Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 3, No.2, March : 2025

ENERGY FLOW MANAGEMENT SYSTEM FOR OPTIMIZED RENEWABLE ENERGY UTILIZATION IN ELECTRIC VEHICLE CHARGING STATIONS

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ABSTRACT
The energy management strategy of renewable energy sources for the EV charging station is proposed under Approach I and II. The first approach of energy flow management strategy (EFMS) is designed to maximize the use of real-time available renewable energy for EV loads and the cost-effective utilization of energy storage battery units and the grid for EV charging. The strategy aims to achieve economic benefits, optimize renewable energy, reduce the utilization of grid energy during peak load conditions, and run energy storage battery units effectively. A multi-objective algorithm is formulated to achieve these goals. A conventional, unstructured charging process is compared with the proposed solution. The effectiveness of EFMS has been evaluated using MATLAB software, and analyses and conclusions have been presented in order to demonstrate the efficacy of the suggested system. In Approach II, a human-driven instruction-based optimization (HDIBO) technique is developed for a grid and renewable energy linked EV charging stand. This technique is designed for fine-tuning of proportional-integral (PI) controllers. The objective of the proposed system is to efficiently distribute renewable energy to electric vehicle loads, properly utilize energy storage batteries, and provide support to 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 increasingly advantageous as alternative solutions for meeting energy requirements. Strategic management of these resources is vital to optimize their usage for charging station energy demands. India possesses significant solar energy potential. India possesses a substantial energy potential of around 5,000 trillion kWh yearly throughout its entire area. Generally, most regions obtain an average of 4 to 7 kWh per square meter daily. India possesses considerable potential for the expansion of solar photovoltaic electricity. Solar power has the benefit of decentralized energy generation and facilitates rapid and efficient capacity growth. Decentralized, off-grid, and low-temperature applications provide substantial advantages for fulfilling energy requirements in both rural and urban settings.
The use of energy management systems for charging stations offers significant benefits for both station operators and electric vehicle owners. The use of energy management systems for charging stations provides substantial advantages for station operators and electric vehicle owners.

- Maximized Revenue: EMS solutions assist station operators in optimizing energy distribution and ensuring operational efficiency, leading to enhanced income. Operators can increase income by catering to a greater number of EV owners, resulting in decreased downtimes and expedited charging speeds.
- Lowered Operational Expenses: Effective energy management may significantly reduce operational costs for charging stations. Effective load distribution and sophisticated charging

algorithms optimize power use, resulting in decreased energy expenses and mitigating strain on the system during peak demand periods.

- Improved EV User Experience: Energy management systems improve the reliability and efficiency of charging services, leading to a more acceptable experience for electric vehicle owners. By implementing efficient processes and ensuring dependable performance, EMS solutions significantly enhance the adoption and satisfaction levels of EV consumers.
- EMS solutions are crucial for the development of an efficient and environmentally friendly charging infrastructure. By employing advanced charging algorithms and load balancing strategies, these solutions promote a more sustainable and eco-friendly future. Utilizing renewable energy sources and intelligently timing charging during off-peak hours can optimize the energy usage of charging stations, significantly diminishing their environmental impact.
- Data-Driven Decision Making: Energy management systems provide critical insights via data analytics, enabling organizations to make educated decisions regarding infrastructure enhancements, capacity planning, and revenue maximization. Operators can effectively adjust and expand their charging networks, providing them with enhanced control and flexibility.

II. Research Objectives:

EMS Approach-I

- Optimize the utilization of renewable energy for electric vehicle charging.
- Enhance the proportion of renewable energy consumption within the system while reducing grid energy utilization under high load conditions.
- Enhance profitability for charging station proprietors
- Economically efficient functioning of energy storage battery systems for electric vehicle charging.

EMS Approach-II

- Develop a novel optimization strategy for the precise regulation of the PI controller to enhance effective and reliable management of power flow in renewable, grid, and battery-powered electric vehicle charging stations.

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.

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ISSN: 0970-2555
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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.

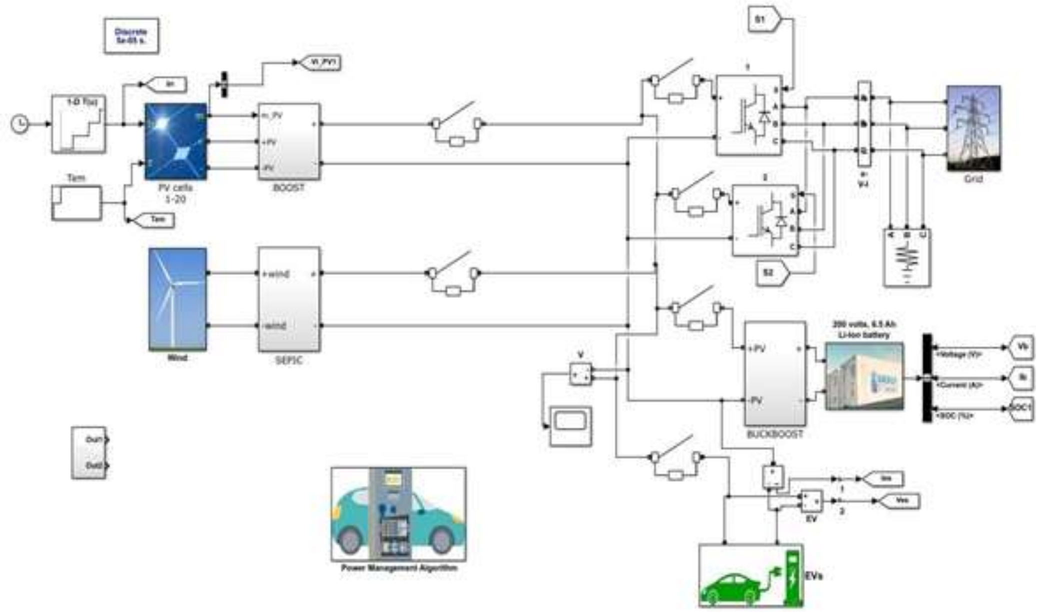

Figure 1 MATLAB simulation model

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

The distinction between load and renewable power is expressed as;

$$\Delta P(t) = P_{RES}(t) - P_{EVL}(t) \tag{41}$$

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ISSN: 0970-2555
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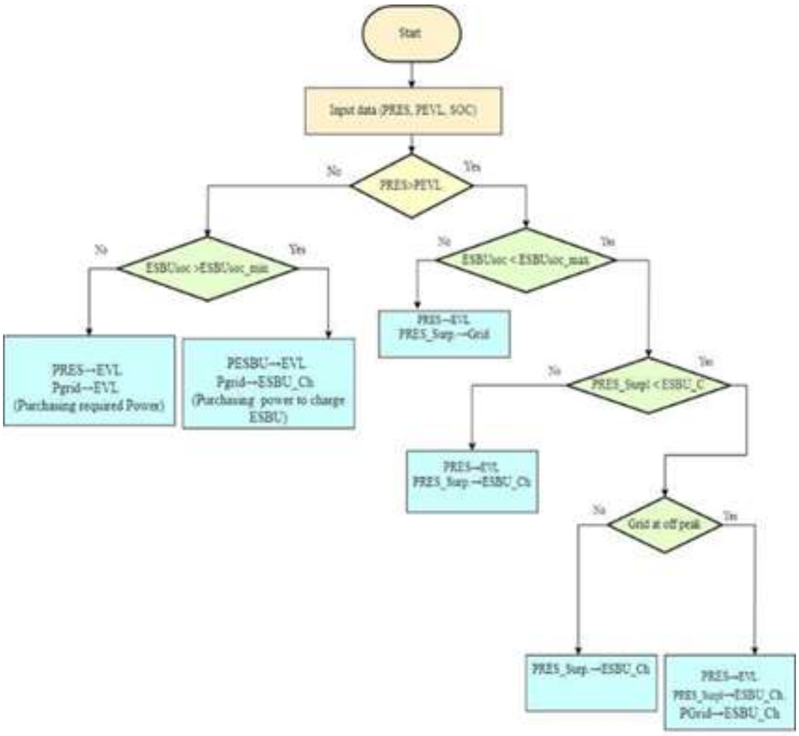

Figure 2 Emergency Medical Services algorithm

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 calculation

Table 1 EV model and battery rating [128]

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

$$P_{EVLoad} = (SOC_{Req} - SOC_{Ini}) \times EVi_{BC} \quad (44)$$

EViBC in equation (44) denotes the rated battery capacity of the connected electric vehicle for charging during the specified time interval, with the value derived from table1.

The load calculation for the unscheduled EV charging scheme is determined according to equation (44). In calculating the load for both schemes, a total of 80 electric vehicles and the corresponding total load have been taken into account.

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4.2.3 Parameters of proposed EMS approach-I

The system parameters utilized in Energy Management Approach-I are delineated in Table 4.3.

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; $\square_{PV}$	17.5	%
Rating of WEC system P_{wt}	50	KW
Efficiency of WEC mechanism; $\square_{wt}$	96	%
Wind Turbine operating wind speed range ($\square_c$ to $\square_r$)	2 to 10	m/s
Wind Turbine disconnect at speed;$\square_o$	25	m/s
Energy storage battery unit name plate rating; PESBU	40	Kilowatthour
Charge-discharge Effectiveness; $\square_{ESBU}$	96	%
Energy storage battery initial and final SOC range	10 to 90	%
Life cycles of ESBU, N_{cy}	$3 \square 10^3$	--
Capital cost of ESBU	$15 \square 10^3$	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.

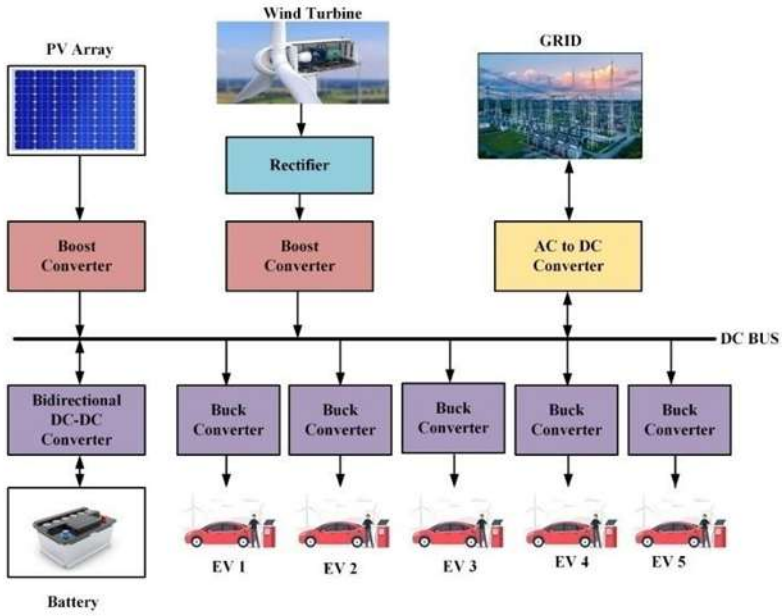

Figure 2 Proposed model of EMS-II

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 [109]. 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 [113].

4.3.8 PI Controller tuning by HDIB Optimization

The parameters K_{mp}, K_{bp}, K_{evp}, K_{ip}, K_{mi}, K_{bi}, K_{evi}, and K_{ii}, of the PI controller, as delineated in equations (52), (53), (54), and (61), are optimized through Driving Instruction-Based Optimization. The optimization seeks to reduce the objective function outlined below:

$$f\left(K_{mp}, K_{bp}, K_{evp}, K_{ip}, K_{mi}, K_{bi}, K_{evi}, K_{ii}\right) = \sqrt{\left(\frac{V_{ref}-V_{PV}}{N}\right)^2 + \sqrt{\left(\frac{V_{dcbusref}-V_{dcbus}}{V}\right)^2} + \sqrt{\left(\frac{I_{evref}-I_{ev}}{N}\right)^2} + \sqrt{\left(\frac{i_{dref}-i_{d}}{N}\right)^2} + \sqrt{\left(\frac{i_{qref}-i_{q}}{N}\right)^2}} \quad ..(73)$$

N denotes the total quantity of samples.

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.

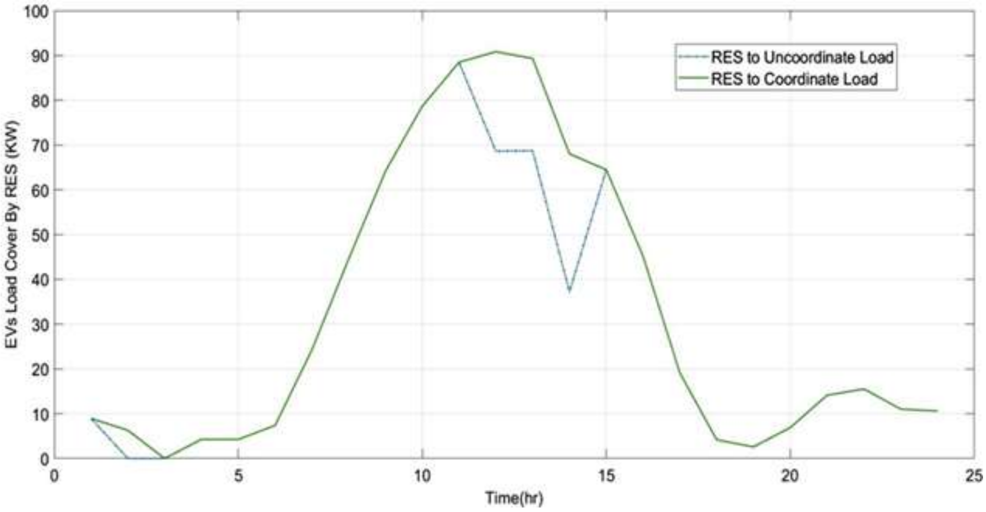

Figure 3 Electric vehicle charging supported by renewable energy

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.

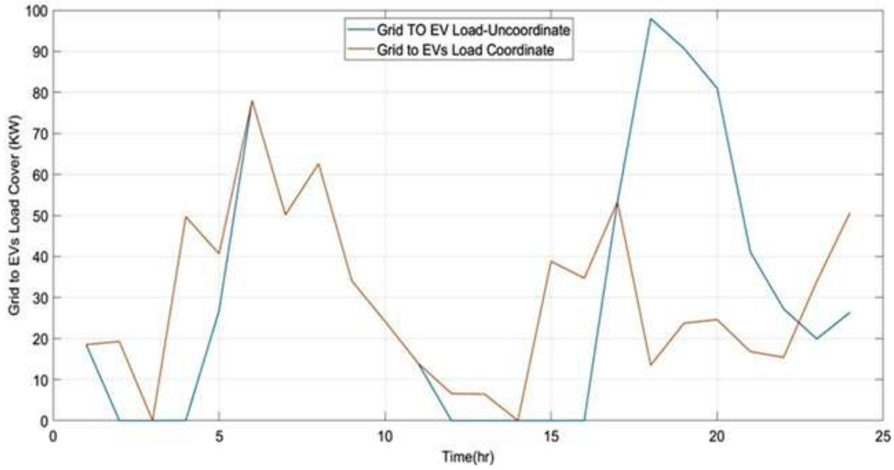

Figure 4 Electric Vehicle Load Supplied by Grid Energy

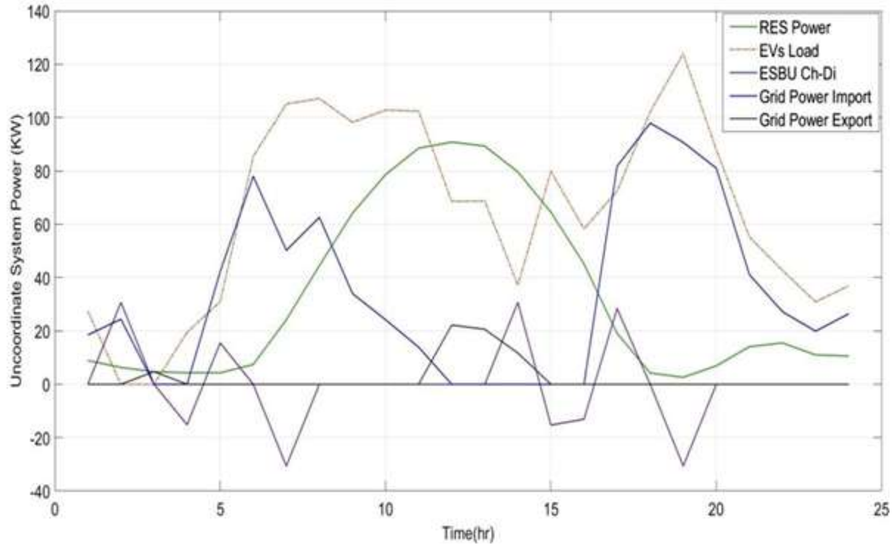

Figure 5 Baseline Scheme power distributions

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.

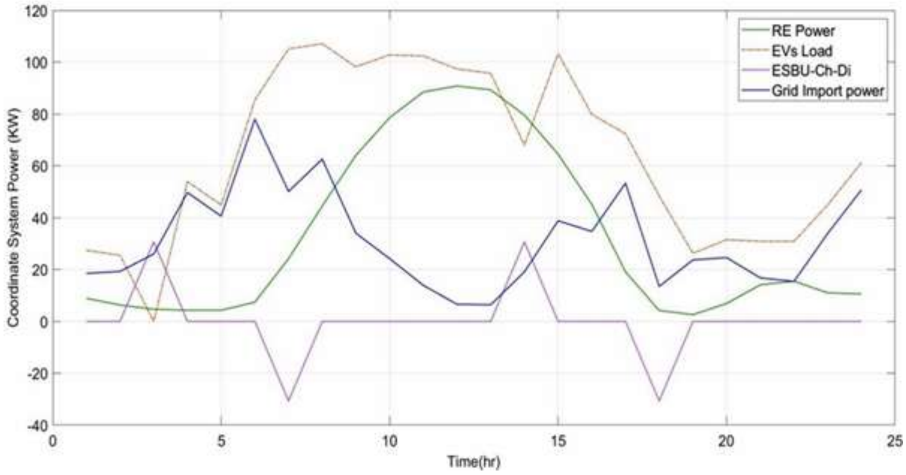

Figure 6 Proposed scheme Power flow

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.

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ISSN: 0970-2555
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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.

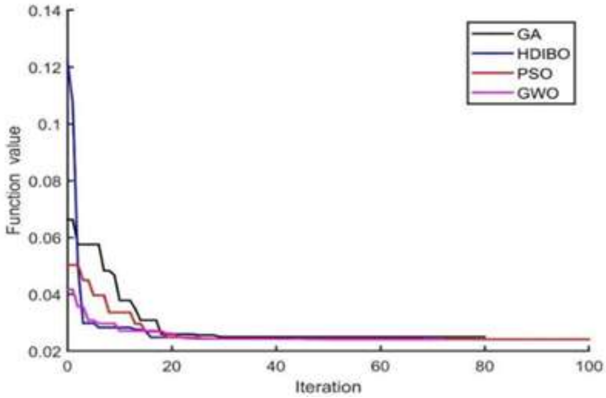

Figure 7 Performance curve for GA, PSO, GWO, and HDIBO optimization.

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.

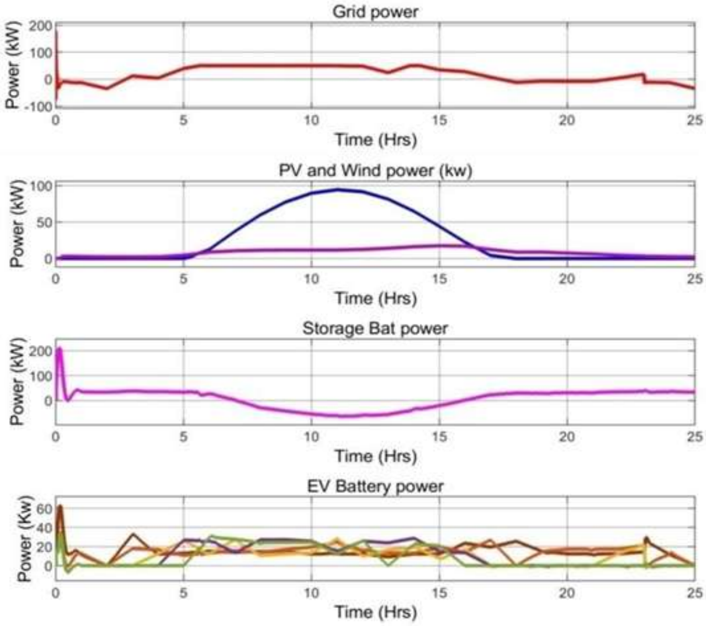

Figure 8 Grid, photovoltaic, wind, energy storage battery, electric vehicle power for the 24-hour period

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.

VI. Conclusions

1. The suggested optimization framework for electric vehicle (EV) charging exhibits substantial enhancements in renewable energy utilization, cost efficiency, and system stability relative to uncoordinated charging approaches. It attains a 10.2% increase in renewable energy consumption, guaranteeing optimal utilization of accessible clean energy resources. An essential benefit of the system is its capacity to decrease energy imports by 27.3% during peak load conditions, thereby mitigating strain on the grid.
2. The proposed strategy increases profitability for EV charging station owners by 5% compared to uncoordinated methods. Furthermore, it attains complete renewable energy consumption within the system, guaranteeing the effective utilization of all generated renewable energy.
3. The optimization method results in a 41.69% decrease in daily operational expenses relative to traditional baseline approaches. Reducing the frequency of charging and discharging cycles of the Energy Storage and Battery Unit (ESBU) enhances profit margins and prolongs battery lifespan.
4. The proposed human-driving-instruction-based optimization method facilitates accurate adjustment of PI controller parameters, surpassing conventional optimization techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO). This guarantees stable and efficient energy management for electric vehicle charging systems, thereby improving overall system reliability and performance.

VII. Future Research Directions

Regarding electric vehicle (EV) charging models, it is essential to integrate a broader spectrum of diversity to introduce additional unpredictability into the model's foundational assumptions. Incorporating multiple levels of charging power, charging locations, and battery capacities into a single model will produce a more accurate representation that effectively addresses the varied requirements of different electric vehicles (EVs). Additional examination of V2G and the regulation of charging and discharging can ascertain a balance between the requirements of vehicle owners and the dependability of the power grid. Additional analysis is required to comprehend the substantial presence of photovoltaic systems, wind energy, and electric vehicles in the electricity market. Further research is necessary to investigate how vehicle owners respond to the requirements of grid operators. Benchmarking studies that evaluate the costs of power production and charging are mandatory.

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