A Microgrid-Based Energy Management Framework for Resilient Electric Vehicle Charging Infrastructure in Transportation Systems

G. Shanmugasundar
Department of Mechanical Engineering
Sri Sairam Engineering College
Chennai 600044, India
ORCID: 0000-0002-5608-7737
shanmugasundar.mech@sairamit.edu.in

D. Manohari
Department of Computer Science and Engineering
PERI Institute of Technology
Chennai 600048, India
pericseofficial@gmail.com

Shakila D
Department of Electronics and Communication Engineering
Cambridge Institute of Technology
KR Puram, Bengaluru 560036, India
lakshmi.cse@cambridge.edu.in

Ahmad Alkhayyat
Department of Computers Techniques Engineering, College of Technical Engineering
The Islamic University
Najaf, Iraq
ahmedalkhayyat85@gmail.com

Pushpendra Kumar Rajput
Department of Computer Science and Engineering ,Sharda School of Computing Science and Engineering
Sharda University
Greater Noida, India
pushpendrakumar.rajput@sharda.ac.in

Anita Saroj
Department of Computer Science and Engineering
Graphic Era (Deemed to be University)
Dehradun, India
anitasaroj.cse@geu.ac.in

B. Swarna
University Centre for Research and Development
Chandigarh University
Mohali 140413, India
bswarna261@gmail.com

***Abstract*—This paper introduces an energy management framework based on microgrids for resilient EV charging infrastructure in transportation systems. The suggested system consists of a solar photovoltaic array, a battery storage system, a utility grid interface, a common DC bus, an EV charger, power electronic conversions, and a supervisory microgrid energy management controller. The controller manages the solar PV use, battery charging/discharging, grid import, and EV charging demand according to the availability of renewables, battery SOC, variable tariff, and grid state. A comparative analysis of EV charging with grid supply versus EV charging with microgrid supply was conducted using a simulation technique over a 24-hour period. The results indicate that the proposed framework could achieve a reduction in the energy consumed by the grid from 2013 kWh to 1044 kWh, which is a reduction in grid dependency of 48.14% per day. The peak reduction in grid import was 26.32%, with a peak from 190 kW to 140 kW. The reduction in daily operating expenses from 355.35 USD to 192.17 USD resulted in a cost saving of 45.92%. The microgrid supplied a total of 969 kWh/day to meet the EV charging demand through solar PV generation and battery support.**

Keywords*— *Electric vehicle charging, microgrid, energy management system, solar PV, battery energy storage, transportation electrification, charging resilience, grid dependency reduction

I. INTRODUCTION

The pace of electrification in the transportation sector has also grown the need for dependable, effective, and sustainable charging infrastructure for electric vehicles (EVs) [1]. With the increasing penetration of EVs, charging stations are shifting from a low-power electrical load to a high-power electrical load, which can impact distribution networks and load characteristics, particularly during high charging periods. Traditional grid-only EV charging solutions rely solely on the utility source, potentially leading to higher peak demand, cost, voltage stress, and dependency. These challenges are exacerbated in urban and transportation-oriented locations, where charging demand for EVs is time-varying and often highly localized, particularly through the morning, afternoon, and evening mobility window [2] [3].

The main advantage of the microgrids is their ability to combine distributed energy resources, battery energy storage systems, connections to the utility grid, and intelligent energy management controllers. The microgrid-based EV charging station may be deployed to model the solar PV (photovoltaic) generation, battery energy storage, grid import, and EV charging load. This coordinated operation enables better use of renewables, decreases reliance on the grid, and increases charging resilience in facing fluctuating grid and environmental conditions [4] [5].

Recent developments in renewable energy technologies and smart-grid-supporting infrastructure have further enhanced the efficiency and sustainability of renewable-powered energy systems [6] [7]. Although solar PV-assisted EV charging stations can lower the carbon intensity of charging, solar generation tends to be intermittent and typically occurs during peak hours of the day, whereas EV charging can peak during evening hours. Advanced energy storage technologies are increasingly recognized as essential enablers of sustainable energy systems, helping improve renewable energy utilization and overall energy management performance in modern power networks [8].

Microgrid-based EV charging infrastructure is important in the context of energy management systems. Intelligent energy management strategies have been increasingly adopted to optimize energy utilization, reduce operational costs, and improve system efficiency in distributed energy systems [9]. Optimization of energy management can lower peak grid

import, lower operating cost, utilize battery usage to the maximum extent, and facilitate grid-friendly charging [10]. Optimization algorithms, artificial intelligence, fuzzy logic, and predictive scheduling approaches have been employed to enhance the operation of EV charging microgrids in a variable renewable scenario, and varying electricity prices have been investigated recently [11] [12].

Another key need for the EV charging infrastructure in transportation systems is resilience. The growing importance of EVs has led to increased awareness that the loss of charging stations can impact public mobility, logistics, emergency services, and urban transport reliability—making charging stations a vital part of infrastructure. Charging station reliability can be impacted by grid outages, cyber-physical disturbances, weather-related disruptions, and power quality issues. Thus, it is essential to incorporate local energy resources and support energy storage, monitoring, and intelligent control in resilient EV charging infrastructure to ensure charging continuity during disturbances [13].

In this context, the present study suggests an energy management framework that is based on microgrids for resilient EV charging infrastructure in transportation systems. The proposed system includes a solar PV array, battery energy storage system, utility grid interface, DC bus, EV charger, and microgrid energy management controller. A simulation-based comparative study is conducted between a conventional grid-only EV charging system and a microgrid-based EV charging system. EV charging load, solar PV generation, battery state of charge, grid import, operating cost, reduction in peak demand, and the contribution to charging load by the microgrid are used to assess performance. The primary goal is to show how the microgrid integration can decrease reliance on the grid, decrease operating expenses, increase utilization of renewables, and increase EV charging resilience.

II. Methodology

The comparative research design was employed in this study to compare the performance of a microgrid-based energy management framework for electric vehicle (EV) charging infrastructure in transportation systems, using a simulation approach. In the proposed framework, which is shown in fig. 1, the two operating conditions were considered: the conventional charging system for EVs and the microgrid-based charging system with PV generation, BESS, and energy management control. The performance was tested for 24 hours of operation, based on the EV charging demand, solar PV generation, grid import from the utility company, battery SOC, and time-varying electricity tariff. The primary goal of the methodology was to assess the potential of integrating microgrids to decrease grid dependence, lower peak grid import, improve renewable energy utilization, lower daily operating cost, and improve the resilience of EV charging infrastructure. The simulation was designed to mimic a transportation charging station with EV charging demand fluctuating across the day with morning, afternoon, and evening travel patterns.

The proposed system was an EV charging station coupled with a local microgrid. The microgrid consisted of solar PV generation, battery energy storage, utility grid connection, EV charging load, power electronic converters, metering devices, and an energy management system. Solar PV generation provided charging demand in the daytime. The battery storage system stored excess renewable energy to release it when there was less sunlight or high demand. When PVs and batteries were unable to provide the rest of the charging demand, the utility grid was used.

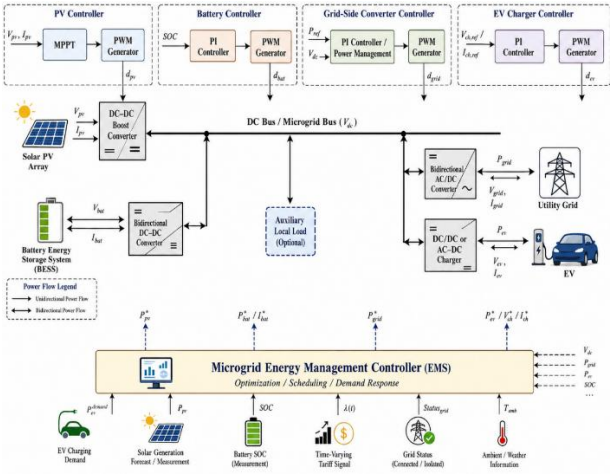

Fig. 1. Proposed microgrid-based EV charging energy management framework

The energy management system managed power sharing between PV generation, battery storage, and the grid. The system optimized PV utilization and battery charging during the high sun generation hours. The system focused on the utilization of PV and the charging of battery systems during the high sun-generation hours. The battery discharged at night during its peak charge demand and high electricity tariff to minimize import on the grid. The aim of this operating strategy was to increase the resilience and economic viability of EV charging infrastructure.

The simulation dataset was created to simulate an EV charging station in a transportation environment for a 24-hour period of time. Hourly EV charging load ranged from 18 kW up to 190 kW. Solar PV generation ranged from 0 kW at night to up to 190 kW around midday. It was assumed in the grid-only system that the required charging power would be imported from the grid. The microgrid-based system, on the other hand, lowered the need for grid imports due to local PV generation and battery support.

The main assumptions used in the simulation were as follows:

$$[T = 1,2,3,\dots,24] \qquad (1)$$

Where,

T represents the 24-hour scheduling period.

$\mathrm{P}EV(t) =$ EV charging demand at hour t

$\mathrm{P}PV(t) =$ solar PV generation at hour t

$\mathrm{P}G(t) =$ utility grid import at hour t

$\mathrm{P}B(t) =$ battery charging or discharging power at hour t

$SOC(t) =$ battery state of charge at hour t

$Ct =$ electricity tariff at hour t

The grid-only EV charging system was modelled as:

$$\mathrm{P}G, only(t) = P_{EV}(t) \qquad (2)$$

This means that all EV charging demand was supplied by the utility grid in the conventional case.

For the microgrid-based EV charging system, the EV demand was supplied by a combination of solar PV, battery storage, and grid import:

$$\mathrm{P}EV(t) = P_{PV,used}(t) + P_{B,dis}(t) + P_{G,micro}(t) \quad (3)$$

where $P_{PV,used}(t)$ represents PV power directly used for EV charging, $P_{B,dis}(t)$ represents battery discharging power, and $P_{G,micro}(t)$ represents grid import under microgrid-based operation.

The addition of battery storage was incorporated to increase charging resilience and decrease grid import during high-demand and high-tariff periods. The state of charge of the battery was modeled based on its charging and discharging. The battery was charged with excess PV generation during periods of high solar output. During evening peak demand, the battery discharged to serve the EV-charging demand.

The SOC update is presented as follows:

$$SOC(t+1) = SOC(t) + \eta_c P_{B,ch}(t) - \frac{P_{B,dis}(t)}{\eta_d} \quad (4)$$

where η_c is the battery charging efficiency, η_d is the battery discharging efficiency, $P_{B,ch}(t)$ is battery charging power, and $P_{B,dis}(t)$ is battery discharging power.

The battery SOC was operated within safe limits:

$$SOC_{min} \le SOC(t) \le SOC_{max} \quad (5)$$

This constraint ensured that the battery did not overcharge or over-discharge during EV charging operation.

The energy management strategy followed a priority-based control logic. Solar PV generation was given first priority because it represented locally available renewable energy. Battery storage was given second priority to support charging demand during low-solar and high-tariff hours. Utility grid import was used as the final source when PV and battery resources were insufficient.

The control logic can be summarized as follows:

- If solar PV generation was available, it was used first to supply EV charging demand.
- If PV generation exceeded charging demand, surplus PV energy was used to charge the battery.
- If EV charging demand exceeded PV generation, the battery discharged to reduce grid import.
- If both PV and battery power were insufficient, the remaining demand was supplied by the utility grid.
- During high-tariff periods, battery discharge was prioritized to reduce operating cost.
- Battery operation was limited by SOC constraints.
- The microgrid-based grid import was therefore minimized as:

$$\mathrm{P}G, micro(t) = P_{EV}(t) - P_{PV,used}(t) - P_{B,dis}(t) \quad (6)$$

subject to:

$$P_{G,micro}(t) \ge 0 \quad (7)$$

The daily operating cost of EV charging was calculated using the hourly grid import and time-varying electricity tariff. For the grid-only charging system, the daily cost was calculated as:

$$Cost_{grid} = \sum_{t=1}^{24} P_{G,only}(t) \times C_t \quad (8)$$

For the microgrid-based charging system, the daily cost was calculated as:

$$Cost_{micro} = \sum_{t=1}^{24} P_{G,micro}(t) \times C_t \quad (9)$$

The cost saving achieved through microgrid integration was calculated as:

$$Cost\ Saving = \frac{Cost_{grid} - Cost_{micro}}{Cost_{grid}} \times 100 \quad (10)$$

The proposed framework was evaluated using key operational and economic indicators.

Daily grid energy use was calculated as:

$$E_G = \sum_{t=1}^{24} P_G(t) \quad (11)$$

Peak grid import was calculated as:

$$P_{peak} = max\big(P_G(t)\big) \quad (12)$$

Grid dependency reduction was calculated as:

$$\text{Grid Dependency Reduction} = \frac{\mathrm{E_{G,only}} - \mathrm{E_{G,micro}}}{\mathrm{E_{G,only}}} \times 100 \quad (13)$$

Peak grid import reduction was calculated as:

$$\text{Peak Reduction (\%)} = \frac{\mathrm{P_{peak,only}} - \mathrm{P_{peak,micro}}}{\mathrm{P_{peak,only}}} \times 100 \quad (14)$$

Microgrid contribution to EV charging demand was calculated as:

$$E_{micro} = E_{EV} - E_{G,micro} \quad (15)$$

Where,

$$E_{EV} = \sum_{t=1}^{24} P_{EV}(t) \quad (16)$$

The percentage contribution of microgrid resources was calculated as:

$$\text{Microgrid Contribution} = \frac{E_{micro}}{E_{EV}} \times 100 \quad (17)$$

The following procedure was used for the simulation: Initially, the hourly charging demand for EVs, generation for

solar PV, electricity tariffs, and battery SOC were set for a 24-hour period. Second, the grid-only EV charging operation was simulated by assuming that all the EV charging demand is met by the utility grid. Third, the operation of the microgrid charging was simulated by allocating the solar PV power, battery charging/discharging, and grid import according to the energy management strategy. Fourth, battery SOC was updated for every hour, and the operating limits were kept safe. Fifth, import was also computed for each hour for both systems. Lastly, the energy consumption from the grid, peak import from the grid, cost of operation, battery SOC profile, and microgrid contribution were computed and compared for one day.

The methodology offered a systematic approach to understanding the contribution of microgrids to the transportation systems' EV charging infrastructure. The study was able to quantify the technical and economic advantage of a microgrid infrastructure when combined with solar PV and battery storage and energy management control by comparing the two approaches. The study compared grid-only charging with a microgrid-based charging system to quantify the technical and economic benefits of integrating solar PV, battery storage, and energy management control. The chosen performance indicators enabled a clear assessment of how well grid dependency was reduced, how peak loads were mitigated, cost savings were achieved, renewable energy was used, and charging resilience was maintained.

III. Results and Discussion

The energy management framework suggested in the microgrids was tested with a 24-hour simulation of an electric vehicle (EV) charging infrastructure for transportation systems. The performance of a conventional grid-only EV charging station was compared to a microgrid-based EV charging station with solar PV generation, battery energy storage, and energy management control. The assessment was based on EV charging demand, availability of solar generation, reduction in grid import, battery state of charge, operating cost, and contribution of the microgrid.

The area chart in Fig. 2 shows the demand and generation of EVs and solar PV for a 24-hour operating period. The charging load of EVs was also low in late nights, ranging from 18 kW to 35 kW between 00:00 and 05:00. The demand picked up from morning to 110 kW by 08:00. A second, more pronounced increase in demand was seen during the evening peak time for transportation, when the EV charging demand peaked at 190 kW at 18:00.

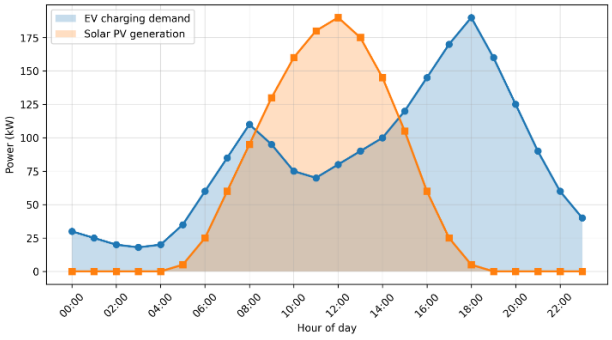

Fig. 2. Area-style profile of EV charging demand and solar PV generation.

Solar PV generation was as expected throughout the day. It was not available in the night; it was increasing after sunrise and peaked at 190 kW at 12:00. Solar generation, however, fell off quickly after 15:00 and was practically unavailable during the peak evening charging times. This mismatch between the energy generated from the sun during the day and the energy consumed by EVs at night shows the need for battery energy storage and energy management within the transportation charging infrastructure. The results indicate that relying solely on direct solar support is inadequate for ensuring reliable EV charging, especially during peak evening demand.

Fig. 3 compares grid-only EV charging with microgrid-based EV charging under a time-varying electricity tariff. In the grid-only charging scenario, the utility grid provided all the charging power, so the amount of power imported from the grid was directly related to the amount of power needed for charging. The grid-only charging case resulted in the highest grid import of 190 kW during the evening. This situation puts strain on the distribution grid, especially given the context of high electricity prices.

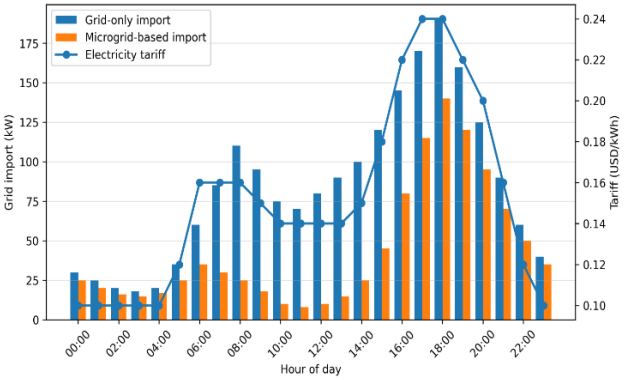

Fig. 3. Grid import comparison with time-varying electricity tariff

In the microgrid-based case, the contribution of solar PV and battery storage resulted in a reduction in grid import for most of the day. The microgrid helped significantly decrease reliance on the grid during periods of high solar energy. For example, the grid import decreased to very low values between 10:00 and 13:00, when solar generation was high. The grid import rose again during evening peak hours due to minimal solar PV generation but was still lower than grid-only due to the battery's contribution to meeting the charging demand. The highest price for electricity, 0.24 USD/kWh, occurred during the evening period, as indicated by the time-varying tariff curve. Therefore, during the period, grid import reduction was technically and economically advantageous.

Fig. 4 shows the energy contribution of the utility grid supply and the microgrid to the EV charging demand in a stacked power profile. The green line is the EV charging demand, and the stacked areas indicate the utility grid and microgrid resources that met the EV charging demand. During the early morning, the contribution from the microgrid was relatively small, as solar generation was not available and the battery was already providing some low-load support. However, during the daytime with solar PV generation, the contribution from the microgrid was much greater.

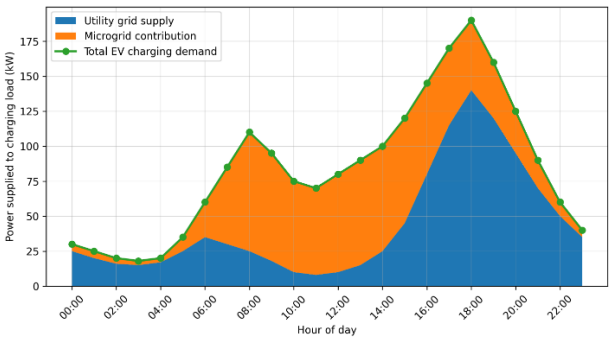

Fig. 4. Stacked energy contribution in microgrid-based EV charging

During the daytime hours of 09:00 to 14:00, when solar power generation peaked, the microgrid provided the best support. During this time period, the microgrid met a significant amount of charging requirements while the utility grid contribution decreased. During the evening time, solar generation was lower; however, battery energy storage remained to limit the overall contribution to the utility grid. This outcome validates the energy management framework developed based on the microgrid, which enhances energy sharing and management between PV, battery storage, and the utility grid.

Fig. 5 presents a step plot of the battery state of charge (SOC) and microgrid-based grid import. The battery SOC dropped from 45% at 00:00 to 25% around 07:00, reflecting battery discharge towards the early morning when solar PV generation was unavailable. The SOC began to rise following sunrise because of the sun's charging, and the maximum value reached was 88% at 14:00. This is a confirmation that solar PV generation was utilized not only for charging the EV but also to charge the battery storage system.

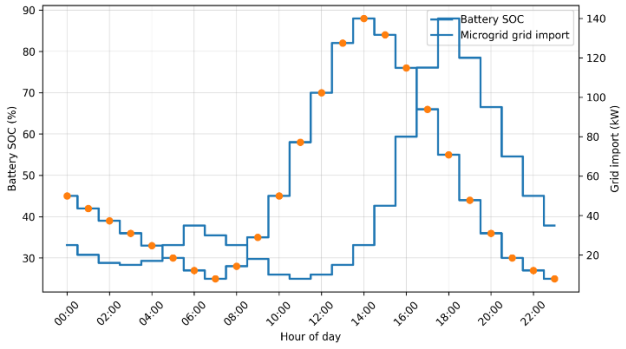

Fig. 5. Battery state of charge and microgrid grid import profile

Following 14:00, the SOC slowly reduced as the battery was used to satisfy EV charging demand for the afternoon and evening. Energy that was stored in the battery was used during times of low solar production and high electricity prices, causing the state of charge (SOC) to drop to 25% at the end of the day. The grid contribution increased during the evening peak period; however, the peak import to the grid was reduced to 140 kW with the battery system, compared to 190 kW without it. This data illustrates how battery storage can be used for peak-load shaving and resilience against charging.

Fig. 6 contains a horizontal bar chart that compares operational performance indicators. This EV charging system in grid mode consumed 2013 KWh of grid energy and had a peak grid import of 190 kW. The microgrid-based EV charging implementation, on the other hand, cut peak energy consumption from the grid to 140 kW and energy use from the grid per day to 1044 kWh. This translates to a reduction of 26.32% on the peak grid import and 48.14% on the grid dependency.

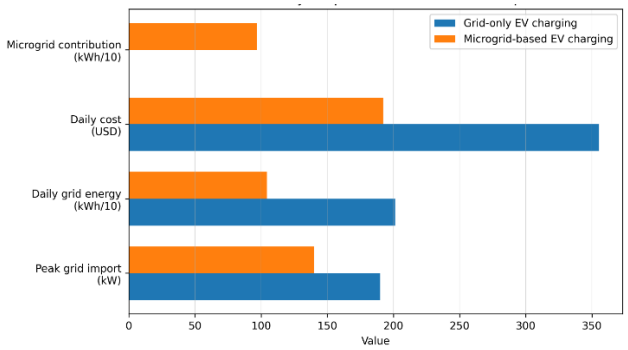

Fig. 6. Operational performance comparison between grid-only and microgrid-based EV charging

There was also a substantial decrease in the daily operating cost. The electricity cost in the grid-only system was 355.35 USD, while in the microgrid-based system, it was 192.17 USD. This is a savings of 45.92% per day. This reduction was accomplished by decreasing grid imports during peak hours at high tariffs and when there was a high proportion of solar energy. Solar PV generation and battery energy storage also helped support 969 kWh/day of EV charging demand within the microgrid.

The scatter-bubble graph in fig. 7 illustrates the relationship between the EV charging demand and the microgrid-based grid import, with the size of the individual bubbles indicating the electricity tariff. The graph reveals that overall, greater import of electricity into the grid occurred during times of high charging demand for EVs. But several points indicate lower grid import at moderate demand even, primarily because of solar PV support and battery operation.

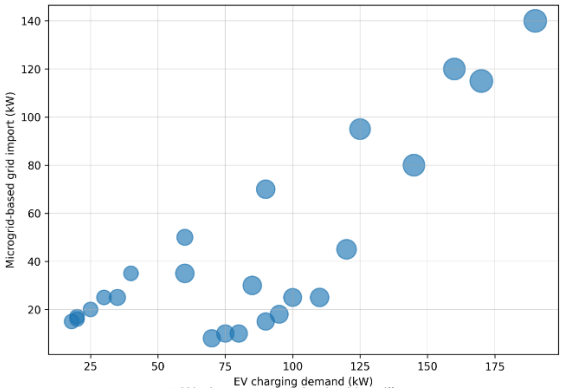

Fig. 7. Scatter-bubble relationship between EV charging demand, grid import, and tariff

The larger the bubble, the higher the tariff, particularly during the late afternoon and evening. During these hours, the microgrid's energy management system offloaded a portion of the grid but continued to import energy due to low solar generation and high charge demands. This outcome suggests that it has significance to have tariff-aware control in EV charging microgrids. The microgrid can smooth out the loading of the grid during high-tariff hours and take full advantage of stored energy, which can lead to lower operating expenses and better charging economics.

Fig. 8 displays the normalized trends of EV demand, solar PV generation, grid import, and grid SOC. The solar PV index

peaked during the day while the EV demand peaked during the evening. This illustrates the mismatch in time between generating renewable energy sources and charging transportation vehicles. The SOC index of the battery was rising during the periods when the sun was present and falling during the evening peak hours, demonstrating the storage system's ability to "time-shift" renewable energy.

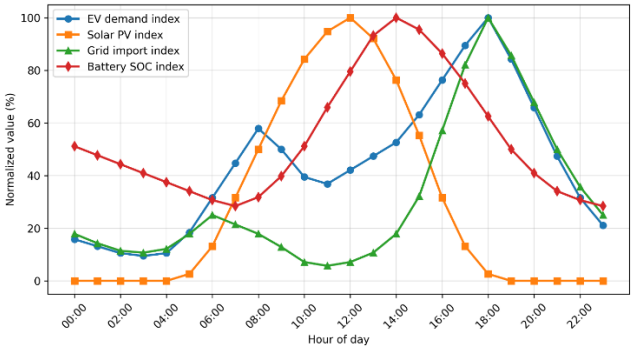

Fig. 8. Indexed trend of normalized microgrid operating variables

The index for solar imports to the grid stayed low during peak solar generation times and peaked during periods of high demand. This behavior proves that the microgrid controller was able to decrease the dependency on the grid when renewable energy was available and to draw from the battery when solar energy was not. The PV generation, battery storage, and grid import are coordinated as part of the proposed energy management, as reflected in the trend that is being indexed.

The overall performance comparison shows the efficiency of the proposed energy management system for the microgrid in improving the performance of EV charging infrastructure in transportation systems. The framework resulted in a reduction in energy consumed from the grid by the daily power consumption, which dropped from 2013 kWh in 2013 to 1044 kWh. Similarly, the peak power that needs to be imported into the grid was reduced from 190 kW to 140 kW. The cost of operation per day was lowered from 355.35 USD to 192.17 USD. The microgrid provided 969 kWh/day of energy demand for EV charging, which is 48.14% of the daily energy demand for EV charging.

The findings illustrate how well the integration of microgrids can enhance the resilience, sustainability, and economic efficiency of EV charging systems. Utilizing solar PV generation helps to lessen reliance on the utility grid during the day, and battery storage helps to meet charging demand during periods of low PV generation and high charging costs. Hence, the proposed framework involving a microgrid is compatible with the transportation electrification applications where there is a need for reliable, low-cost, and renewable-supported EV charging infrastructure.

IV. Conclusion

This paper proposed a microgrid-based energy management solution for resilient electric vehicle charging stations in transportation systems. The proposed framework comprised solar PVs, battery energy storage, a grid interface, EV charging units, a converter (power electronics), and a microgrid energy management controller. This energy management strategy integrates solar PV utilization, battery charging/discharging, importing from the grid, and charging demand from EVs, according to the availability of renewables, battery state of charge, time-varying electricity tariffs, and the operating status of the grid. A comparison was made between a traditional EV charging system (based on only a grid) and the proposed EV charging system (based on a microgrid) through a simulation of the two systems over a 24-hour period. The presence of microgrids greatly enhanced the operation of EV charging infrastructure, as the findings revealed. The grid's energy consumption decreased from 2013 kWh to 1044 kWh per day, a reduction of 48.14%. Peak grid import was reduced from 190 KW to 140 KW, a 26.32% reduction in peak load. Furthermore, the daily running cost is decreased from 355.35 USD to 192.17 USD, saving 45.92%. This microgrid provided 969 kWh/day of the EV charging demand via solar PV generation and battery energy storage support. The results validate that the use of microgrid-based EV charging infrastructure can help mitigate grid stress, better utilize renewable energy, decrease operating cost, and increase charging resilience.

References

[1] G. Shanmugasundar, J. V. N. Ramesh, K. Karthik, S. Muthukumarasamy, V. Ramesh, S. Rathee and A. Kumar, Enhancing accessibility and interaction in autonomous vehicles, Wiley, 2025, p. 233–250.

[2] H. Jin, S. H. Nengroo, S. Lee and D. Har, “Power management of microgrid integrated with electric vehicles in residential parking station,” in 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, 2021.

[3] M. Colley et al., “Accessible autonomous vehicles: A human–computer interaction literature review,” in Proc. ACM Conference on Human Factors in Computing Systems, 2025.

[4] J. Engelhardt, J. M. Zepter, T. Gabderakhmanova and M. Marinelli, "Energy management of a multi-battery system for renewable-based high power EV charging," eTransportation, vol. 14, p. 100198, November 2022.

[5] A. K. Karmaker, M. A. Hossain, H. R. Pota, A. Onen and J. Jung, “Energy management system for hybrid renewable energy-based electric vehicle charging station,” IEEE Access, vol. 11, p. 27793–27805, 2023.

[6] Sundaram and S. Balamurugan, “Enhanced Thermo-physical properties of titanium dioxide nanofluids: Applications in renewable energy systems and smart grid cooling technologies,” in 2025 International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, 2025.

[7] Sundaram and S. Balamurugan, “Viscosity behaviour of multi-walled carbon nanotube nanofluids for advanced renewable energy cooling and storage systems,” in 2025 International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, 2025.

[8] S. Manikandan, Y. Devarajan and S. Vickram, "Advancing thermal energy storage with industrial and agricultural waste-derived phase change materials: A path towards sustainable energy systems," Process Saf. Environ. Prot., vol. 198, p. 107068, June 2025.

[9] G. Shanmugasundar, "Optimizing smart home energy analysis with sailfish and random forest algorithms," in Studies in Computational Intelligence, Cham, Springer Nature Switzerland, 2025, p. 603–616.

[10] G. Shanmugasundar, "Innovative machine learning techniques for pedestrian detection in autonomous vehicles," in Studies in Computational Intelligence, Cham, Springer Nature Switzerland, 2025, p. 231–247.

[11] K. N. D. V. Sai Eswar, M. Arun Noyal Doss, M. Shorfuzzaman and A. Elrashidi, “Microgrid system for electric vehicle charging stations integrated with renewable energy sources using a hybrid DOA–SBNN approach,” Front. Energy Res., vol. 12, January 2025.

[12] M. T. Sarker, M. Al Qwaid, S. J. Shern and G. Ramasamy, "AI-driven optimization framework for smart EV charging systems integrated with solar PV and BESS in high-density residential environments," World Electric Veh. J., vol. 16, p. 385, July 2025.

[13] E. Mogire, P. Kilbourn and R. Luke, "Resilient electric vehicle charging stations in urban areas: A systematic literature review," World Electric Veh. J., vol. 17, p. 148, March 2026.

.