Journal of Nano- and Electronic Physics
Vol. **17** No 6, 06011(5pp) (2025)

Журнал нано- та електронної фізики
Том **17** № 6, 06011(5cc) (2025)

REGULAR ARTICLE

Efficient Energy Management of Hybrid Renewable Power Generation Based on Charging Station Demand

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(Received 02 August 2025; revised manuscript received 17 December 2025; published online 19 December 2025)

Resources for energy are very important for the existence of mankind. The choice of power generation methods and their economic feasibility vary depending on the demand and geographical region. The scarcity of charging stations is the major obstacle in the adoption of electric vehicles. This research suggests the implementation of integrated charging stations powered by hybrid solar and wind energy and an algorithm that optimizes energy management. The proposed charging station that utilizes a hybrid renewable energy source has been enhanced by the implementation of simulation done on MATLAB based on a fuzzy logic inference controller system. The ultimate aim focuses on reducing the need for charging and optimizing the use of hybrid renewable energy sources through effective management of power generation, power utilization, distribution, charging timelines, demand and electric vehicle power consumption. When compared to the demand, the results demonstrate that the suggested algorithm leads to a reduction in energy demand and management. The efficiency of the system increased to 95.3 % in utilization of renewable energy, 93.2 % in usage of storage batteries and decreased to 5.7 % in loss of energy to build this system for the transfer of energy in balanced and effective power management.

Keywords: Hybrid renewable energy, IEVCS, Fuzzy logic, Load forecast, EV scheduling, Demand analysis.

DOI: 10.21272/jnep.17(6).06011 PACS numbers: 07.05.Mh, 88.05.Gh

1. INTRODUCTION

The growth in worldwide power demand has resulted in the extraction of fossil fuels, which has caused environmental damage and accelerated global warming [1]. Due to their non-linear operation, the linkage of multiple electric car chargers to the distribution system often leads to power quality issues. Possible occurrences include power dissipation, harmonic distortions, and voltage fluctuations [2]. To close the demand-supply gap in the electrical industry, researchers all over the world are working to develop renewable resources that are both cost-effective renewable resources and environmentally beneficial, responsible [3]. The charging of batteries, the performance of converters, the usage of renewable energy, and the management of energy are all areas that can be improved in order to find solutions to these issues [4].

The infrastructure for the generation of renewable energy sources is expensive and occasionally breaks by incorporating hybrid renewable energy sources into charging stations for electric vehicles, it is possible to overcome these challenges [5]. Renewable energy sources such as solar and wind offer a tremendous amount for the alter-native of fossil fuels. Integrated Electric Vehicle Charging Stations (IEVCS) are reliable based upon an optimization technique for an efficient charging management outcome [6]. An efficient resulting algorithm is based on fuzzy logic has higher ability to decision-making, Fuzzy Logic Inference Controller systems are ideal for use to operate electric vehicle charging stations and have the ability to model nonlinear functions. Methods that are based on fuzzy logic inference con-troller system are beneficial and have the ability to make decisions, recognize patterns, identify, optimize, and control [9]. To enhance the IEVCS, optimization looks at factors such as power generated, EMS (Energy management system), energy demand, and transmission loss [10].

The technique commonly used is the block chain where the energy management on the demand is challenging [11]. The optimization algorithms help the system to work for the decision [12]. The most common algorithm is the particle swarm which fetches the results [13,14]. In fuzzy systems the algorithms are combined for better efficiency [15]. Thus, the system proposed with the logic and optimization algorithm is utilized.

This research focuses on the under-standing of hybrid renewable energy sources to be concentrated on the alternate of fossil fuels and focuses on the next level as maximum utilization of energy based on fuzzy logic techniques and checking the demand analysis and load forecasting to manage the energy efficiently.

The section of the paper is structured as described below. The conceptual pro-posed Integrated Electric Vehicle Charging Stations and Sugeno-type fuzzy logic inference controller system model are presented in Section II. Section III dis-cussed the Mathematical model of FUZZY LOGIC INFERENCE CONTROLLER SYSTEM

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Cite this article as: Muthu Kumaran C et al., *J. Nano- Electron. Phys.* 17 No 6, 06011 (2025) https://doi.org/10.21272/jnep.17(6).06011

for IEVCS. In Session IV, are the results and discussion of the proposed IEVCS. Presented in Section V are the conclusion and the implications for future research.

2. PROPOSED WORK

For electric vehicle charging stations, the source has to be from renewable energy that a single source can't afford due to the weather conditions, uncertainty, losses and malfunctioning. So, the hybrid system is employed and maintained with proper energy management to meet the demand and organize the supply in a proper way.

In this proposed work, it is necessary to utilize a combination of renewable energy sources as the power generation unit in order to fulfill the demand for electric vehicles, energy management is accomplished through the utilization of fuzzy logic in conjunction with the interconnection of charging stations.

This work is carried out in three stages as shown in fig 1. Stage 1 is a Combined energy source named SWB (Solar, Wind, Backup Battery) source, Stage 2 is completely of FLICS (Fuzzy Logic Inference Controller system), Stage 3 consists of IECV (Integrated charging stations).

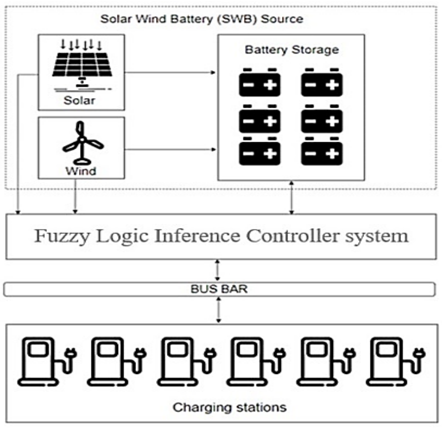

Fig. 1 – Proposed System with Fuzzy Logic Controller

Stage 1. The hybrid renewable energy sources (solar and wind) are used as the energy generation part. In addition to this an additional Battery back is maintained for storing the excess energy or the sur-plus power which is received during the off-peak hours where there is no demand by the electric vehicles to the charging station and the transmission of energy is not required. During peak hours when the demand is very high and if the solar & wind can't deliver the energy needed, then the stored energy has to be directed towards the charging station. The above conditions can be used to determine whether the battery pack has to store the energy/transmit the stored energy.

During peak hours when the demand is very high and if the solar & wind can't deliver the energy needed, then the stored energy has to be directed towards the charging station.

This will be applicable for three conditions.

1. Demand is high (peak hour)
2. Solar power is not available (night / rain)
3. Wind energy is not received by climatic conditions.

The above conditions can be used to determine whether the battery pack has to store the energy / transmit the stored energy.

Stage 2. The optimization is done with Fuzzy Logic Inference Controller System (FLICS) which will control the amount of energy generated, level of battery backup storage and the decision made for the battery action status (receive / transmit). This will collect the data from the input (Generation side) and the output (distribution side). Another set of output data is received from the charging station about the status of the available power, demand of the Electric vehicle waiting to get charged. The optimization technique uses Hybrid algorithm (Particle Swarm and Ant Colony.

The first Technique (PSO) is used to identify the availability of adequate charge in the particular charging station so the electric vehicle movement can be diverted for the maximum utilization of energy without waiting time for the vehicle in the stations.

The second technique (ACO) is used to check the properties of the integration of charging stations to yield the maximum power transfer within the charging stations based on the findings of the previous technique handled.

Stage 3. The charging stations are interconnected with one another to form a (IEVCS) Integrated Electric Vehicle Charging station and do the bi-directional transfer of energy when re-quired. Data from stations is given to the FIS which will check for the individual demand as well as the whole IEVCS demand also and ensures that the power generated is utilized properly based on the requirement of the charging stations.

This system will ensure that the power generated is utilized properly based on the requirement of the charging stations.

3. MATHEMATICAL MODEL FOR FLICS-IEVCS

The model suggests the IEVCS with hybrid (solar & wind) renewable resources for the efficient management of energy by using the optimization done by fuzzy logic. An illustration of the proposed IEVCS with a capacity of power coming from solar and wind sources, respectively.

3.1 Power Generation

The power that is generated by the IEVCS that has been suggested can be described as follows:

Power Generated from hybrid renewable source $\mathrm{P_{swg}}$ is calculated by equation (3.1)

$$\mathrm{P_{swg}} = \mathrm{f}(i_s, i_w)_r \qquad (3.1)$$

where 'i_s' and 'i_w' denote solar energy and wind energy.

3.2 Energy Management System of IEVCS

This part deals with the efficient system to manage the energy with the fuzzy for the IEVCS. The two major objectives of the system are the first is to maximize the exploitation of renewable resources and the second is to minimize the charging station battery energy wastage.

Each of the objectives are described in the following equations (3.2), (3.3), (3.4), (3.5)

$$Max(EV_{Utilization}) and\ Min(CSB_{charging}) \qquad (3.2)$$

$$Max_{soc} \geq In_{soc} \geq Min_{soc} \quad (3.3)$$

$$B_{dc} = \frac{(CSBmax_{soc} - CSBmin_{soc})}{\mathrm{Bc} \times \eta} \quad (3.4)$$

$$P_{swg} \geq P_{IEVCS_P} \quad (3.5)$$

Where B_{dc} stands for Battery charging duration, P_{swg} denotes the amount of power that is generated by renewable resources (solar and wind), B_c is the Battery capacity, P_{IEVCS} is the Overall Power maintained in the Integrated Charging stations, η is the efficiency and CSB is the Charging station battery.

Whereas the state of charge (SOC) restrictions is considered in order to prevent electric vehicle batteries from failing. The size of the battery and SOC of the electric vehicle have a role in determining the amount of electricity that the vehicle requires.

$$T_C = T_e - T_i - T_h \quad (3.6)$$

where T_i, T_e, and T_h are the starting time, departure time and holding time.

It is necessary for the IEVCS to produce power that is either greater than or equal to the power that it demands in order for it to operate well. "Charge duration" (T_C) refers to the amount of time that must pass before the cells can be charged once more. The duration of the vehicle charge is shown in the equation (3.6).

Thus, the mathematical modelling of IEVCS with the Generated power and the battery SOC's of the charging stations will prove that the handling of energy can be done in an efficient way, and the additional support will be given by the optimization techniques. This will help in maintaining sufficient energy in the charging stations during the off-peak period and supply required energy during the on-peak period and finally store the surplus or available energy to the storage battery and even supply the grid as future scope.

4. RESULTS & FINDINGS

For this IEVCS, the Sugeno-type fuzzy logic inference controller system model is applied for a range of input situations in order to identify the desirable charging rate that utilizes a hybrid renewable energy source. This is done in order to maximize efficiency. Within the context of this particular modeling technique, the defuzzification strategy that is based on the centroid is applied. The amount of power that is generated, as well as the obtainable amount of output power, EMS, energy demand, and transmission loss are the input factors that the fuzzy model takes into consideration. It is generally accepted that the output factors include the demand resolved, EMS, generation balance, and electric vehicle scheduling.

The phases of the input and output variables are characterized by membership functions that are triangular, trapezoidal, Gaussian accordingly. In the event that solar and wind resources are sufficient, there is the potential for an increase in power generation. The amount of energy used by the vehicle is determined by the capacity and soc of the battery. This optimization strategy can also be demonstrated to you by a fuzzy logic inference controller system as in Fig 2. which will show how the rules are organized.

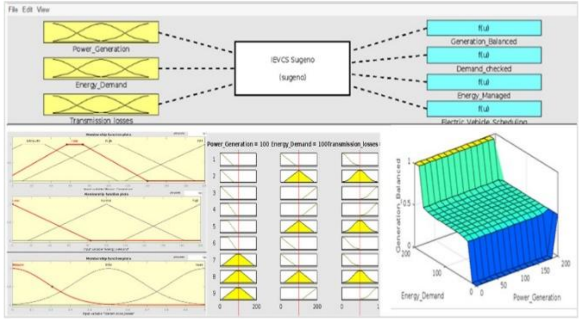

Fig. 2 – Model, Rules and Surface plot of the Sugeno system

The fuzzy-based optimization that has been presented takes into consideration the amount of solar and wind resources. The IEVCS is optimized using a hybrid renewable resource for charging times, electricity demand, temperature and battery capacity. If there is not enough power generated then power will be drawn from backup battery.

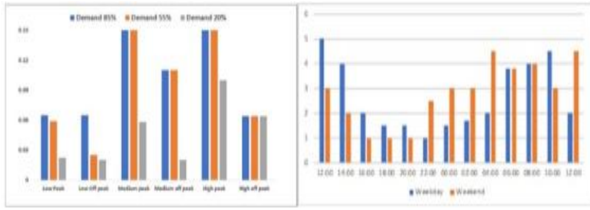

Fig. 3 – Demand for On / Off-peak hours in a charging station

Due to the fact that the intended IEVCS generates power through the utilization of solar and wind resources, and the quantity of electricity obtained and efficient depend upon energy management of fuzzy logic inference controller system and demand during peak hours may be reduced even further.

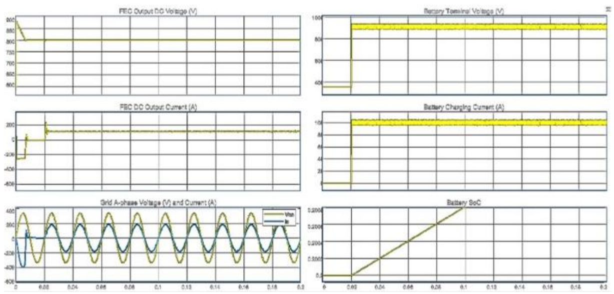

Fig. 4 – Voltage, Current and Battery characteristics

The voltage and current of the source, battery parameters as charging current, terminal voltage, SOC and the characteristics of the system are analyzed in Fig 4.

The elements in Fig 5. illustrate how the demand for charging and the use of renewable energy shift in response to changes in electric vehicle power demand, renewable utilization and battery backup. When there is sufficient electricity, the demand decreases, but when there is not sufficient power, the demand increases.

The demand varies based on the amount of power that the electric vehicle requires. Electric vehicles consume more power during peak hours, which causes the distribution network to move more slowly.

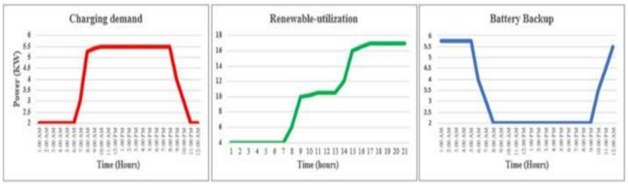

Fig. 5 – Demand, utilization and backup

Table 1 – Comparison of the procedures with Fuzzy

Procedure	Source	Storage	Loss
GA [7]	85 %	90 %	17 %
BCFL [8]	94.5 %	92.5 %	10 %
Fuzzy	95.3 %	93.2 %	5.7 %

The values obtained from the proposed system are compared with the Block chain federal learning technology (BFCL), Genetic Algorithm (GA) and suggest that the proposed Fuzzy system as shown the Table 1 performs with high efficiency on renewable usage, Battery storage and less in Energy Loss. When more renewable energy sources are utilized, the amount of power that is drawn from the utility grid is reduced. In addition to reducing emissions of greenhouse gases, solar-wind-based energy conversion and storage (SWB) reduces the system's dependence on the power grid by utilizing a variety of renewable energy sources.

5. CONCLUSION

The fuzzy algorithm predicts the appropriate charging demand by considering the amount of power available. The hybrid renewable energy sources are utilized effectively by the energy management system so the amount of energy that is required and the transmission loss is under control. This illustrates that the hybrid renewable energy-based integrated energy delivery and control system (IEVCS) has a lower energy consumption than grid energy systems, particularly during off-peak hours. There is a de-crease in the demand for battery charging, and the establishment of an efficient energy management system for the pro-posed IEVCS is dependable. A new strategy V2G (Vehicle to Grid) technology, can be developed in order to establish a two-way energy sharing system that functions similarly to a smart grid for integrated electric vehicle charging stations

AKNOWLEDGEMENTS

Authors are grateful to the Editor-in-Chief of the Journal of Nano- and Electronic Physics Protsenko Ivan Yuhymovych for a critical reading of the manuscript and his valuable comments.

REFERENCES

1. Y. Yang, W. Zhao, Y. Yang, M. Xu, H. Mukhtar, G. Tauqir, P. Tarolli, *IEEE Trans. Geosci. Remote Sens.* **62**, 4405014 (2024).
2. K.N.D. Malamaki, D.A. Christofis, G.C. Kryonidis, C.S. Demoulias, *IEEE Trans. Industry Appl.* **60** No 5, 7656 (2024).
3. P. Bastida-Molina, *Renew. Energy* **179**, 737 (2021).
4. S. Usha, P. Geetha, S. Parasuraman, A. Manimaran, T. Karthika, S. Selvan, D. Kumutha, *J. Nano- Electron. Phys.* **15** No 3, 03009 (2023).
5. O. Hafez, K. Bhattacharya, *Renew. Energy* **107**, 576 (2017).
6. A. Eid, O. Mohammed, H. El-Kishky, *J. Energy Storage* **55**, 105644 (2022).
7. S. Mohseni, A. Brent, D. Burmester, A. Chatterjee, *Australasian Universities Power Engineering Conference (AUPEC -2018)* (IEEE: 2018).
8. K.B. Bhaskar, A. Prasanth, P. Saranya, *Int. J. Commun. Syst.* **35**, e5189 (2022).
9. T. Mao, X. Zhang, B. Zhou, *Energies* **12** No 2, 255 (2019).
10. P. Justin Raj, V. Vasan Prabhu, V. Krishnakumar, M. Clement Joe Anand, *Int. J. Fuzzy Syst.* **25** No 7, 2876 (2023).
11. M.O. Okoye, J. Yang, J. Cui, A. Hussain, V.H. Bui, D. Espin-Sarzosa, *IEEE Access* **12**, 111970 (2024).
12. D.C. Huynh, L.D. Ho, H.M. Pham, M.W. Dunnigan, C. Barbalata, *IEEE Access* **12**, 48027 (2024)
13. M.A. Jawale, A.B. Pawar, S.K. Korde, D.S. Rakshe, P. William, N. Deshpande, *J. Nano- Electron. Phys.* **15** No 3, 03004 (2023).
14. Q. Wang, S. Li, H. Ding, M. Cheng, G. Buja, *CSEE J. Power Energy Syst.* 10 No 2, 574 (2023).
15. S.M.R. Rostami, Z. Al-Shibaany, *IEEE Access* **12**, 67665 (2024).

Ефективне управління енергією гібридної відновлюваної енергетики

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Енергетичні ресурси дуже важливі для існування людства. Вибір методів виробництва енергії та їхня економічна доцільність залежать від попиту та географічного регіону. Дефіцит зарядних станцій є основною перешкодою у впровадженні електромобілів. Це дослідження пропонує впровадження інтегрованих зарядних станцій, що працюють на гібридній сонячній та вітровій енергії, та алгоритм, який оптимізує управління енергією. Запропонована зарядна станція, яка використовує гібридне відновлюване джерело енергії, була вдосконалена шляхом впровадження моделювання, виконаного в MATLAB на основі системи контролера з нечіткою логікою. Кінцева мета зосереджена на зменшенні потреби в зарядці та оптимізації використання гібридних відновлюваних джерел енергії шляхом ефективного управління виробництвом енергії, використанням енергії, розподілом, термінами зарядки, попитом та споживанням енергії електромобілями. У порівнянні з попитом, результати показують, що запропонований алгоритм призводить до зниження попиту на енергію та управління нею. ККД системи збільшився до 95,3 % у використанні відновлюваної енергії, до 93,2 % у використанні акумуляторних батарей та знизився до 5,7 % у втратах енергії, що дозволило побудувати цю систему передачі енергії зі збалансованим та ефективним управлінням енергоспоживанням.

Ключові слова: Гібридна відновлювана енергія, IEVCS (Інтегрована система контролю електричних транспортних засобів), Нечітка логіка, Прогнозування навантаження, Планування руху електромобілів, Аналіз попиту.