Comparative Case Study: Renewable Energy vs Conventional AC Grid-Powered EV Charging Stations

Suresh Chand Meena[1]; Pushpendra Kumar Sharma[2]; Dr. Ramesh Bharti[3]

[1]Research Scholar (M. Tech) Jagannath University
[2]Assistant Professor, Electrical Department Jagannath University
[3]Professor, Electrical Department Jagannath University

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Abstract: The rapid adoption of electric vehicles (EVs) places significant stress on conventional electrical grids, driving the need for sustainable charging alternatives. This paper presents a comparative case study evaluating the design, technical viability, economic feasibility, and environmental impact of two distinct EV charging infrastructures: a renewable energy-powered station (utilizing solar photovoltaic arrays and a battery energy storage system) and a conventional grid-tied AC charging station. Using simulation software, both systems were modeled under identical geographical and vehicle load profiles to assess performance metrics, including energy efficiency, grid dependency, and operational costs. The technical analysis highlights how localized renewable generation mitigates peak demand stress on the conventional AC grid. Financially, the study compares the higher initial capital expenditure (CAPEX) of the renewable infrastructure against its lower long-term operational expenses (OPEX) and shorter payback period facilitated by reduced grid reliance. Environmentally, the renewable integration demonstrates a substantial reduction in lifecycle carbon emissions compared to the fossil-fuel-reliant conventional AC system.

Keywords: *Electric Vehicle; Solar PV Cell; SAE J1772 Charger; DC-AC Converter; PWM Controller.*

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I. INTRODUCTION

The global shift toward electric vehicles (EVs) requires a robust, scalable charging infrastructure, but traditional grid-dependent systems face significant challenges regarding peak demand, power quality, and stability. Integrating local renewable energy sources, such as solar (PV) and battery storage (BESS), offers a sustainable solution to buffer grid stress, forming the basis for this comparative analysis. This case study evaluates the technical, financial, and environmental impacts of renewable-driven charging against conventional systems, providing a blueprint design for future infrastructure [6].

The global transportation sector is undergoing a rapid transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs). This shift is driven by international climate agreements, stricter emission standards, and rapid advancements in automotive battery technology. However, the environmental promise of EVs depends heavily on the source of electricity used to charge them. If the charging infrastructure relies entirely on a conventional electrical grid powered by fossil fuels, the carbon footprint is merely shifted from the vehicle tailpipe to the power plant [1].

With the abundant option of renewable energy sources only solar energy is found to be effective with the comparison of normal AC voltage supply and will find out reliability, sustainability and efficiency between both energy system to access electric car charging because at some places it is very difficult to provide AC systems. Solar energy is found to be effective because of the easy availability and environmental friendly and it is better option for a greener community.

II. LITERATURE REVIEW

"Recent Advances in Smart Grid Architecture and Grid-Electric Vehicle-Charging Station Interaction" by Dongning Zhang. This paper reviews reduction of pressure on grids, reduction in carbon production, sustainable transportation and future techniques like vehicle to grid.[8]

"Renewable Energy Power Assimilation to the Smart Grid and Electric Vehicles via Power Transfer Technology" by H. Allamehzadeh and S. Shakya. This paper reviews in

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smart grid use of WPT technique to connect renewable energy with electric vehicles. This paper shows how centralization of renewable energy can be done , wireless power transfer, wireless EV charging [12]

III. SYSTEM STRUCTURE

The system design compares a conventional AC grid-powered station with a DC-coupled renewable hybrid configuration utilizing solar PV, battery energy storage (BESS), and grid integration. Key components include an MPPT-controlled DC/DC converter for solar harvesting, a bi-directional converter for BESS, and an EMS that manages power flow between the PV array, BESS, and grid to ensure uninterrupted charging.

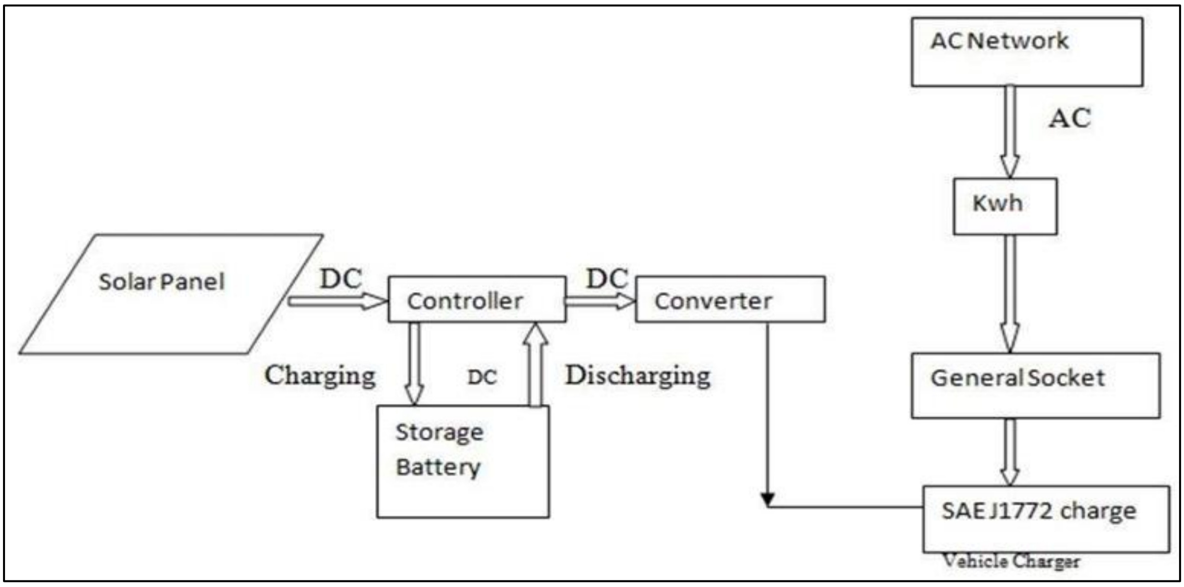

Fig 1 System Structure

Basically, a microcontroller is a part of system which regulates the current/voltage between batteries it is basically a electronic apparatus it monitors complete battery discharging or overcharging. It protects battery and increases their life. It could be referred as standalone apparatus or IC system that is integrated circuit system is attached to a battery system. It consists of mainly three parts.

- MPU controller
- PWM controller
- MPPT controller

➢ *SAE J1772 Standard Charger*

Fig 2 SAE J1772 Slandered Charger

This charger is based on American standard of electrical safety for electric vehicle and this charger is cared by SAE. SAE is a global association of commercial vehicle industry. This charger follows the protocol of the fields below.

- Communication
- Physics
- Electrical

Now we discuss parameters of SAE chargers for our system

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Table 1 Comparing Both Alternating Currents (Level 1 and Level 2)

	Level of Voltage	Supply Phase	Maximum current	Rating of Power
Level 1 Alternating Current	120 Volt	Single Phase	15 A	1.94 kW
Level 2 Alternating Current	220-240 Volt	Split Phase	80 A	19.31kW

IV. RESULTS AND DISCUSSION

By merging wind turbines and solar photovoltaic technologies, the proposed hybrid EV charging framework exhibits superior performance over traditional setups. Grid-reliant charging stations suffer from high operating expenses and heavy carbon footprints, with literature confirming that grid-dependent infrastructure drives environmental degradation and energy waste. Conversely, incorporating decentralized renewable sources fortifies grid reliability and operational longevity by securing a steady power supply amid fluctuating weather. Studies validate that hybrid green energy systems optimize efficiency while curbing reliance on legacy grids. Ultimately, this clean energy approach accelerates eco-conscious transit and advances the deployment of resilient smart grids.

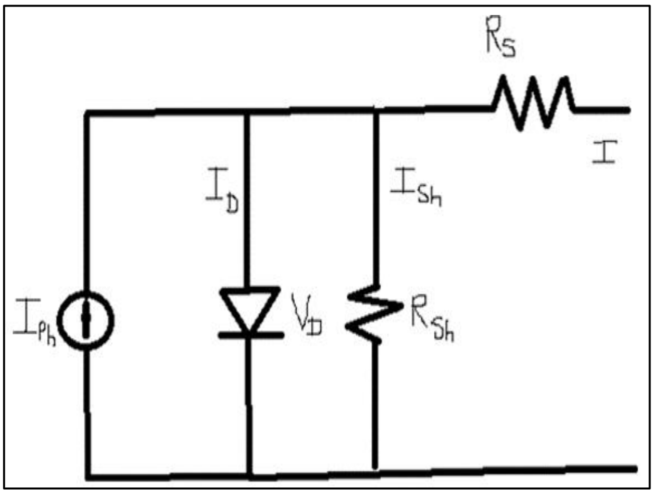

Fig 3 A Single Solar Cell Module

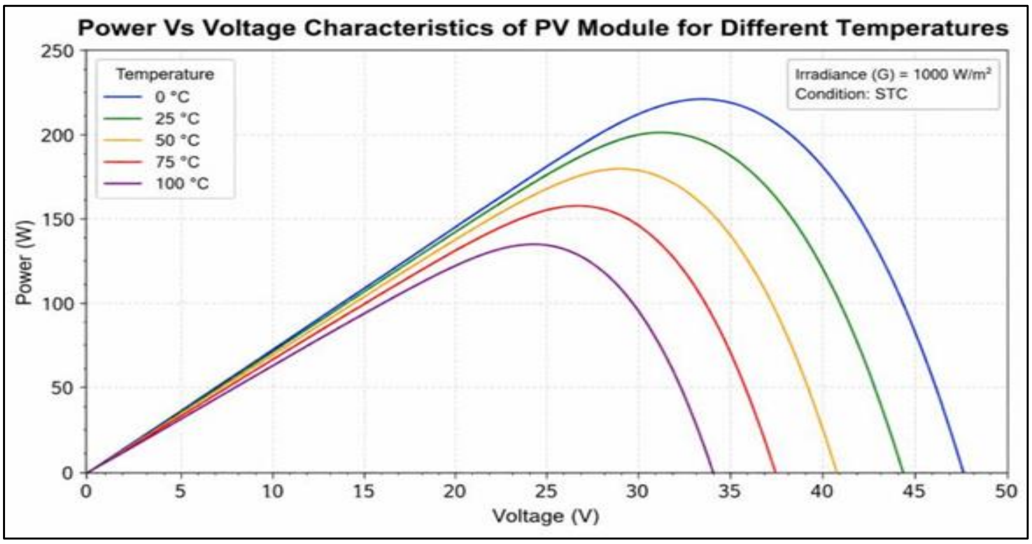

Fig 4 Power vs Voltage Characteristics of PV Module for Different Temperatures

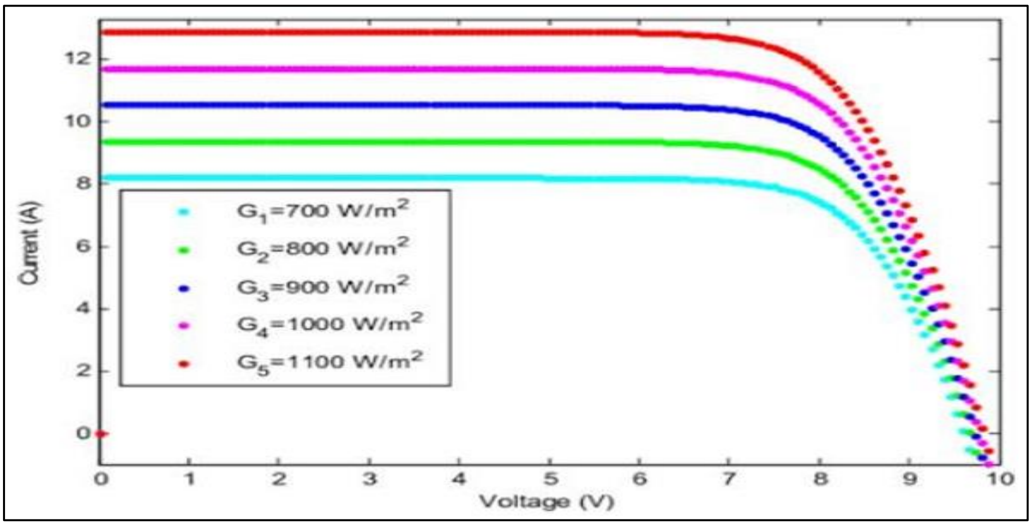

Fig 5 Voltage vs Current Characteristics of PV Module for Solar Irradianc

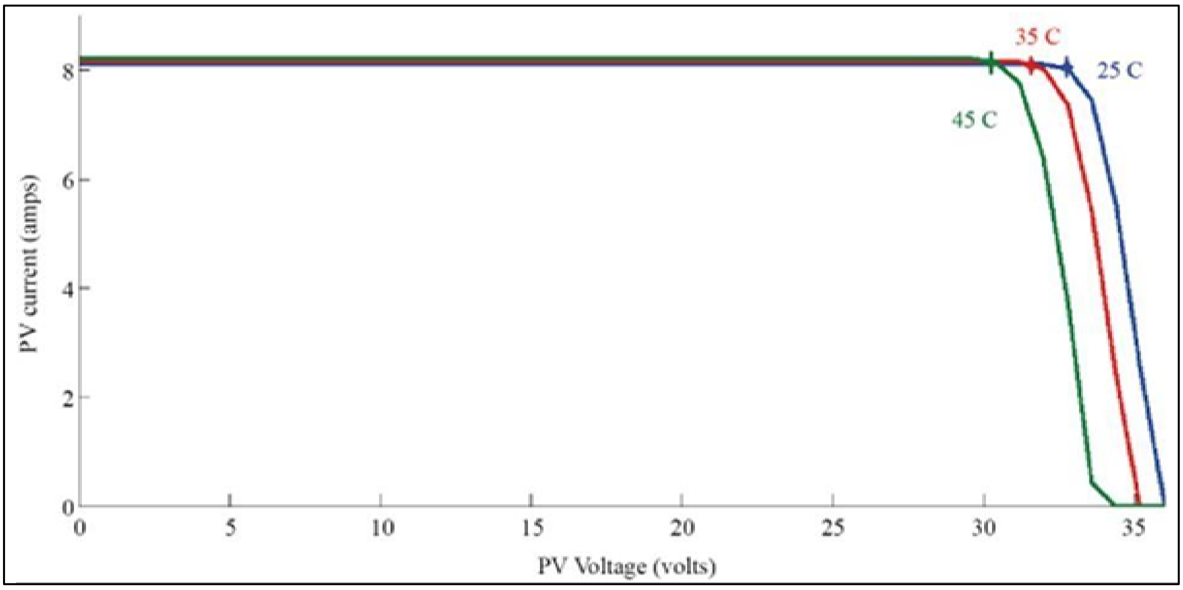

Fig 6 Voltage vs Current Characteristics of PV Module for Different Temperatures

➢ *Comparative Summary: Grid vs. Solar EV Infrastructure*

- System Efficiency: Traditional electrical grids deliver superior operational efficiency relative to independent solar energy platforms.
- Capital Investment: Solar-powered setups benefit from significantly lower upfront deployment and installation costs than expansive grid connections.
- Vehicle Performance: Vehicles utilizing grid-tied infrastructure enjoy minimized charging durations alongside reduced overall energy consumption.
- Bi-directional Power Flow: Utility grids uniquely support vehicle-to-grid (V2G) technology, allowing a reverse flow of electricity that solar arrays cannot achieve natively.
- Generation Economics: Solar energy production is highly cost-effective at ₹5.3 per unit, presenting an economical alternative to the grid rate of ₹8.9 per unit.
- Ecological Impact: Charging via solar power drastically lowers carbon dioxide emissions, mitigating the automotive industry's contribution to climate change.
- Spatial Optimization: Integrating solar panels directly onto parking structures eliminates the requirement for dedicated, supplementary land use.
- Supply Reliability: Centralized power grids provide uninterrupted, round-the-clock energy availability, whereas standalone solar generation remains weather-dependent and intermittent

V. CONCLUSION

The findings of this study demonstrate that the proposed approach can significantly contribute to improving the efficiency and overall performance of the photovoltaic (PV) system. The analysis of the PV characteristics under varying operating conditions indicates that appropriate system optimization can enhance power extraction and improve energy conversion performance. The observed results further confirm that temperature and operating conditions have a considerable influence on the electrical characteristics and efficiency of the PV module.

In the results highlights the potential of the approach for practical photovoltaic applications. Therefore, the developed system can serve as a suitable basis for further optimization of PV energy-generation systems, particularly through advanced control strategies, maximum power point tracking, and adaptive techniques for changing environmental conditions.

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