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TECHNO-ECONOMIC ANALYSIS (TEA) OF RENEWABLE ENERGY-BASED EV CHARGING STATION LOAD

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ABSTRACT -
The need for effective and sustainable charging infrastructure has grown due to the electric vehicle (EV) market's explosive expansion. Conventional grid-based charging stations indirectly add to carbon emissions and put more strain on the utility system. As a result, combining renewable energy sources like solar photovoltaic (SPV), wind turbines (WT), and battery energy storage systems (BESS) with EV charging stations has shown to be a practical option. This project uses MATLAB/Simulink ideas and research-based analysis to give a techno-economic study of an EV charging station load based on renewable energy. Battery storage, wind turbines, and SPV panels make up the suggested system. converters, and EV charging loads connected with the utility grid. The study analyzes load demand, renewable energy generation, system sizing, battery operation, and cost evaluation parameters such as Total Net Present Cost (TNPC), Levelized Cost of Energy (LCOE), and payback period. The proposed renewable-based charging station reduces dependency on conventional fossil fuel-based electricity generation and improves environmental sustainability. The study concludes that renewable energy integrated EV charging stations are technically feasible, economically viable, and environmentally beneficial for future transportation infrastructure.

I. INTRODUCTION

Alarming levels of widespread use of fossil fuels, such as coal, petroleum, gasoline, and diesel, have resulted in serious environmental damage and climate change. Sustainable energy alternatives are desperately needed to fulfill the growing global demand as a result of the depletion of these non-renewable resources. Renewable energy sources have become viable alternatives in this situation, providing long-term, sustainable answers to the current energy problem. Therefore, guaranteeing sustainable energy generation and distribution requires effective RES implementation, administration, and collection. India has made impressive strides in the use of renewable energy due to its abundance of solar and wind resources. The nation is now a global leader in the field of renewable energy thanks to the coordinated efforts of the public and commercial sectors as well as stakeholders. mitigate the adverse impacts of conventional energy systems, such as the emission of CO_2, NO_x, SO_2, and particulate pollutants, transitioning toward clean energy technologies is imperative. One promising initiative in this direction is the widespread adoption of plug-in electric vehicles (PEVs), which contribute to both emission reduction and improved energy efficiency.

Rapid rise in coal, gasoline, and diesel usage is leading to climate change, air pollution, and depletion of non-renewable energy sources. Electric Vehicles (EVs) are emerging as a sustainable solution to reduce carbon emissions and dependence on fossil fuels. India is witnessing fast growth in the EV sector due to government policies and public awareness. EV sales increased from 16,000 in 2014 to 4.29 lakh in 2022. However, challenges remain: high cost, range anxiety, and lack of charging infrastructure.

Despite their advantages, the large-scale adoption of EVs remains in its formative stage due to challenges such as limited driving range, high initial cost, battery safety issues, and inadequate charging infrastructure. To address these limitations and curb transportation-related emissions, governments worldwide have accelerated policy support and research initiatives focused on EV development and deployment. Considering their superior energy efficiency and zero tailpipe emissions, The transportation environment of the future is anticipated to be dominated by EVs.

Under national initiatives like FAME (Faster Adoption and Manufacturing of Electric Vehicles), the Indian government has implemented a number of legislative frameworks, subsidies, and incentives that have greatly increased public interest and investment in the EV industry, especially in metropolitan areas.

A modified Slap Swarm Algorithm was used in a study carried out in Northwest Delhi to maximize both technical and economic criteria, showing superior performance compared to the conventional SSA and results obtained through HOMER software. The work in proposed a hybrid pole system integrating renewable energy resources, street lighting, and EV charging through a DC microgrid equipped with an energy storage device. This model provided both fast and slow charging options, and results indicated that a group-based configuration of hybrid poles offered improved efficiency over single-pole systems. In researchers optimized the sizing of system components for EV charging stations in Labuan Bajo, Indonesia, developing an economic model that incorporated operational costs and TNPC.

Integrating Renewable Energy Sources (RES) like solar and wind with EV charging stations can ensure clean, cost-effective, and sustainable transportation. This aligns with UN Sustainable Development Goals (SDGs), particularly Affordable & Clean Energy (SDG 7) and Good Health & Well-being (SDG 3).

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II. LITERATURE REVIEW

Electric Vehicle charging infrastructure powered by renewable energy sources has become an important research area in recent years. Many researchers have studied solar powered EV charging systems, battery storage integration, and techno-economic analysis to improve charging efficiency and reduce environmental impact. The following table summarizes the previous research work related to the proposed project.

A comprehensive review of existing literature was carried out to understand the techno-economic performance of renewable energy-based Electric Vehicle (EV) charging stations. Various researchers have investigated the integration of renewable energy sources such as solar photovoltaic (PV), wind turbines (WT), and battery energy storage systems (BESS) with EV charging infrastructure to improve sustainability and reduce operating costs.

Ahmad et al. (2025) – IEEE SeFet Renewable-based EV charging Hybrid PV–WT–BESS reduces LCOE & TNPC; shown optimal compared to grid-only systems.

Ahmad et al. (2025) presented a techno-economic evaluation of a renewable energy-based EV charging station using a hybrid PV–WT–BESS configuration. The study compared the performance of hybrid renewable systems with conventional grid-dependent charging stations. The results indicated that the hybrid configuration significantly reduced the Levelized Cost of Energy (LCOE) and Total Net Present Cost (TNPC), making it the most economical and environmentally sustainable solution. The study highlighted that the proper integration of renewable energy resources and battery storage can enhance system reliability while minimizing dependence on utility grids.

Bilal et al. (2023) – Elsevier ECM Techno-economic analysis across India for New Delhi: 64.5% wind, 33.5% solar, 1.9% grid; achieved LCOE = $0.0051/kWh, TNPC = $14,853.63.

Bilal et al. (2023) conducted a techno-economic analysis of renewable energy-powered EV charging stations for different locations in India. Their research focused on optimizing the energy mix to achieve the lowest operational cost. For New Delhi, the optimal system configuration consisted of 64.5% wind energy, 33.5% solar energy, and 1.9% grid contribution. The proposed system achieved a remarkably low LCOE of $0.0051/kWh and a TNPC of $14,853.63. The study demonstrated that location-specific renewable resource assessment plays a vital role in designing cost-effective EV charging infrastructure.

Ahmad et al. (2021–2022, cited in SeFet) Optimization models Demonstrated significant cost reduction with hybrid optimization compared to standalone solar or wind.

Studies conducted by Ahmad et al. during 2021–2022 focused on optimization techniques for renewable energy systems. These studies employed advanced optimization models to determine the most economical combination of solar PV, wind turbines, and battery storage systems. The results showed substantial cost reductions when hybrid systems were used instead of standalone solar or wind-based charging stations. The findings emphasized the importance of optimal sizing and energy management strategies in improving the economic feasibility of EV charging stations.

III. OBJECTIVES

- To research the increasing need for infrastructure for electric vehicle (EV) charging.
- To create an EV charging station system powered by renewable energy.
- To evaluate the suggested system's efficiency and technical performance.
- To assess the charging station's payback duration, operational costs, and economic viability.
- To use renewable energy to lessen reliance on traditional energy sources.
- To reduce carbon emissions and environmental pollution by using clean energy.
- To encourage environmentally friendly, dependable, and sustainable transportation systems.

IV. METHODOLOGY

4.1 Mathematical Modeling of Energy System Component

The following section shows the mathematical modeling of various energy system components in order to meet PEV charging criteria. The hybrid energy system includes an SPV unit, a WT, a BES system, and an inverter. The BES system, particularly the battery, is critical for managing changes in renewable energy generation and ensuring a more stable power supply for PEV charging.

4.1.1 Mathematical Modeling of Solar Photovoltaic (SPV) Array

The size of the panel, the amount of sunlight it receives daily, the temperature of the solar cells, and the location's geographic coordinates all have an impact on the power generation of a solar photovoltaic system. These elements work together to influence how well the SPV system performs in transforming solar energy into useful electrical power. The amount of SPV power can be determined using Eqn. (1

$$(t) = \eta \quad P^{max} n \quad \frac{I(t)}{\eta} \quad (1 - \lambda \; (T + \frac{(NOCT - 20)}{} I \; (t) - 25))$$

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SPV SPV SPV ____ T 800 amb

am (1)

wire 1000 b

Where, n_{SPV} denotes the number of SPV cells, P^{max}_{SPV} denotes the maximum power obtained from the SPV cells, η_{SPV} and η_{wire} are the efficiency and wiring efficiency of SPV cells, $P_{SPV}(t)$ is the power output of the SPV cells, λ_T is the thermal coefficient of the SPV panels, T_{amb} stands for the ambient temperature, I(t) represents the incident solar radiation, $I_{amb}(t)$ denotes the solar radiation at ambient temperature condition and NOCT denotes the Nominal Operating Cell Temperature.

The total power output obtained from the SPV arrays can be mathematically expressed as:

$P^{max}(t) = N_{SPV} \times P_{SPV}(t)$

4.2 Mathematical Modeling of Wind Turbine (WT)

The output power from WT is determined by the wind speed and hub height characteristics, which may be computed using the following formula.

Where, V_1 denotes the wind speed at height H_1 and V_2 represents the wind speed at hub height H_2, μ_{WT} is the coefficient of friction and its value is taken to be 0.143 in this work.

The relationship between wind speed and electricity generation by WT is not linear. Individual WT units' output power is determined by factors such as the rated power of the WT unit, cut-in wind speed, cut-out wind speed, and rated wind speed.

$$P_{WT} = \begin{cases} 0 & V(\tau) \leq V_{cut-in} \text{ or } V(\tau) \geq V_{cut-off} \\ P_{WT-rated} \dfrac{V(\tau) - V_{cut-in}}{V_{rated} - V_{cut-in}} & V_{cut-in} < V(\tau) < V_{rated} \\ P_{WT-rated} & V_{rated} < V(\tau) < V_{cut-o} \end{cases}$$

4.3 Mathematical Modeling of Renewable Output Power

The energy losses take place in conversion process are modeled based on their efficiencies. The total renewable power delivered by SPV and WT units consider the efficiency of AC to DC converter and DC to DC converter.

$$P_{RES}(t) = \eta_{dc\ to\ dc} \times \sum_{n=1}^{NSPV} P_{SPV}(t) + \eta_{ac\ to\ dc} \times \sum_{n=1}^{NWT} P(t)$$

Where, P_{RES} is the power obtained from RES, $\eta_{dc\ to\ dc}$ represents the efficiency of dc-to-dc conversion, $\eta_{ac\ to\ dc}$ is the efficiency of ac to dc conversion.
In this research work, the efficiency of DC to DC and AC to DC conversion is

considered to be 95%.

Due to the stochastic nature of wind speed and solar radiation, the output energy of SPV and WT units is not consistent and has stochastic nature. In order to supply the system load constantly, these SPV units must be paired with BES that improves the supply reliability depending on the charging and discharging pattern.

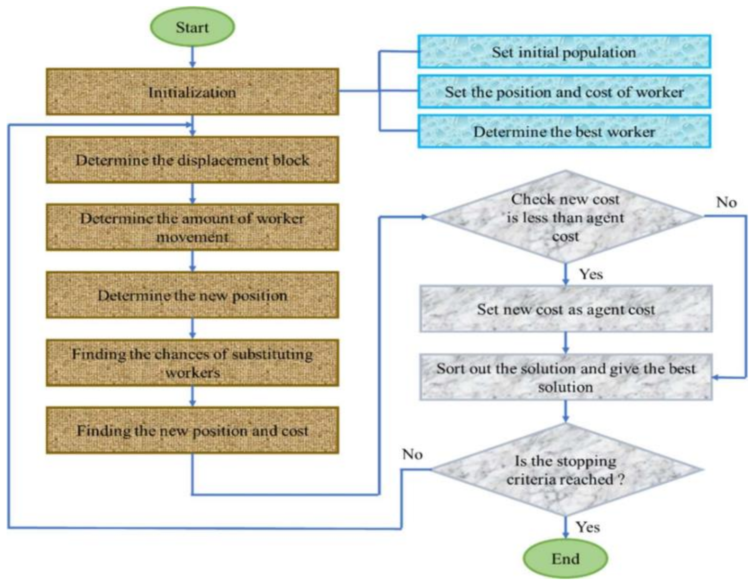

Fig. 1: Flow chart of GPC

V. DETAILS OF DESIGN

5.1 System Simulation Model

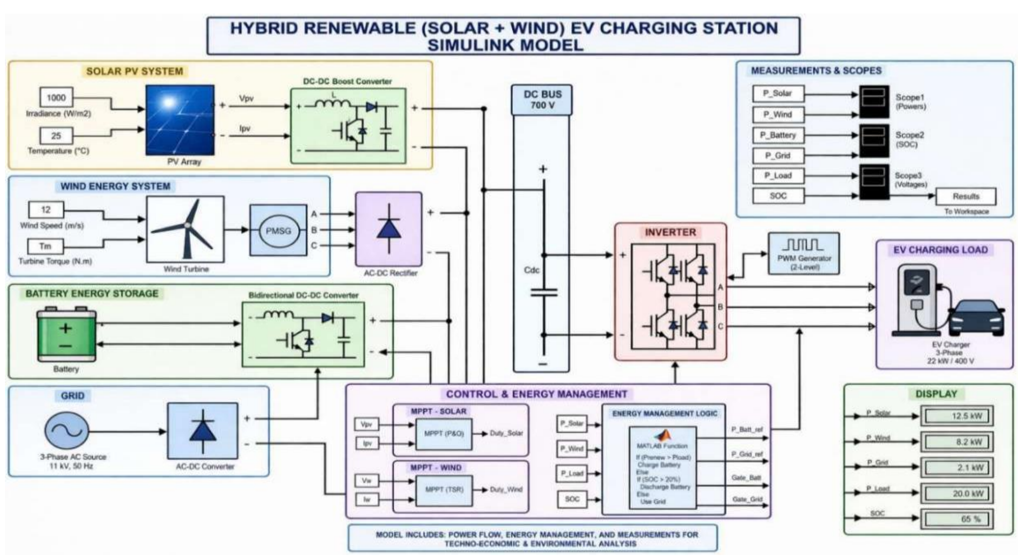

Fig.2 Hybrid Renewable (Solar + Wind) EV Charging Station Simulation

A hybrid renewable energy-based EV charging station is depicted in the simulation model above, which was created with MATLAB/Simulink. The grid connection, solar PV, wind energy, battery energy storage system, inverter, and EV charging load are all integrated into the model.

The battery system stores extra energy for backup operation while converters and controllers from solar and wind energy sources power the EV charging system. When renewable energy output is minimal, the grid is connected to supply power continuously. The system performance, power flow, and techno-economic operation of the suggested EV charging station are examined using the constructed simulation model

VI. RESULT

6.1 Load vs Renewable Power

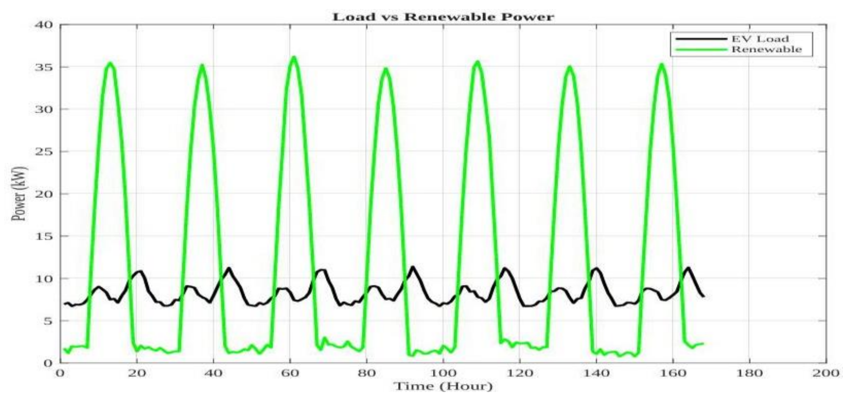

Fig.3 Load vs Renewable Power

The demand for EV charging and the production of renewable energy are contrasted in the Load vs. Renewable Power graph. Throughout the simulation time, the majority of the charging demand was met by renewable energy sources, such as solar PV and wind energy. The charging station's overall energy sustainability was enhanced and reliance on the utility grid was greatly decreased by the incorporation of renewable resources.

6.2 Battery State of Charge (SOC)

The Battery State of Charge (SOC) graph illustrates the charging and discharging characteristics of the battery energy storage system throughout the simulation period. SOC represents the percentage of energy available in the battery relative to its total storage capacity. Effective SOC management is essential for ensuring

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reliable operation, maximizing battery life, and maintaining energy balance within the EV charging station.

In the proposed system, the battery operates within predefined SOC limits of 25% and 90%. The upper limit prevents overcharging, while the lower limit avoids deep discharge, both of which can significantly reduce battery lifespan. During periods of excess renewable energy generation, the battery stores surplus energy and its SOC increases.

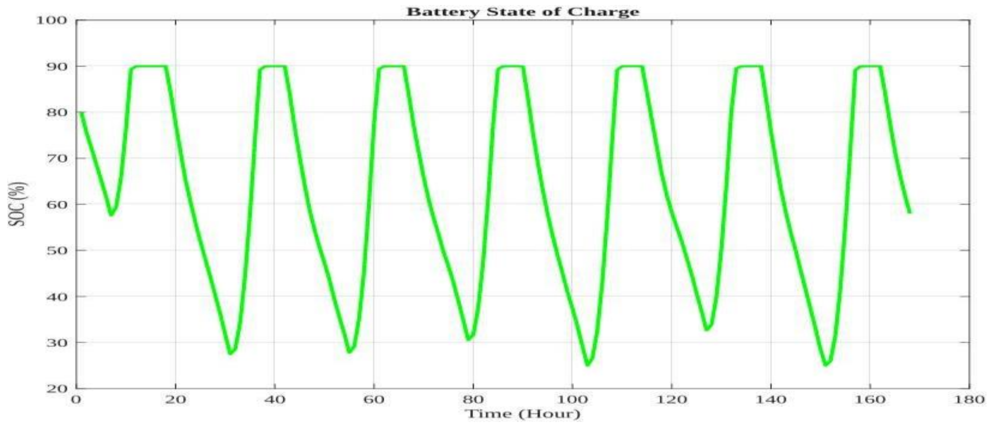

Fig.4 Battery State of Charge (SOC)

VII. CONCLUSION

The techno-economic study of a renewable energy-based EV charging station utilizing solar photovoltaic systems, wind turbines, battery energy storage systems, and utility grid assistance is presented in this project. MATLAB/Simulink was used to construct and analyze the suggested hybrid system in order to assess its technical, financial, and environmental performance.

According to the simulation's findings, renewable energy sources can efficiently supply a sizable amount of the demand for EV charging while greatly lowering reliance on traditional grid electricity. By storing extra renewable energy and providing electricity during times of low generation, the battery energy storage system increases the charging station's dependability.The techno-economic analysis demonstrates that the proposed system can reduce operating costs, improve renewable energy utilization, and minimize carbon emissions associated with EV charging. Parameters such as Levelized Cost of Energy (LCOE), Total Net Present Cost (TNPC), payback period, and CO_2 emission reduction confirm the economic feasibility and sustainability of the proposed charging infrastructure.

Overall, the proposed renewable energy-based EV charging station provides an environmentally friendly, reliable, and cost-effective solution for future electric mobility. Further improvements can be achieved through the integration of artificial intelligence-based energy management systems, smart grid technologies, fast charging infrastructure, and Vehicle-to-Grid (V2G) applications.

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