20–21	0	0	0	0	0	0	0	0	0	0	0	0	**0**
21–22	0	0	0	0	0	0	0	0	0	0	0	0	**0**
22–23	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23–24	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**2776**	**2967**	**3337**	**3631**	**4373**	**4822**	**5512**	**6117**	**6157**	**5004**	**3378**	**2420**	4208

Solar radiation measurement was used to determine how much solar energy can be harnessed. This process also optimises the design of charging station systems, identifies ideal locations, and analyses the performance of these charging stations.

Electric Vehicle (EV) Power Requirements

The electric charging station offered three sockets for charging electric vehicles. Data regarding the energy requirements of electric vehicle (EV) users was essential as a basis for energy management strategies, enabling the prioritisation of renewable energy sources in fulfilment of energy demands. The energy requirements for EVs were measured over 30 days. A dashed line graph illustrated the fluctuations in electricity consumption throughout the usage period from morning until evening, as depicted in Figure 5. The average energy

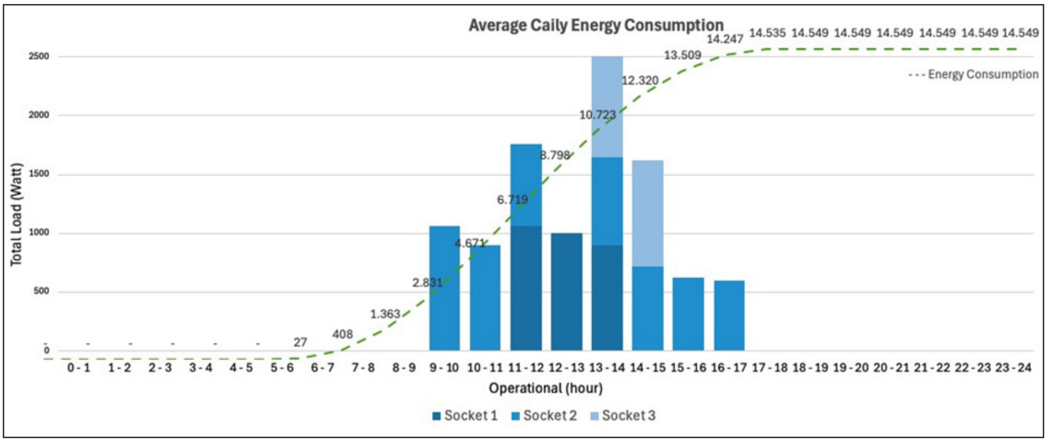


Figure 5. Daily load profile of the charging station

requirement for EVs was recorded at 14,549 Wh. The bar chart analysis reveals that the peak of energy consumption occurs between 1:00 PM and 2:00 PM. This data implies that several charging processes occurred simultaneously during this timeframe.

The study utilised conventional socket charging stations for data collection, allowing for the use of various charging adapters. Monitoring devices recorded charging power for each electric motor ranging from 600 to 1,000 watts. This data was used as a reference for effectively managing energy supply at the charging stations, considering fluctuations in energy consumption and measured charging capacity.

Daily Energy Management of Solar Charging Station

The charging station was equipped with three charging ports, enabling simultaneous use by three electric vehicles (EVs). This study analysed the energy management reports of the charging station over seven days, with a particular focus on energy consumption from photovoltaic (PV) sources. Considering that the charging station was situated in a campus parking area, it was noted that the average users of this station are active during the institution's working hours, specifically between 6:00 AM and 9:00 PM.

On the first day, the utilisation of the charging station is illustrated in Figure 6. The EV charging at socket 1 was entirely fulfilled by the PV energy source, as indicated by the orange colour. However, when the other two sockets were used for EV charging, the power supply from the PV system was insufficient to meet the demand, necessitating additional energy from the battery between 7:00 AM and 8:00 AM. During this period, the battery undergoes a discharge process, decreasing energy levels, as represented by the dashed line. The solar energy absorption in the morning has not reached its full potential. However, as the sun reaches its zenith, the energy generated from the PV system gradually increases, allowing the power needs of the EV to be fully met by the PV source. The excess power generated by the photovoltaic system is transferred to the battery at 1:00 PM.

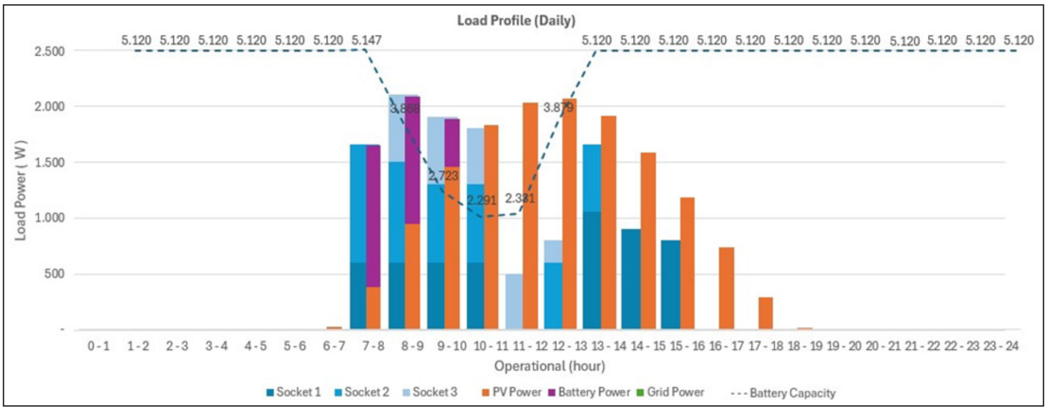
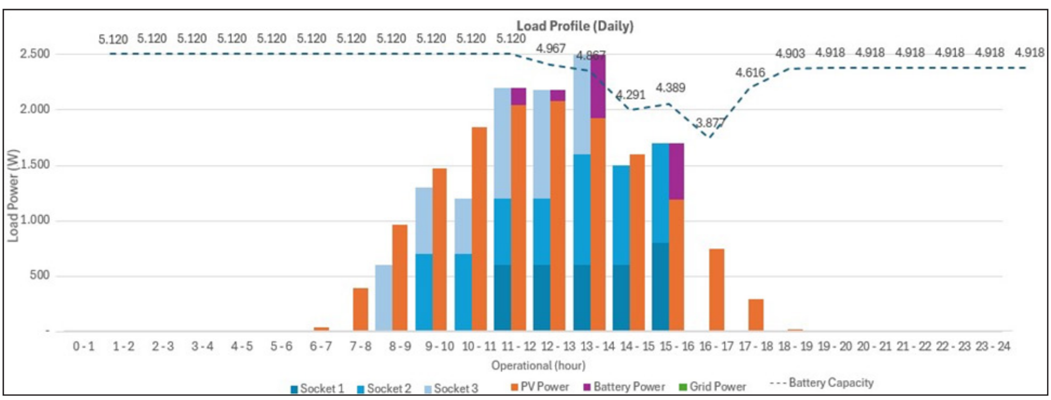


Figure 6. Load profile of day one

During the time range of 8:00 AM to 11:00 AM, the total energy consumption amounted to 2,372 watts, with three EVs utilising the charging stations. The energy requirements for the sockets were 600 watts for socket 1, 1,000 watts for socket 2, and 600 watts for socket 3. At that time, solar energy had not yet reached its full potential, requiring additional support from the battery supply. Once solar energy absorption achieved optimal levels, if the battery's State of Charge (SOC) fell below 15%, the battery would initiate a recharge. During the first day of assessment, the power demand was sufficiently met without drawing from the electrical grid. This enabled the designed charging stations to effectively reduce the reliance on fossil fuels.

For several days following the operation of the EV charging station, the energy requirements could be met through photovoltaic energy and battery storage. Figures 7 to 10 illustrate the effectiveness of this system in maintaining sustainability and energy efficiency at the EV charging station. The photovoltaic system and batteries had consistently delivered a sufficient energy supply for an extended period, allowing the station to function independently without solely depending on grid energy sources.



Gambar 7. Load profile of day two

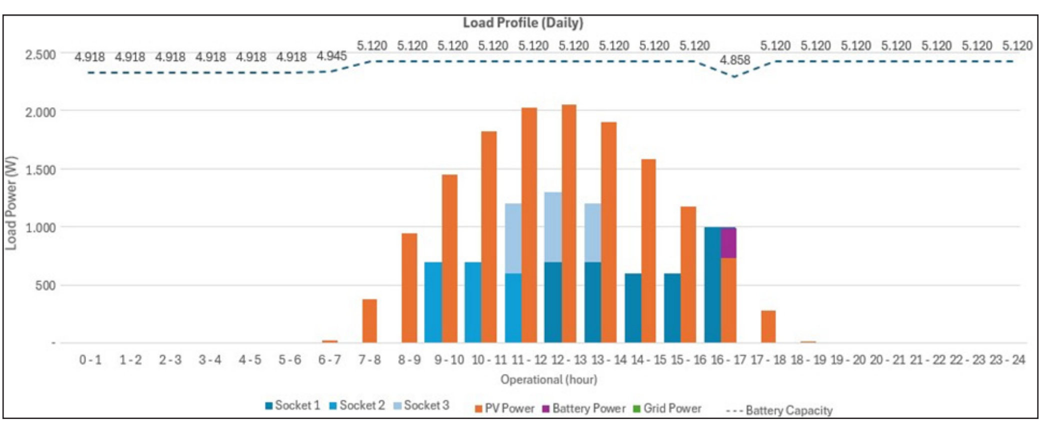


Figure 8. Load profile of day three

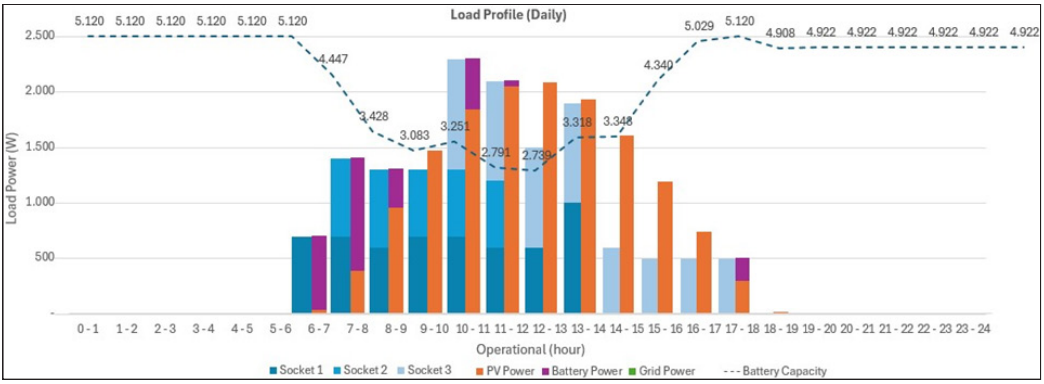


Figure 9. Load profile of day four

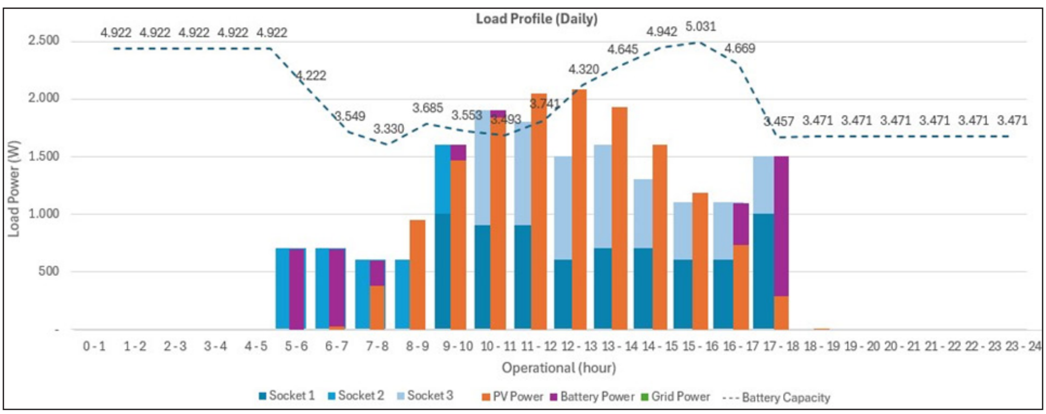


Figure 10. Load profile of day five

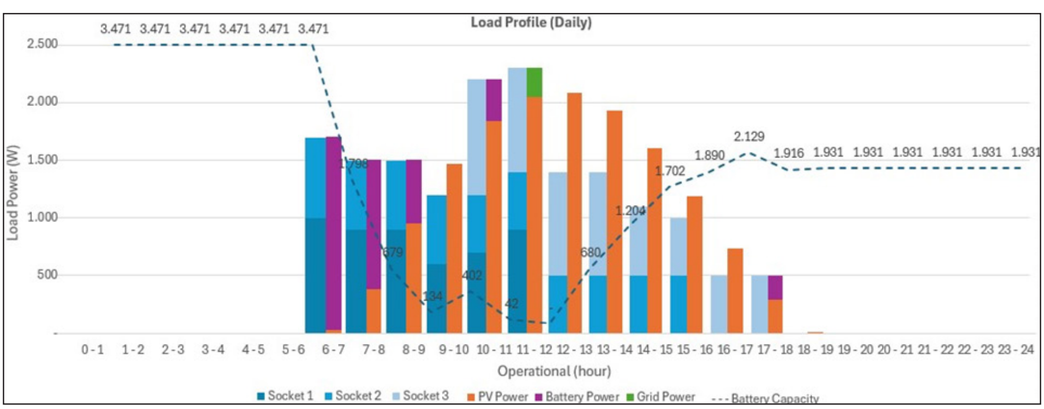


Figure 11. Load profile of day six

In the case observed on the sixth day, as illustrated in Figure 11, it was noted that in the morning, when the solar panels (PV) were not yet generating power, several EVs were charging, each requiring 600 watts and 1,000 watts, respectively. The vehicles were powered by utilising the energy stored in the batteries. During this procedure, the batteries were discharged. Therefore, this ultimately leads to a decrease in the SOC. Fortunately, the PV systems were able to mitigate the situation by effectively harnessing solar energy.

At 10:00 AM, it was recorded that three EVs were charging, with capacities of 600 watts, 1,000 watts, and 1,000 watts, while the battery conditions were nearing the minimum SOC. As the power generated by the photovoltaic (PV) system and batteries was insufficient to meet the energy demands of the EVs, the power supply was sourced from the electricity grid. The grid provided only 253 watts of the total energy requirement of 18,712 watts. In terms of percentage, the energy contributions were 78% from the PV system, 21% from the batteries, and 1% from the grid on that sixth day.

By the seventh day, the solar panels (photovoltaic) had not fully charged the battery. In the morning, the EVs were observed utilising power from the battery, as shown in Figure 12. When the battery's SOC approached its limit, and the PV system was not providing optimal power, the electrical grid supplied the EVs. As the sun moved, the PV system subsequently took over as the primary energy source for the charging station. Overall, on the seventh day, only 1,795 watts of energy were required from the electrical grid out of a total daily consumption of 17,318. By mean, only 10% of the daily energy requirements for electric vehicles were sourced from the electrical grid. Therefore, it's demonstrating an effective approach to reducing the dependence on fossil fuels.

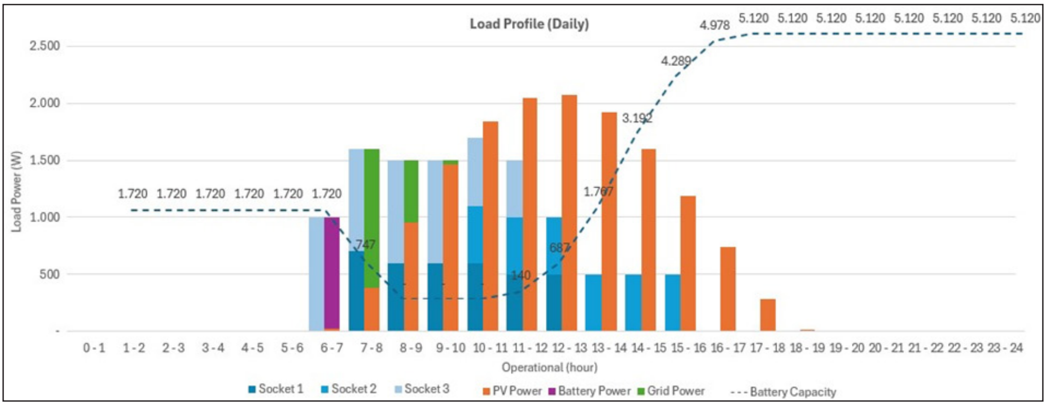


Figure 12. Load profile of day seven

As energy management increasingly relies on power supply from PV systems, the batteries do not engage in charging during the night. The primary focus for battery charging was on utilising PV energy during daylight hours. This approach focuses on harnessing charging stations as renewable energy sources to reduce reliance on fossil fuels and mitigate greenhouse gas emissions. Strategically positioning charging stations throughout campus enhanced the adoption of photovoltaic energy for battery charging purposes. Future research could explore more complex solutions that would enable EV users to charge their vehicles from day to night. The development of electric vehicle infrastructure necessitates a comprehensive examination from multiple perspectives to ensure that goals are successfully achieved. Research on renewable energy plays a crucial role in contributing to energy sustainability and addressing pollution and environmental degradation issues.

Studies have addressed similar topics to enhance and bolster the advancement of infrastructure for EV utilization, in addition to initiatives aimed at decreasing reliance on fossil fuels. Table 2 presents comparable studies that address the utilisation of renewable energy for charging stations or supporting infrastructure for EV users. Several key highlights were examined from the perspective of developing supporting infrastructure for EVs, encompassing both simulations and implementations. The studies listed in Table 2 focus solely on the energy management of charging stations derived from hybrid sources. The proposed research indicates a significant contribution, suggesting that charging stations with the development of multi-source inverters provide straightforward energy management while simultaneously reducing reliance on fossil fuels. Furthermore, installing charging stations on campus provides complimentary power for members of the academic community who utilize electric vehicles. Such initiatives undoubtedly have a positive impact on reducing operational costs and mitigating greenhouse gas emissions.

Table 2
Similar research

Works	Description	Highlight
Kouka and Krichen (2019)	Simulation	Energy management is being implemented in hybrid sources, with a priority on utilising renewable energy; however, this research is still in the simulation phase.
Cheikh-Mohamad et al. (2023)	Simulation	Electric vehicles (EVs) can utilise 75% of the total energy while charging at a charging station, providing a significant advantage over traditional vehicles. This is attributed to the limitations on the energy consumed by EVs. The Vehicle-to-Grid (V2G) service can be customised to accommodate the user's specific capacity needs.
Chacko and Sachidanandam (2021)	Simulation	A smart energy management system has been developed for a bidirectional converter that can be connected to the grid and installed in electric vehicles. This research focuses on the communication and price negotiation for electric vehicle usage and charging station systems.
Cabrera-Tobar et al. (2022)	Simulation	The current focus of the research is on assessing Energy Management Systems (EMS), with a particular emphasis on reducing emissions and minimising energy costs. At this stage, the research is primarily focused on simulation.
Mohan and Dash (2023).	Simulation	The charging station's resources are derived from hybrid sources. The management of the DC microgrid power is developed using Fuzzy-SSA. This research has been simulated using MATLAB software.

Table 2 *(continue)*

Works	Description	Highlight
Kumar et al. (2023)	Review	The article reviews EV charging infrastructure, power management, and control techniques. It discusses charging station availability, power efficiency, and technological control methods for optimising energy use. The article aims to provide insights into the current state and future of EV charging.
Cheikh-Mohamad et al. (2022)	Application	The smart grid efficiently manages power balancing by using cutting-edge technology, including batteries, to store excess electricity from solar and traditional sources. This innovative approach optimises renewable energy use and helps us meet fluctuating grid demands, ensuring reliable and sustainable energy for our customers.
Proposed method	Application	The multisource inverter plays a vital role in integrating hybrid sources and filtering, protecting, and prioritising energy from photovoltaic (PV) systems. This involves facilitating direct EV charging services and battery charging capabilities. Energy supplied from the grid is considered the last option when energy demands are not met. The reliance on fossil fuels for EV energy requirements is minimal, accounting for only up to 10% of total energy needs.

CONCLUSION

The establishment of electric vehicle (EV) charging stations powered by multiple energy sources was of significant importance, particularly in facilitating the transition to clean energy and accelerating the adoption of electric vehicles. The implementation of a multi-source inverter, supported by an energy management system, prioritises the use of power generated from photovoltaic (PV) systems. This approach provided a viable solution for the development of EV charging infrastructure. Notable reductions in fossil energy consumption have been observed following the deployment of these charging stations on a university campus. Primarily powered by the PV system, these stations could meet the energy demands of EVs within just two days, contingent on the availability of power from the electrical grid. The peak consumption of grid power occurs on the seventh day. During this period, EVs utilised only 1,795 watts of fossil energy, while the PV system contributed a substantial 17,318 watts. The energy management strategy employed at these stations has effectively reduced fossil energy usage by up to 90%. Furthermore, any excess power generated by the PV system was directed towards charging batteries, which significantly enhances fossil energy savings.

However, a notable limitation arises from the predominant reliance on PV energy, as batteries cannot be charged during nighttime. This situation was not deemed problematic since the charging station was situated within a campus environment, which typically experiences low activity levels at night. Grid power was only harnessed when there was an increase in EV demand, which predominantly occurs during daylight hours. Future research should explore the operation of charging stations during nighttime to address more complex scenarios similar to those encountered in public area stations. Such investigations will deepen the understanding of energy management across varied operational contexts and aid in the optimisation of renewable energy sources within the broader energy grid. For future research, it is essential to consider the operation of charging stations at night to introduce a more complex scenario akin to charging stations located in public areas.

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