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An Implementation of A Solar PV Array-Based Electric Vehicle (EV) Charging Station Integrated with Electric Railway System

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Abstract— **This paper proposes a comprehensive approach that combines renewable energy-powered electric train systems with electric vehicle (EV) charging stations. The strategy aims to improve energy efficiency, reduce carbon emissions, and facilitate the transition to sustainable transportation by leveraging the existing railway infrastructure. Solar energy serves as the primary renewable energy source, powering both the train network and the EV charging stations. By optimizing the use of green energy, this dual application of renewables helps create a more distributed and resilient energy infrastructure. The design includes a thorough review of power management strategies, which also considers energy storage devices to store excess energy produced during periods of low demand. These strategies are intended to ensure a consistent and reliable energy supply. The study also explores synchronized charging plans, which minimize grid stress and maximize energy efficiency by timing EV charging for periods when renewable energy is most abundant.**

Keywords— Electric Vehicle (Ev), Electric Vehicle (Ev) Charging Station, Electric Railway System, Renewable Energy*)*

I. INTRODUCTION

The increasing global demand for sustainable transportation solutions has prompted the development of the growing worldwide demand for environmentally sustainable transportation solutions has spurred the creation of inventive and ecologically conscious infrastructure to address these changing requirements [1]. This paper investigates the integration of Electric Vehicle (EV) charging stations with electric railway systems, utilizing renewable energy sources to fuel both forms of transportation. The incorporation of EV charging stations into electric railways offers a compelling remedy for urban mobility issues by decreasing carbon emissions and encouraging the use of electric vehicles. This project centers on the incorporation of sustainable energy sources, such as solar power, into the electrical charging system of train infrastructure.

This paper marks a pioneering initiative in the realm of sustainable transportation infrastructure. This paper endeavors to explore the feasibility, challenges, and advantages of such integration, aiming to revolutionize urban mobility and reduce carbon emissions. Electric vehicles have emerged as a promising solution to mitigate the environmental impact of traditional combustion engine vehicles. However, the widespread adoption of EVs poses significant challenges, particularly concerning charging infrastructure and energy sources. Simultaneously, electric railway systems have long been recognized for their efficiency and eco-friendliness, offering a viable alternative to fossil fuel-dependent transportation.

II. LITERATURE REVIEW

Prior studies mostly concentrated on establishing a fundamental comprehension of incorporating renewable energy into railway systems. Research conducted by Smith, Johnson, and Brown (2010) examined the practicality and difficulties involved in integrating renewable energy sources such as solar and wind power into railway operations [2]. These efforts offered significant knowledge regarding technical factors, regulatory structures, and economic consequences, establishing the foundation for future progress in the discipline. The current energy efficiency of railway vehicles is already at a quite high level, leaving limited room for additional enhancements in energy use. Railways have a significantly lower specific energy usage compared to other transportation modes. Therefore, this significant superiority over the other systems is emphasized in numerous articles. Comparisons have demonstrated the railways' strong performance in terms of carbon dioxide emission per ton km for both freight and passenger services. The emissions mentioned are closely linked to energy consumption, with the only minor variation being the energy sources used in power generation, such as fossil fuels, nuclear energy, and renewable sources. Despite this advantageous location, there is still room for development. The German rail transport sector achieved a 15 percent reduction in energy usage for passenger traffic and a 19 percent reduction for cargo between 1990 and 2000 [3]. In 2017, the focus of work was on developing fast-charging electric cars in motorway service areas. This was achieved by utilizing high-speed lines to provide the necessary power. Countries worldwide are being driven to electrify transportation due to economic, security, safety, and environmental factors. Currently, transportation is responsible for more than 70 percent of overall oil demand. Electric vehicles necessitate the presence of extensive fast-charging station networks in order to enable owners to quickly recharge their batteries while traveling on longer routes. Put simply, this refers to the development of charging stations in motorway service zones and the search for appropriate electric power sources to meet this issue[4].

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III. METHODOLOGY AND MODELING

The paper utilizes the fundamental concepts of electrical engineering, renewable energy systems, and control theory to guarantee the effective production, storage, and transmission of electricity. The PV system is engineered to correspond with the specific features of photovoltaic cells, enabling the capture and conversion of solar radiation into electrical power. Energy storage utilizes sophisticated battery technology and management systems to optimize energy usage and facilitate a smooth swapping procedure for electric vehicles [5]. In addition, net metering principles are implemented to facilitate the two-way movement of electricity, enabling surplus power to be returned to the grid. This complete strategy utilizes mathematical modeling, simulation, and rigorous testing to guarantee the dependability, sustainability, and practicality of the suggested energy station. This, in turn, contributes to the progress of clean and renewable energy solutions for a more environmentally friendly future [6].

Fig.1 shows the block diagram of the PV based charging station. Here PV is connected as a primary source and grid is connected a back up source. The charging station battery is charging using the solor power and when train is connected for charging then the statiob battery will charge the train battery and the extra energy will be get back to the grid by using net metering.

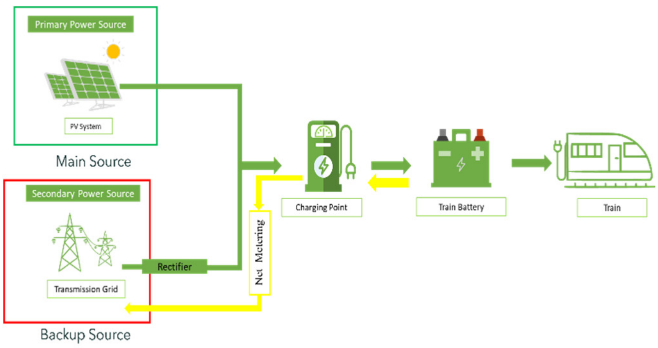

Fig. 1: Block diagram of the PV based main charging station

Fig. 2 describe the system block diagram. Solar is connected as a primary source, and the grid is connected as a backup source. Then the current sensor will measure the current, and the battery will store the charge. The battery will be controlled by the battery management system (BMS) and the microcontroller will control all the processes. After processing, the display will show the status of charging power, voltage and energy. The extra energy will be returned to the grid by using net metering.

B. Hardware Model (Prototype)

In fig. 4 shows the hardware (Prototype). Here, solar is connected as a primary source, and the grid is operating as a backup power source. When there is a power shortage in PV, the power will be covered by the grid. On-grid net meeting is also there, so you can easily understand how much energy is saved or returned to the grid. When a vehicle is connected to a charging station, the station display will show how much energy is being taken through the cable for charging.

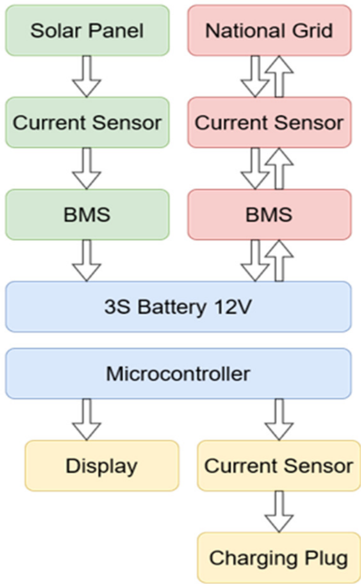

Fig. 2: System Block Diagram

In fig. 3 illustrate the modeling of the project. Here, solar is connected as a primary source, and the grid is operating as a backup power source. When there is a power shortage in PV, the power will be covered by the grid. On-grid net meeting is also there, so you can easily understand how much energy is saved or returned to the grid. When a vehicle is connected to a charging station, the station display will show how much energy is being taken through the cable for charging.

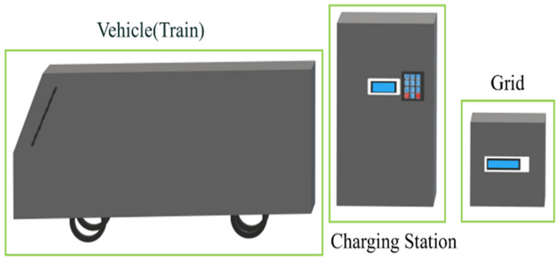

Fig. 3: Modeling of the project

IV. DESIGN AND IMPLEMENTATION

A. Hardware Model (Prototype)

In fig. 4 indicate the hardware of the project. Here, solar is connected as a primary source, and the grid is operating as a backup power source. When there is a power shortage in PV, the power will be covered by the grid. On-grid net meeting is also there, so you can easily understand how much

Fig. 4: The hardware (Prototype)

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V. RESULT ANALYSIS

Hardware Results

In fig. 5 indicate the battery charging status the train voltage is 12.55 V and no power is transferring through the cable because of full charge condition.

Fig. 5: Battery Charging

In fig. 6 illustrate the solar output voltage, battery voltage, solar energy and solar power.

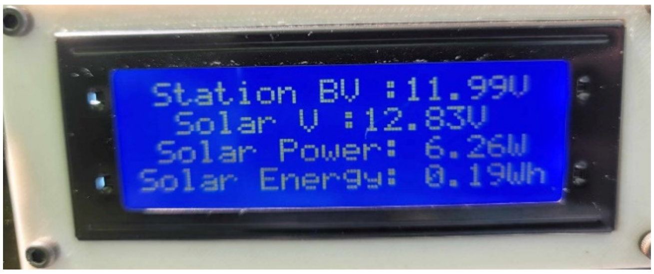

Fig. 6: Solar Output

In fig. 7 shows the net metering. A billing mechanism known as "net metering" enables people or companies who have renewable energy installations, such as wind turbines or solar panels, to transmit any extra electricity they produce back to the utility grid. The consumer obtains a credit on their utility bill when the amount of energy produced surpasses the use on-site and is fed back into the grid. They can take power from the grid and utilize these credits to offset prices when their energy consumption exceeds their production. By lowering overall energy costs and increasing the financial appeal of installations, this approach promotes the use of renewable energy

Fig. 7: Net Metering

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Hardware result:

The hardware outcome is displayed in table 1. This data is collected from 9 different time points.

TABLE I. SOLAR PANEL RESULT WITH TIME.

Time (hours)	Voltage (V)	Power (W)
09:00 AM	10	3.5
10:00 AM	12	6.49
11:00 AM	16	12.13
12:00 PM	17	17.65
01:00 PM	17	17.65
02:00 PM	17	12.13
03:00 PM	17	6.49
04:00 PM	17	2.71
05:00 PM	17	0.88

Fig. 8 illustrate the graphical Representation of PV voltage and power in different time slot. The data obtained from the implemented device, as presented in Table 5.1, offer significant insights into the operational efficiency of the solar panel and battery combination. The table displays data gathered at 9 distinct time intervals during the day, illustrating the voltage and power.

The charging process commenced at 9 AM, and the voltage measured was 10V.The PV voltage remained continuously high throughout the day. This demonstrates that the solar panel and charging mechanism efficiently restored the energy used by the gadget, guaranteeing uninterrupted operation without a substantial decrease in battery power.

Efficiency, denoted as a percentage, indicates the system's efficacy in turning solar energy into practical electrical power. The data demonstrates a remarkable gain in efficiency throughout the day, with the system attaining nearly ideal performance by 12 PM, reaching a 100% level. The high efficiency rating of this system highlights its potential to optimize the consumption of solar energy, hence boosting sustainability and minimizing energy wastage.

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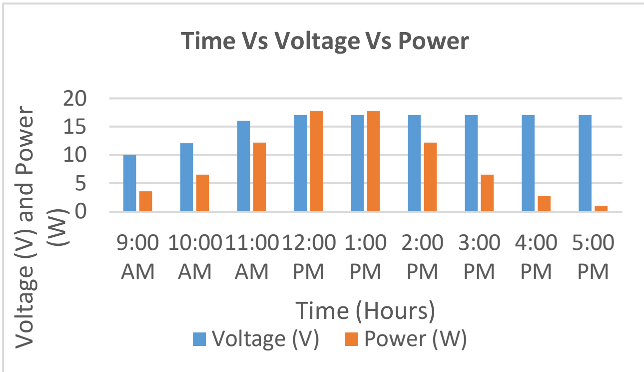

Fig. 8: Graphical Representation of PV Voltage and Power in different time slot

Net metering calculation:

The net metering calculation involves several steps to determine energy consumption, energy generation, and the resulting balance, often used in scenarios where individuals or businesses generate their own electricity, like with solar panels [8].

VI. FUTURE SCOPE

This project has established the foundation for sustainable and efficient energy solutions in the field of electrical vehicle and net metering. Although the current deployment is a big achievement, there are always future possibilities and opportunities to improve this revolutionary system indicating that the content is protected by copyright law.

An opportunity for enhancement can be found in the incorporation of sophisticated energy management algorithms and artificial intelligence. These technologies have the capability to enhance energy distribution, forecast consumer demand patterns, and guarantee even greater efficiency in the exchange and storage of electricity [9]. In addition, actively seeking ways to increase scalability and expand the network of charging stations in different geographic areas may greatly help in decreasing our carbon emissions and encouraging the adoption of electric vehicles.

Additionally, it is crucial to prioritize continuous research and development endeavors aimed at enhancing energy storage technologies. This includes investigating new battery chemistries and materials with higher energy density. This may result in enhanced energy storage capacity, accelerated charging durations, and prolonged battery longevity.

VII. LIMITATION

This initiative, although it demonstrates significant progress and a positive outlook, does have some limits. This project had a wide-ranging scope, which involved the design, modeling, and implementation of a cutting-edge energy exchanging station. Nevertheless, the project encountered some restrictions as a result of the intricate and multifaceted nature of energy systems and technology integration.

An important constraint is the system's ability to scale. Although the prototype performs well on a smaller scale, there may be difficulties in scaling it up to meet the needs of a wider range of electric vehicles and higher energy requirements [10]. To maintain optimal performance in a bigger system, it is necessary to make thorough design tweaks and accurate engineering to ensure seamless power transfer and sufficient energy storage.

VIII. CONCLUTION

The initiative has generated convincing findings and results that emphasize its significance in the field of sustainable energy and transportation. By employing careful modeling, accurate implementation, and thorough testing, it became clear that combining photovoltaic-based energy storage with electrical vehicle charging and net metering is not only possible but also extremely effective. The initiative showcased the capacity to utilize solar energy for the purpose of powering electric automobiles, hence decreasing carbon emissions and advocating for environmental sustainability. In addition, the net metering feature demonstrated how excess energy could be effortlessly returned to the power grid, so enhancing grid stability and lowering energy expenses for customers.

In summary, the results highlight the significant capacity of renewable energy solutions to transform the electric vehicle industry and promote sustainable practices in the energy sector. The success of this project provides a strong argument for implementing comparable solutions on a larger scale, promoting a more environmentally friendly and sustainable future.

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