Smart Solar Powered Electric Vehicle: IoT-Enabled Cloud Data Engineering for Performance Optimization

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Abstract: This paper presents the design and development of a solar powered electric vehicle prototype integrated with Internet of Things based monitoring and cloud driven analytics for performance optimization. The objective of this study is to address the challenges of limited charging infrastructure and energy inefficiency in conventional electric vehicles by utilizing renewable solar energy combined with intelligent data engineering. The prototype is developed using a 12V solar panel, lithium ion battery, ATmega328 microcontroller, INA219 sensor, relay module, wireless charging coil, ESP Wi-Fi module, and a 16×2 LCD display. Real time operational parameters such as voltage, current, and battery status are collected and transmitted through Wi-Fi to the ThingSpeak cloud platform for continuous monitoring. The collected data is further processed using Azure Data Factory, Blob Storage, and Databricks to perform advanced analytics including solar panel efficiency evaluation, charging and discharging cycles, energy consumption trends, and anomaly detection. Results from experimental trials show that the integration of solar charging with IoT based monitoring improves sustainability, reduces dependence on conventional grid charging, and provides actionable insights for enhancing energy management. However, limitations such as dependency on weather conditions, restricted storage capacity, and efficiency losses in wireless charging were identified. The findings emphasize the potential of combining renewable energy, IoT, and cloud computing to develop next generation sustainable electric vehicles, while highlighting future directions such as predictive analytics, hybrid energy models, and scalable fleet wide implementations.

Keywords: *Solar Powered Electric Vehicle, IoT, Cloud Analytics, Renewable Energy, Data Engineering, Sustainability.*

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I. INTRODUCTION

The increasing global demand for sustainable and eco-friendly transportation has accelerated research and development in the field of electric vehicles (EVs). Although EVs are widely considered a cleaner alternative to conventional internal combustion engine vehicles, their large-scale adoption is hindered by limitations such as restricted charging infrastructure, long charging times, and battery degradation [1].

To address these challenges, the integration of renewable energy sources, particularly solar power, has emerged as a promising solution to enhance the self-sustainability of EVs while reducing dependence on grid-based electricity [2]. Recent studies have explored the potential of solar-powered EVs, focusing on aspects such as energy harvesting, wireless charging efficiency, and hybrid energy systems [3], [4]. While these works demonstrate the feasibility of solar-based EVs, they often lack real-time monitoring, intelligent data management, and advanced analytics capabilities, which are critical for performance optimization and long-term sustainability.

With the rapid advancement of Internet of Things (IoT) technologies and cloud computing platforms, it is now possible to continuously monitor vehicle performance, store large-scale sensor data, and apply data engineering techniques for predictive insights [5].

This study proposes a prototype of a solar-powered EV model integrated with IoT-based monitoring and cloud-driven analytics. The system is designed using a 12V solar panel, Li-ion battery, ATmega328 microcontroller, INA219 sensor, relay module, wireless charging coil, and ESP Wi-Fi module for real-time data acquisition and transmission to the ThingSpeak IoT cloud platform. The captured data is further processed using Azure Data Factory, Blob Storage, and Databricks to analyze parameters such as solar panel efficiency, charging/discharging cycles, and energy consumption patterns.

➢ *Objectives and Scope of Work*

The scope of this research lies in combining renewable energy, IoT, and cloud data engineering to provide a holistic framework for sustainable EV performance optimization. The primary contributions of this work are:

- Development of a working solar-powered EV prototype with integrated IoT monitoring.
- Implementation of a cloud-based data pipeline for storage and analysis.
- Experimental evaluation of system performance and identification of strengths and limitations.
- Insights for future improvements, including AI-based predictive analytics and scalable EV fleet applications.

By bridging renewable energy systems with cloud-enabled analytics, this research contributes to the ongoing efforts in designing intelligent, self-sustaining EV solutions that can play a pivotal role in addressing the energy and environmental challenges of the future.

II. SIGNIFICANCE OF STUDY

In addition to energy optimization, the integration of IoT and cloud computing enables predictive maintenance, fault detection, and performance trend analysis, which are often overlooked in conventional EV research. By continuously monitoring system parameters, potential issues such as battery degradation, power losses, and charging inefficiencies can be detected early, thereby extending battery life and improving overall vehicle reliability.

Moreover, solar-powered EVs offer significant environmental benefits by reducing greenhouse gas emissions and minimizing reliance on fossil fuels. This study emphasizes not only the technical performance of the prototype but also the environmental and sustainability implications of integrating renewable energy into transportation.

III. METHODOLOGY (BRIEF OUTLINE)

- Prototype Design: A 12V solar panel, Li-ion battery, ATmega328 microcontroller, INA219 sensor, relay module, and wireless charging coil.
- Data Acquisition: ESP Wi-Fi module for real-time data transmission.
- Cloud Integration: ThingSpeak IoT platform, Azure Data Factory, and Blob Storage.
- Analytics & Visualization: Databricks used for performance evaluation, energy efficiency analysis, and trend forecasting.

IV. EXPECTED OUTCOME

The integration of renewable energy, IoT, and cloud-based analytics provides:

- Improved EV performance optimization.
- Early fault detection and predictive maintenance.
- Environmental benefits via reduced carbon emissions.
- A framework for scalable deployment in future smart EV fleets.

V. CONCLUSION

This research positions itself at the intersection of renewable energy, embedded systems, IoT, and cloud-based data engineering, highlighting a novel framework for holistic performance evaluation and optimization. The integration of real-time data acquisition, cloud storage, and advanced analytics provides a platform for scalable deployment, future fleet management, and AI-based predictive modeling, thereby contributing to the development of intelligent and self-sustaining electric mobility solutions.

FIGURES AND TABLES

The performance of the solar panel and battery under multiple trials is summarized in Table 1. Figure 1 illustrates the trend of battery efficiency across trials. Similarly, Table 2 presents energy consumption and efficiency data, while Figure 2 highlights the system efficiency comparison.

Table 1: Solar Panel and Battery Performance Data

Parameter	Unit	Trial 1	Trial 2	Trial 3
Solar Panel Voltage	V	12.5	12.3	12.4
Solar Panel Current	A	1.2	1.1	1.15
Battery Voltage	V	12.1	12.0	12.05
Battery Charging Time	Hours	3.5	3.7	3.6
Battery Discharging Time	Hours	2.8	2.9	2.85
Power Delivered to Load	W	14.0	13.5	13.8

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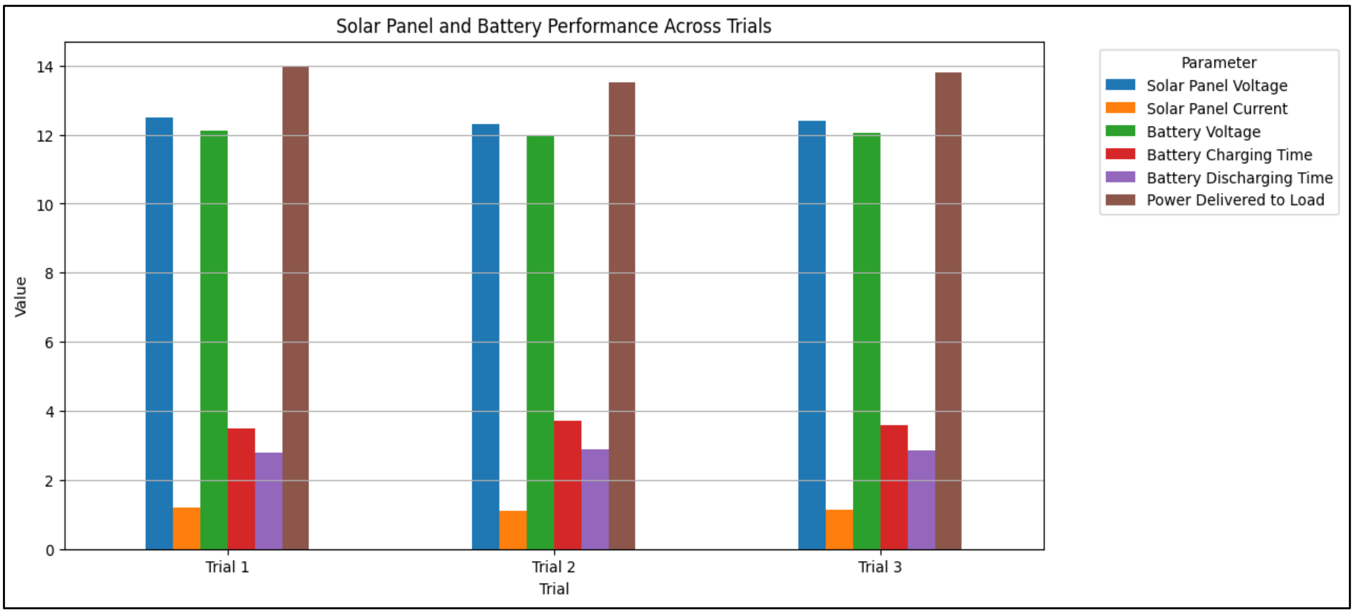

Fig. 1: Battery Efficiency Trend

Table 2: Energy Consumption and Efficiency Data

Parameter	Unit	Trial 1	Trial 2	Trial 3
Energy Input from Solar Panel	Wh	42.0	41.5	41.8
Energy Stored in Battery	Wh	36.0	35.5	35.8
Energy Delivered to Load	Wh	33.0	32.5	32.8
Charging Efficiency (%)	%	85.7	85.5	85.6
Overall System Efficiency (%)	%	78.6	78.3	78.5

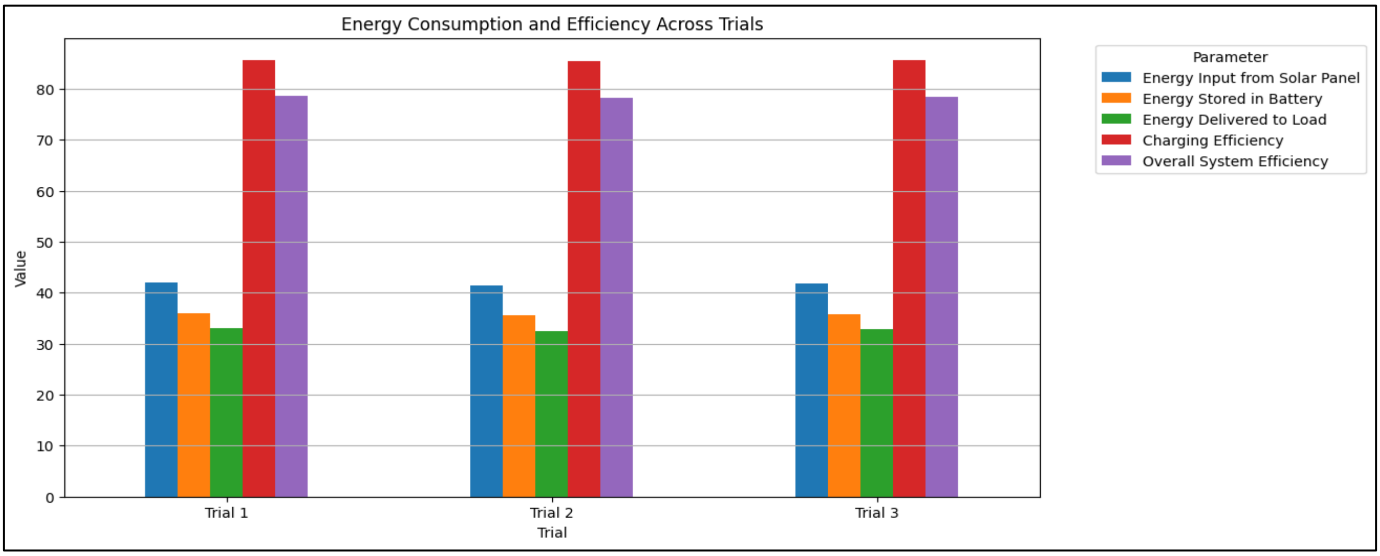

Fig. 2: Energy Consumption and Efficiency

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