International Journal of Trend in Innovative Research (IJTIIR)
Available Online @ www.ijtiir.com | ISSN: 2582-0354

Optimized Renewable Energy Allocation for Electric Vehicle Charging: Hybrid Control of Grid, Storage, and Renewable Sources

[1]Harshal B Patil, MTech Scholar, RKDF College of Engineering Bhopal (MP)
[2]Pramod Kumar Rathore, Assistant Professor, RKDF College of Engineering Bhopal (MP)

Abstract-- The energy management method for renewable energy sources at the EV charging station is provided in Approaches I and II. The initial strategy of the energy flow management system (EFMS) is to optimize the usage of real-time renewable energy for electric vehicle (EV) loads, while also ensuring the economical use of energy storage batteries and the grid for EV charging. The method is to attain economic advantages, enhance renewable energy use, minimize grid energy consumption during peak load periods, and operate energy storage battery systems efficiently. A multi-objective algorithm is developed to attain these objectives. A traditional, unstructured charging method is contrasted with the suggested approach. The efficacy of the EFMS has been assessed using MATLAB software, with studies and findings provided to illustrate the system's usefulness. Approach II introduces a human-driven instruction-based optimization (HDIBO) approach for an electric vehicle charging station connected to a grid and renewable energy sources. This method is intended for the optimization of proportional-integral (PI) controllers. The aim of the proposed system is to effectively allocate renewable energy to electric car loads, optimize the use of energy storage batteries, and assist the local grid.

Keywords-- Energy Flow Management Strategy (EFMS), Renewable Energy, Electric Vehicle (EV) Charging, Energy Storage Battery, Grid Energy, Multi-Objective Algorithm, MATLAB Simulation, Peak Load Reduction, Economic Optimization, Human-Driven Instruction-Based Optimization (HDIBO), Proportional-Integral (PI) Controller, Smart Charging, Renewable Energy Integration, Grid Support.

I. INTRODUCTION

Solar and wind energy sources are becoming beneficial as alternate methods for fulfilling energy demands. The strategic management of these resources is essential to maximize their use for the energy requirements of charging stations. India has considerable solar energy potential. India has a significant energy potential of over 5,000 trillion kWh annually throughout its whole territory. Typically, most areas get an average of 4 to 7 kWh per square meter each day. India has significant potential for the growth of solar photovoltaic energy. Solar energy has the advantage of decentralized power production and enables rapid and effective capacity expansion. Decentralized, off-grid, and low-temperature applications provide significant benefits for meeting energy needs in rural and urban environments.

Implementing energy management systems at charging stations provides substantial advantages for both station operators and electric car owners. Implementing energy management systems at charging stations offers significant benefits for both station operators and electric car owners.

- Revenue Optimization: EMS technologies enable station operators to optimize energy distribution and boost operational efficiency, resulting in increased revenue. Operators may enhance revenue by accommodating a larger population of EV owners, leading to reduced downtimes and accelerated charging rates.
- Reduced operating Expenses: Efficient energy management may substantially decrease operating expenses for charging stations. Efficient load distribution and advanced charging algorithms enhance power use, leading to reduced energy costs and alleviating system stress during peak demand times.
- Enhanced Electric car User Experience: Energy management systems augment the reliability and efficiency of charging services, resulting in a more satisfactory experience for electric car owners. Through the implementation of efficient procedures and the assurance of reliable performance, EMS solutions markedly improve the adoption and satisfaction rates of EV users.
- EMS solutions are essential for the establishment of an effective and sustainable charging infrastructure. Utilizing sophisticated charging algorithms and load balancing techniques, these solutions foster a more sustainable and environmentally friendly future. Employing renewable energy sources and strategically scheduling charging during off-peak hours may enhance the energy efficiency of charging stations, significantly reducing their environmental footprint.
- Evidence-Based Decision Making: Energy management solutions provide essential insights via data analytics, allowing enterprises to make informed choices about infrastructure improvements, capacity planning, and revenue optimization. Operators may efficiently modify and augment their charging networks, giving them improved control and adaptability.

II. RESEARCH OBJECTIVES

- To maximize the utilization of renewable energy for electric vehicle charging while minimizing grid dependency, especially during peak load periods.
- To ensure efficient and economical operation of energy storage batteries through optimized charging and discharging strategies.
- To develop and validate a multi-objective energy flow management system (EFMS) that outperforms traditional charging methods using MATLAB-based simulations.

III. LITERATURE REVIEW

Ashish Kumar Karmaker; Md. Alamgir Hossain; Hemanshu Roy Pota [1] This work presents an energy management algorithm for a hybrid electric vehicle charging station (EVCS) utilizing solar and biogas, addressing techno-economic and environmental considerations. The suggested technique is intended for a 20-kW Electric Vehicle Charging Station (EVCS) and employs a fuzzy inference system in MATLAB SIMULINK to regulate power generation, electric vehicle power demand, charging intervals, and current charging rates to maximize real-time charging expenses and renewable energy usage.

Seema Mahadik; Pabitra Guchhait [2] This thesis is to develop a solar-powered charging station for urban environments utilizing solar energy. Popular commercial electric vehicles are considered while developing simplified electric vehicle load models. The electric vehicle battery is recharged by both solar energy and the electrical grid. The PID principle is utilized in all applications requiring precise and efficient automated control, since it autonomously adjusts a control function promptly and accurately. The current value of the SP PV error, e(t), is inversely related to term P.

R. Madhumitha; P. Priya; S. Saravanan [3] In the age of electrified transportation, insufficient charging infrastructure and the absence of energy storage technologies are significant issues that must be resolved to encourage customers to swiftly transition to Electric Vehicles (EVs). The extensive integration of these cars into the electrical grid may impose significant strain on the current infrastructure.

Mangal S. Kushwah; Mohd Azeem; Prasant Kumar [4] Vehicles are considered essential components of daily life for various forms of mobility. The rising global apprehension over air pollution prompted us to transition to electric automobiles. Therefore, it is essential to establish an extensive network of charging stations. Charging stations powered by hybrid renewable energy will contribute to a healthier environment and reduce the burden on the main grid.

Mohd Azeem; Prasant Kumar; Ashish Singhal [5] When solar PV irradiation was inadequate, a combination of solar energy, a diesel generator, and an electric vehicle yielded a good result in sustaining a dependable power supply. A solar energy system serves as the principal energy source for the building, engineered to fulfill all of its daily energy needs. During inadequate solar irradiation, auxiliary energy storage solutions, like plug-in hybrid electric cars and diesel generators, are employed to provide an uninterrupted power supply. Three-phase active filters are utilized in electrical systems to enhance power quality, manage power, and rectify imbalances.

Ahmed M. A. Haidar; Lim Wei Han; Tony Ahfock [6] The transportation industry in Sarawak is entirely reliant on fossil fuels, resulting in significant greenhouse gas emissions. An appropriate design of charging stations for electric vehicles (EVs) coupled with grid-connected renewable energy resources (RERs) can assist in mitigating this problem. This article aims to improve the operational needs of hybrid-powered electric vehicle charging stations (EVCSs) in Sarawak.

Yuanfei Li; Nan Zheng; Jun Zhang; Qiyuan Cai [7] Effective design of electric vehicle charging stations is essential for the systematic development of the electric car industry. This work constructs an optimization model for the design of electric car charging stations, utilizing least annual cost as the objective function while considering constraints related to charging capacity and investment.

Vaideeswaran V; Veerakumar S; Sharmeela C [8] Conventional electric car charging stations utilize regulated rectifiers with closed-loop operation. In these stations, the primary concern for the construction of charging stations at diverse places is the power quality of the grid. The simultaneous charging of several electric vehicles at a single station generates increased harmonic distortion and significantly reduces the power factor to the grid.

Ubaid Qureshi; Arnob Ghosh; Bijaya Ketan Panigrahi [9] The unregulated charging of electric vehicles can significantly affect the power distribution infrastructure, rendering the widespread adoption of electric mobility unfeasible. This work proposes an online sequence for charging and discharging decisions for electric cars at a commercial charging station, aimed at minimizing total charging costs while adhering to various limitations.

Sayali Ashok Jawale; Sanjay Kumar Singh; Pushpendra Singh [10] Advancements in electric car charging systems have been undertaken in several domains. In electric vehicle systems, factors such as bidirectional power flow, power converter control, charging control strategies, and charging station management are crucial for enhancing efficiency and performance prior to the implementation of electric vehicle charging stations.

IV. MODELING AND CONTROL OF SYSTEM COMPONENTS ENERGY MANAGEMENT STRATAGY

4.1 Introduction

The energy flow strategy for the charging station is proposed under approaches I and II.

In Approach I, a management strategy is intentionally designed to facilitate the charging of electric vehicles based on the real-time availability of renewable energy and the time-sensitive usage tariffs of the grid. This strategy entails charging the energy storage battery units during off-peak periods of the grid and utilizing surplus renewable energy. Conversely, discharging them during the peak demand for electric vehicles. The strategy seeks to attain economic advantages, increase renewable energy utilization for electric vehicle charging, and optimize the operation of energy storage battery systems. The proposed method is contrasted with a disorganized EV charging scheme under identical EV load and renewable energy source generation.

The structured management system provides various advantages for a charging station, particularly in terms of energy distribution between the grid and battery units, in a cost-effective manner. The optimal allocation of renewable energy for the charging of electric vehicles is emphasized throughout the study.

Approach-II employs a Human-driven instruction-based (HDIB) optimization technique for the fine-tuning of proportional-integral (PI) controllers.

The proposed system intends to efficiently supply renewable energy to electric vehicle loads, optimize the use of energy storage batteries, and bolster the local grid. The proposed optimization is being evaluated against other contemporary methods for the benchmark.

4.2 Energy Management Strategy Approach -I

The MATLAB software is utilized for a Simulink model of the proposed system. The model subsystem comprises an irradiation and temperature-inputted photovoltaic block, a wind energy converter, and a battery unit with measurement components. The grid system comprises a converter, an R-L load, a management algorithm control block, and an EV charging unit with a converter block. Figure 4.1 illustrates a Simulink model.

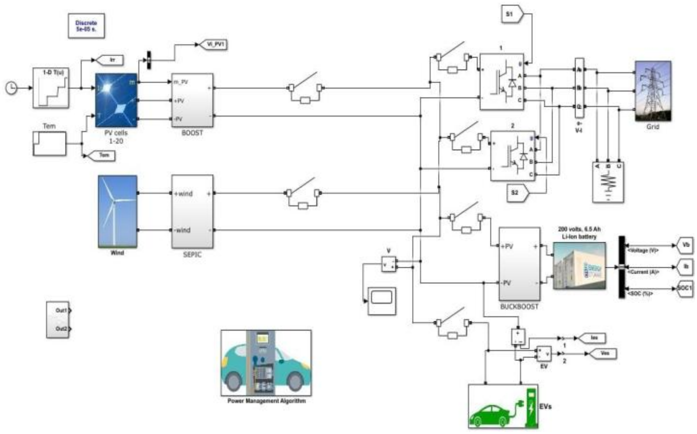

Figure 1: MATLAB simulation model

The simulation is executed utilizing MATLAB R2021b software. The energy management system is structured based on real-time load and generation information.

4.2.1 Energy management strategy (EMS) algorithm

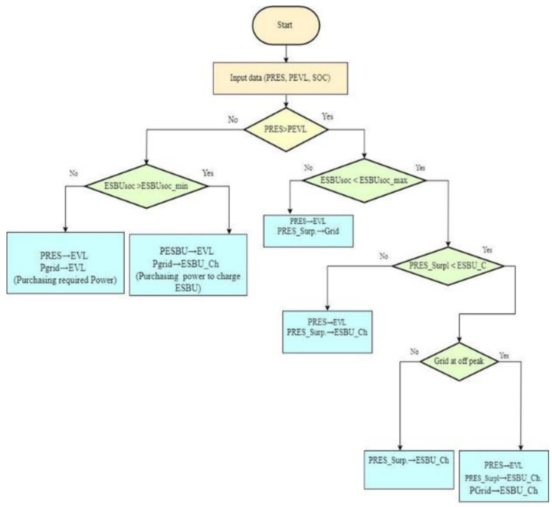

Figure 2: Emergency Medical Services algorithm

Figure 2 depicts the power flow algorithm; the power flow modes are formulated based on the current power generation from renewable energy sources and the status of the battery and grid at that moment. When the battery unit reaches its maximum state of charge, power is transmitted from the renewable energy source (RES) to the electric vehicle (EV) load; concurrently, any surplus from the RES is supplied to the grid. As the battery unit is not fully charged to its maximum capacity, any surplus renewable energy source (RES) electricity is first directed to the battery before being supplied to the grid network.

If the total solar wind power is insufficient to meet load demand and the battery unit is fully charged, the deficit energy is sourced from the battery to fulfill the EV load. If both sources remain inadequate, the required power is procured from the grid. If the ESBU SOC drops below the designated minimum threshold, the grid will provide the requisite power to maintain uninterrupted charging of electric vehicles.

4.2.2 EV Load Parameters

Table 1: EV model and battery rating

EV Model	Make	Rated battery capacity (KWh)
Tigor	Tata	26
Nexon	Tata	40.5
eVerito	Mahindra	21.2
Xpres-T	Tata	21.5
ZS	MG	45
Kona	Hyundai	39.2
eSupro	Mahindra	25

4.2.3 Parameters of proposed EMS approach-I

The system parameters utilized in Energy Management Approach-I are delineated in Table 2.

Table 2: System Parameters for EMS Approach-I

Particulars	Value	Unit
Rated power of photovoltaic system,;P_{pv}	100	KW
Individual PV Module rating	305	Wp
PV Module Efficiency; $□_{PV}$	17.5	%
Rating of WEC system P_{wt}	50	KW
Efficiency of WEC mechanism; $□_{wt}$	96	%
Wind Turbine operating wind speed range ($□_c$ to $□_r$)	2 to 10	m/s
Wind Turbine disconnect at speed;$□_o$	25	m/s
Energy storage battery unit name plate rating; PESBU	40	Kilowatthour
Charge-discharge Effectiveness; $□_{ESBU}$	96	%
Energy storage battery initial and final SOC range	10 to 90	%
Life cycles of ESBU, N_{cy}	3 □ 10^3	--
Capital cost of ESBU	15 □ 10^3	INR

4.3 Energy Management Approach – II

In the energy management approach II, the energy management strategy employs an HDIB optimization-based PI controller to effectively regulate power flow within the proposed system.

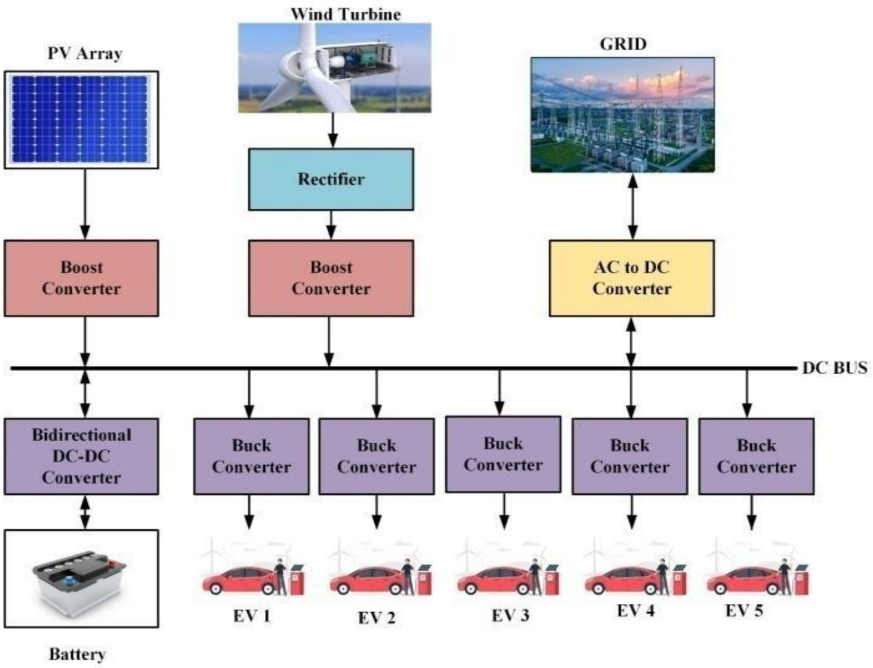

Figure 3: Proposed model of EMS-II

Figure 3 illustrates the system's structure. The system comprises several components, including photovoltaic panels, a wind-to-electricity mechanism, converters, a battery source, plugged electric vehicles, and a DC link.

The photovoltaic array converts received sunlight into direct current during the MPPT control process by utilizing the characteristics of PV cell output. The excess direct current power from renewable energy sources is transmitted to the grid via the voltage source converter.

V. RESULTS AND DISCUSSION

5.1 Results of EMS Approach – I

The outcomes of the proposed energy management strategy are presented herein. Figure 4 illustrates the instantaneous power output from renewable energy sources.

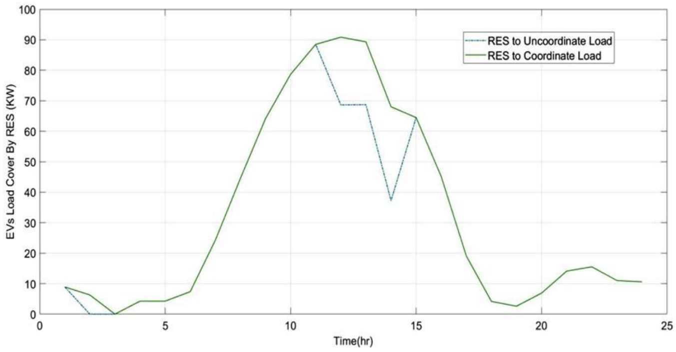

Figure 4: Electric vehicle charging supported by renewable energy

Figure 4 illustrates that the proposed charging scheme accommodates 770.8 KWh of electric vehicle (EV) load utilizing renewable energy, whereas the uncoordinated scheme supports 690.7 KWh of EV load through renewable energy. The proposed scheme attains a 5.2 percent superior load coverage compared to rival schemes.

Figure 5 illustrates that the proposed scheme utilizes 61.4 KWh of grid energy to meet EV demand, whereas competing schemes consume 105.3 KWh. As an essential element of the strategy, reduced energy is imported during peak grid hours while increased energy is imported during off-peak hours. This task is advantageous for profit enhancement for charging station operators. The system's effectiveness is clearly evident in the projected results.

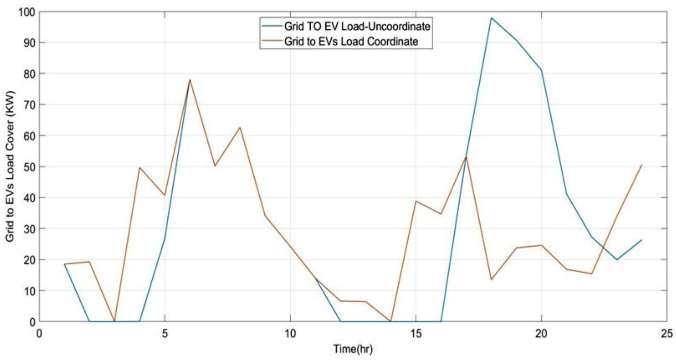

Figure 5: Electric Vehicle Load Supplied by Grid Energy

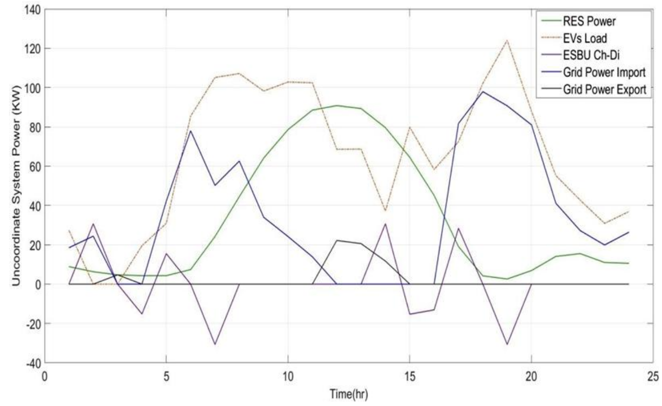

Figure 6: Baseline Scheme power distributions

Figures 6 and 7 depict the power flow in both the baseline and the developed scheme. The executed scheme effectively attains a greater utilization of renewable energy, specifically 770.8 KWh for the load, in contrast to the baseline scheme, which achieves only 690.7 KWh of renewable energy consumption.

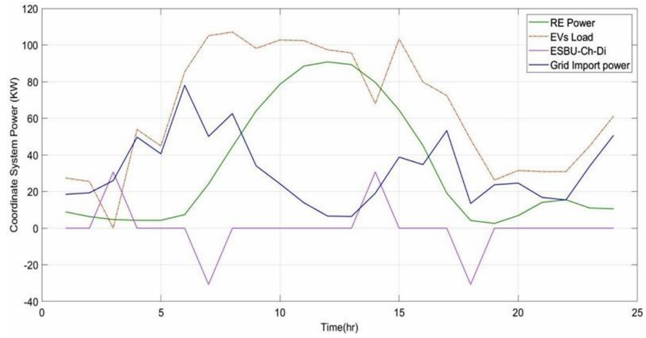

Figure 7: Proposed scheme Power flow

The outcome indicates that a diminished percentage of energy is sourced from the grid. The interval from 07:00 to 11:00 hours and from 18:00 to 22:00 hours is considered the peak period for the grid. The interval from 11:00 AM to 6:00 PM and from 10:00 PM to 7:00 AM is designated as off-peak hours according to Figure 5.4.

The strategic implementation of energy storage battery units and renewable energy substantially reduces the grid's energy consumption by 27.2% during peak hours. Table 5.3 presents a comparison of the performance between coordinated and uncoordinated charging schemes.

Table 3 Summary of performance statistics

Sr. No.	Parameters	Scheme	
		Base	Proposed
1	RE Consumption for EV Load (%)	87.8	98
2	Use of Grid energy during the grid's peak period (%)	64.3	37
3	Profit (%)	83	88

4	RECR within system	0.92	1
5	ESBU Ch-Di cycles	9	4
6	Operating Cost of ESBU (INR)	505.44	294.72

5.2 Results and Description of Energy Management Approach – II

This paragraph delineates the efficacy of the developed optimization technique, utilized to improve the performance of the PI controller for optimal power flow in the proposed system, as illustrated in Figure 4.9.

The system specification for EMS approach II is delineated in Table 4.4. The photovoltaic system's design configuration comprises a total of 41 modules, with 11 arranged in series and 30 in parallel. The capacity of a single module is 305 watts peak. Consequently, the system possesses an installed capacity of 100 KW. The module's sub-parameters are presented in Table 4.4. The secondary energy source at the charging station is a 50 kW capacity wind turbine, exhibiting an efficiency of 90% and employing a boost converter configuration analogous to the photovoltaic system. The third source is a battery unit with a capacity of 40 kWh, operating at 300 volts, which stores and delivers energy through a bidirectional converter. The system is designed to charge a maximum of five electric vehicles simultaneously, with a battery capacity ranging from 5 to 40 kWh. The EV battery charging power is sourced from the DC link through a converter. Statistics of the optimization process are displayed in Table 5.4.

Table 4: Specifications GA, PSO, Grey Wolf and HDIBO

Method	Depiction	Value
GA	Number of Population	100
	Maximum Number of Iteration	100
	Selection Process	Roulette wheel
	Cross Over rate	0.4
	Mutation rate	0.05
PSO	Number of Population	100
	Maximum Number of Iteration	100
	Inertial weight	0.9
	Cognitive Weight	1.5
	Social Weight	1.5
GWO	Number of Population	100
	Maximum Number of Iteration	100
HDIBO	Number of Population	100
	Maximum Number of Iteration	100

Table 4 delineates the parameters of Particle Swarm Optimization [103], Genetic Algorithm [108], Grey Wolf Optimization [107], and the proposed technique. HDIBO surpasses the existing gray wolf algorithm regarding performance, given an equivalent population size and iteration count.

Figure 8 illustrates the iteration graph of optimization, detailing the parameter values outlined in table 5.5.

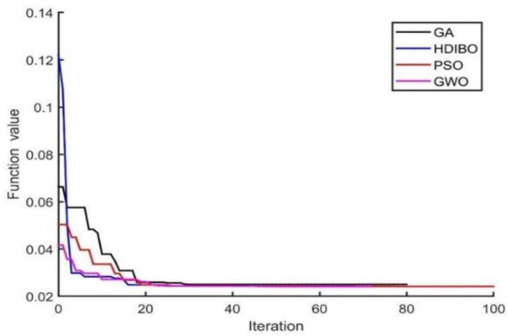

Figure 8: Performance curve for GA, PSO, GWO, and HDIBO optimization.

Table 5: Comparison of tuned values of benchmark and proposed system

Parameters	**Optimization Methods**			
	GA	**PSO**	**GWO**	**HDIBO**
Kmp	0.042	0.0058	0.0158	0.0854
Kmi	0.458	0.632	0.854	0.254
Kbp	0.0235	0.0854	0.0412	0.0125
Kbi	0.235	0.145	0.524	0.562
Kevp	0.039	0.0048	0.0125	0.0814
Kevi	0.412	0.675	0.898	0.222
Kip	0.025	0.0056	0.025	0.086
Kii	0.456	0.656	0.853	0.2258
Mean	0.045	0.056	0.042	0.031

Standard Deviation	0.056	0.034	0.047	0.0023
Best Fitness Value	0.032	0.031	0.028	0.025
Computation time (sec)	86.5	74.3	43.3	28.2

The proposed method, as illustrated in Table 5.5, demonstrates that the values for proportional and integral gain, mean value, standard deviation, and computation time are inferior to those of alternative methods. A lower value signifies superior performance of the proposed scheme. Table 5.6 presents the hourly electric vehicle load alongside the corresponding weather data for power forecasting.

The irradiance and cell temperature data are obtained from [131], while the wind speed data is sourced from [132]. The dynamic electric vehicle loads for five distinct battery capacity electric vehicles are computed according to equation (44), wherein the state of charge ranges from 10 to 90 percent.

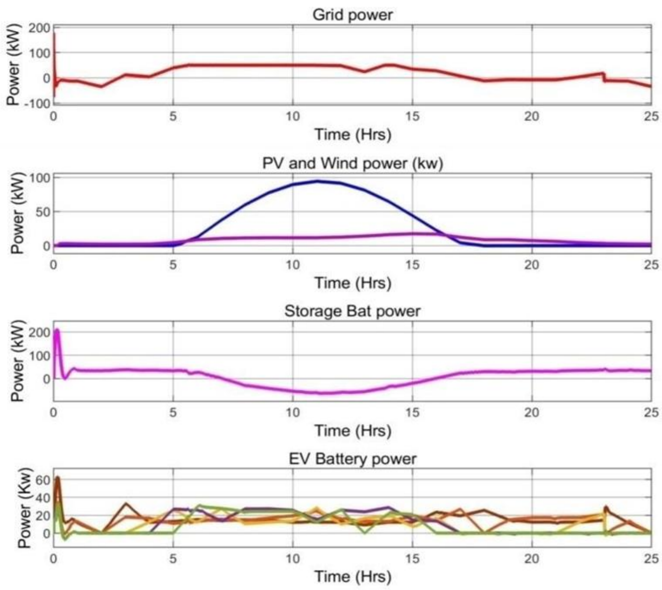

Figure 9: Grid, photovoltaic, wind, energy storage battery, electric vehicle power for the 24-hour period

Figure 9 illustrates the grid, photovoltaic (PV) energy, wind energy, energy storage batteries, and electric vehicle (EV) power over a 24-hour period. The data demonstrates the effective management of battery, grid, photovoltaic, and wind energy for charging electric vehicles at a charging station. HDIBO employs human insights alongside computational accuracy to adeptly respond to changing conditions, facilitating a versatile energy management strategy.

The fluctuating electric vehicle load over a 24-hour period is supplied by grid power, photovoltaic energy, wind energy, battery storage, or a combination of these sources, contingent upon the power availability relative to instantaneous load demand. Owing to the elevated irradiation levels, the photovoltaic power output is significantly higher between 9:00 AM and 4:00 PM. The energy produced by the wind system compensates for the photovoltaic power deficit during the morning and evening. Therefore, the ongoing generation of renewable energy satisfies the energy requirements of electric vehicles.

For example, when renewable energy generation exceeds the electric vehicle (EV) demand, the graph illustrates that storage batteries absorb energy from photovoltaic (PV) and wind sources to subsequently supply it to the EV load. During periods of reduced renewable energy generation in the morning and evening, electricity is utilized to meet the power demands of electric vehicles. Consequently, the engineered system enhances power distribution for electric vehicle charging stations.

The numerical data from Figure10 is presented here;

The imported grid power was 13 kW at hour 1, 33.5 kW at hour 2, 11 kW at hour 18, 7.6 kW at hour 19, 8.3 kW at 9 PM, and 12.5 kW at hour 24, according to the real-time renewable power and load conditions. During the remaining hours, specifically 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20, 22, and 23, a cumulative total of 548.5 kW of power was consumed.

The mean photovoltaic energy production from 6:00 am to 5:00 pm is 678.4 units, while wind energy generation over a 24-hour period is 221.9 units.

Charging the energy battery requires 455.2 units of energy during the day, whereas a balanced 284.8 KWh is discharged to fulfill the EV load.

Over the course of 24 hours, five electric vehicles consistently charged, utilizing between 10 and 40 kWh each. This comprehensive analysis of their charging behaviors elucidates our energy consumption.

CONCLUSIONS

The proposed optimization framework for electric vehicle (EV) charging demonstrates significant improvements in renewable energy use, cost efficiency, and system stability compared to uncoordinated charging methods. It achieves a 10.2% rise in renewable energy consumption, ensuring optimum use of available clean energy resources. A key advantage of the system is its ability to reduce energy imports by 27.3% during peak load circumstances, thereby alleviating pressure on the grid.

The suggested solution enhances profitability for EV charging station owners by 5% vs to uncoordinated approaches. Moreover, it achieves total renewable energy consumption inside the system, ensuring the efficient use of all produced renewable energy.

The optimization strategy yields a 41.69% reduction in daily operating costs compared to conventional baseline strategies. Minimizing the frequency of charging and discharging cycles of the Energy Storage and Battery Unit (ESBU) increases profit margins and extends battery longevity.

The suggested optimization approach based on human driving instructions enables precise tuning of PI controller settings, exceeding traditional optimization methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO). This ensures steady and effective energy management for electric car charging systems, consequently enhancing overall system dependability and performance.

References

[1] 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, pp. 27793–27805, 2023.

[2] S. Mahadik and P. Guchhait, "Innovative solution for electric vehicle charging: The hybrid renewable energy-based charging station," in 2023 IEEE Fifth International Conference on Advances in Electronics, Computers and Communications (ICAECC), 2023, pp. 01–07.

[3] R. Madhumitha, P. Priya, and S. Saravanan, "Hybrid renewable energy based electric vehicles charging station," in 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), 2022, pp. 2348–2352.

[4] M. S. Kushwah, M. Azeem, P. Kumar, A. K. Singhal, and P. Rajawat, "Hybrid renewable energy based electric vehicle Eco-friendly charging station," in 2022 IEEE Conference on Interdisciplinary Approaches in Technology and Management for Social Innovation (IATMSI), 2022, pp. 1–6.

[5] M. Azeem, P. Kumar, A. Singhal, and S. Roy, "Performances of hybrid renewable energy based electrical charging station," in 2022 International Conference for Advancement in Technology (ICONAT), 2022, pp. 1–5.

[6] A. M. A. Haidar, L. W. Han, and T. Ahfock, "Feasibility analysis of implementing hybrid powered electric vehicle charging stations in Sarawak," in 2022 IEEE Sustainable Power and Energy Conference (iSPEC), 2022, pp. 1–6.

[7] Y. Li, N. Zheng, J. Zhang, Q. Cai, Z. Zhong, and X. Qian, "Planning model for electric vehicle charging station considering battery capacity," in 2021 IEEE 5th Conference on Energy Internet and Energy System Integration (EI2), 2021, pp. 3768–3771.

[8] Vaideeswaran, Veerakumar, Sharmeela, Bharathiraja, and P. Chandrasekaran, "Modelling of an electric vehicle charging station with PWM rectifier to mitigate the power quality issues," in 2021 IEEE Transportation Electrification Conference (ITEC-India), 2021, pp. 1–6.

[9] U. Qureshi, A. Ghosh, and B. K. Panigrahi, "Real-time control for charging discharging of electric vehicles in a charging station with renewable generation and battery storage," in 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET), 2021, pp. 1–6.

[10] S. A. Jawale, S. K. Singh, and P. Singh, "Control strategies for electric vehicle charging station: A review," in 2021 2nd International Conference for Emerging Technology (INCET), 2021, pp. 1–5.