

Integration of PV and Fuel Cell for Automation of Automotive and Locomotive Charging

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Abstract— With the rising prominence of electric and hybrid locomotives, there is a growing need for efficient, sustainable, and decentralized power systems to support their operation. This project proposes a hybrid power system integrating hydrogen fuel cells, solar photovoltaic (PV) energy, and battery storage to drive electric locomotives with high efficiency and low environmental impact. The proposed system is modeled in MATLAB/Simulink, incorporating a DC-DC converter, BLDC motor, and advanced control strategies to optimize power flow and motor performance. The hydrogen fuel cell serves as the primary energy source, supported by solar energy and battery backup to ensure reliable and uninterrupted operation. This hybrid approach not only reduces dependence on grid-based infrastructure but also aligns with future transportation goals of green mobility. The system is especially suited for urban environments where automated parking and charging stations can utilize rooftop solar panels to offer fast DC charging. The integration of such systems can significantly contribute to India’s vision of “Shared, Connected, and Electric Mobility,” targeting 100% electric vehicle adoption by 2030.

Keywords— *Electric Vehicle Charging Station (EVCS), Fuel cell, Fast charging, Maximum Power Point Tracking (MPPT), Dual Input Super Boost Converter, Depth of Discharge (DoD), battery swapping, Compound Annual Growth Rate (CAGR)*

1. INTRODUCTION

The vehicle population is increasing day by day and is expected to exceed the human population in the upcoming years. This would also result in the consumption of fossil fuels and in the extinction of the non-renewable resources. The automotive sector would be the major culprit for this extinction. Hybrid and electric vehicles have been a suitable replacement and have been so far managed to keep the usage of fossil fuels under control. Britain aspires to completely ban the sales of gasoline- and diesel-powered passenger cars by 2035 which is a step in the right direction but needs proper resources and infrastructure to support these EVs. A proper working infrastructure includes an automated charging station with maintained power quality, automated parking system, fast charging support, etc. Type 1 and Type

2 AC charging have been more prominent but recent developments have shown that DC charging can be equally effective. Solar though being an intermittent source of energy but with the usage of a proper power condition in the unit can provide a reliable supply. This can be visualized using MATLAB Simulink tool.

A grid-connected solar micro-system helps in using excess solar generation during the peak hours of solar irradiations to charge EVs and also to export the power back to the grid to earn revenues. For designing a universal charging station, proper standardization of the battery capacity and charging connectors is to be made. Maintaining proper DoD of the battery helps to increase the battery life. Proper Battery Management System (BMS) is equally important. EVCS can also operate as an exchange station to support battery swapping [3]. Qualcomm has already proved that charging while driving is possible, even while the vehicle is traveling at up to 70mph. The technology is being profoundly known as Dynamic Electric Vehicle Charging (DEVIC) and is expected to be implemented in major highways. Basically, the EV batteries do not get filled, but they are also not losing any power. But installing such a system in actual practice is a mighty task. Volterio, a famous EVCS designing company is coming up with technological solutions to implement a smart automated charging system starting from domestic applications to major commercial stations. This will boost the usage of EVs amongst the consumer and the EVCS will start replacing gas stations in upcoming years.

II. TYPES OF CHARGING

Basic classification of EV charging can be based on ac or dc. But there is another way of categorizing i.e.

A. Conductive charging

Generally, a physical connection is required between the EV's battery and the power supply for conductive charging. But recent developments such as Honda's study about charge-on-the-move for conduction between vehicle rollers and road power, with 100 kW of power (DC 375 V, 300 A) at a vehicle speed of 70 km/h, and possibly higher.[1] and Stanford scientists have developed a way to wirelessly deliver electricity to moving objects such as electric vehicles and personal devices.

B. Inductive charging

Charging based on Faraday's law of Induction, the EV should be placed near the inductive pad of a charging station without the need for any precise alignment for making electrical contact with a plug or a dock. Greater distances for charging can be achieved by resonant inductive coupling between sender and receiver coils. The emerging SAE J2954 standard allows inductive car charging over a pad, with power delivery up to 11 kW.[2] Synchronization of both the methods of charging can be effectively implemented to increase the rate of charging. For designing of EVCS, we are employing conductive charging only. Research on charging while driving infrastructure is being carried out by top car manufacturers which will be evolutionary engineering marvel.

III. DESIGN

Advancement in the electronics industry has led to an improvement in comfort and performance. Performance analysis and vehicular diagnostics can be easily monitored and communicated to the OEMs via Wi-Fi or Bluetooth.

MPPT based controller is used to obtain maximum photovoltaic conversion and power conditioning unit enables to obtain reliable regulated DC supply. Solid-state relays are used for switching between solar output and auxiliary/grid supply and control actions are provided by the master controller. Parameters such as battery voltage, temperature, SoC, SoH can be monitored for the efficient operation of the charging station.

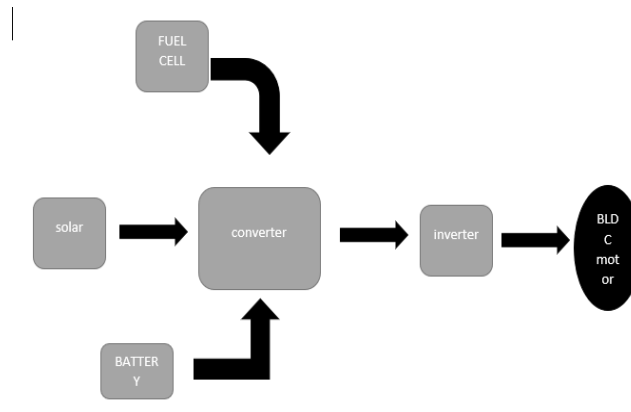


Fig. 1. Simple Block Diagram of Proposed Block Diagram

There is a need to standardize the battery voltages and the connectors as various car manufacturers have their own company designs. This increases complexity while designing the EVCS. Either the standardization should be done or the EVCS should be compatible with all specifications.

IV.FLOWCHART

Commercial solar-powered charging and exchange stations along with parking facilities especially in malls, institutes, IT sector multi-story parking buildings [4] will have a great scope and a proper business plan will help them to obtain a payback period of fewer than 3 years [5]. An RFID based card system [6] for a customer helps to authenticate the user and allocate the right parking space and fast payment gateway. This system will be similar to a FASTag RFID based system initiated in highways in India for avoiding long queues at toll booths. Automated conductive charging and standardized connectors will be used to charge the EV. Solar availability implies using it to charge the vehicle, solar not available, the auxiliary supply or grid connection can be used. As solar penetration is increasing at a rapid rate, especially in sub-tropical nations like India, its effect on the duck curve also getting affected which needs to be monitored and stabilized [4]. The status of charging is continuously monitored and also communicated to the customer to maintain a transparent and fair operation of EVCS. The ground floor can be reserved for fast charging or battery swapping for fast-track customers. The time-of-use

pricing model along with the monitored power transfer rate is utilized in the EVCS for billing. A database of users can be maintained for historical data analysis. Charging status and billing criteria can be viewed by the users in mobile App or website.

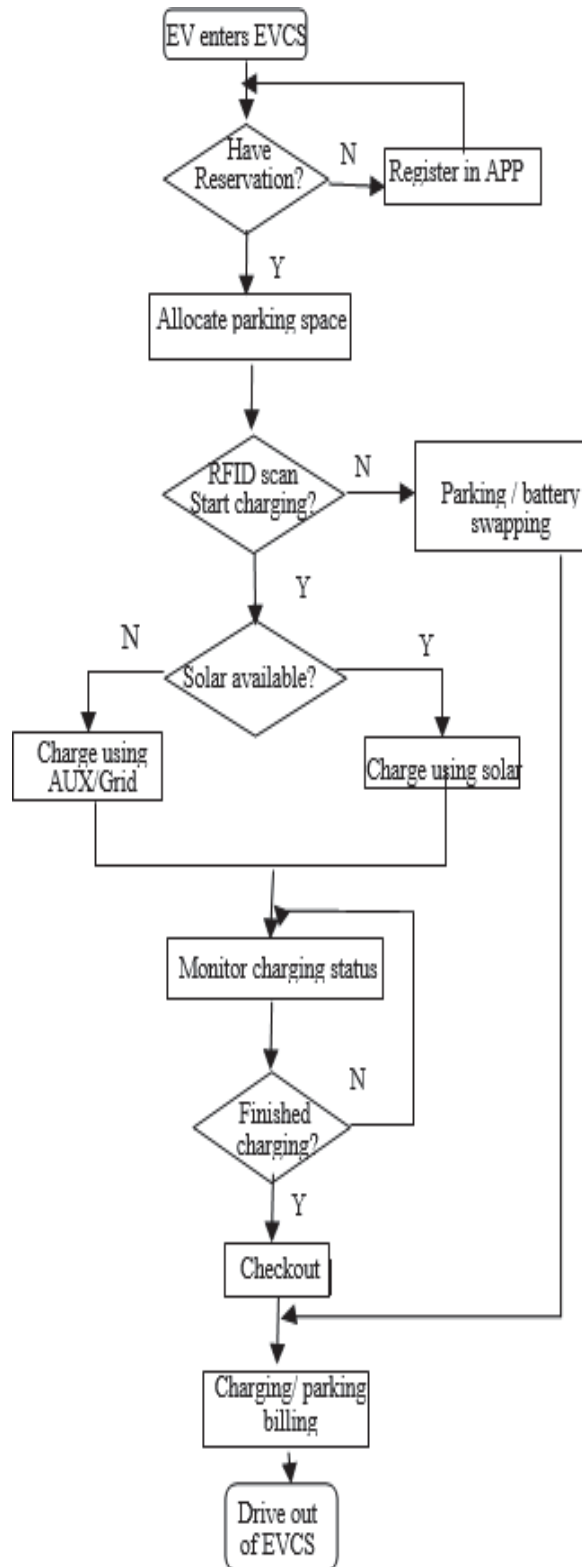


Fig. 2. Flow chart for billing in EVCS

V.PLANT MODELLING

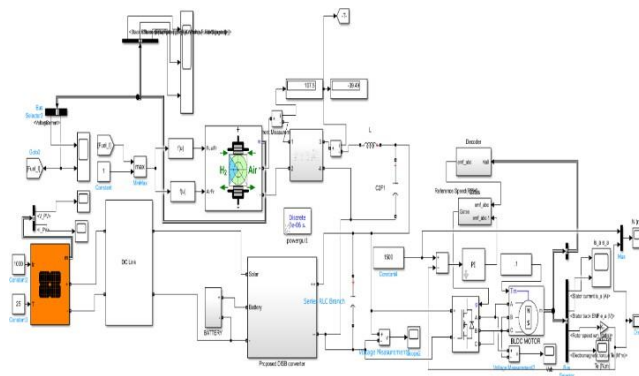


Fig. 3. MATLAB model of EVCS

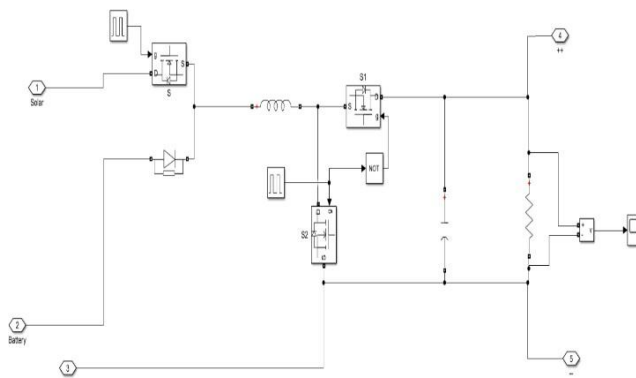


Fig. 4. MATLAB simulation block for solar subsystem (DISB)

An electric vehicle is a load of about 2kW. The solar plant for domestic application can be designed based on the available space. As the population density is quite high in India. Especially in metro cities, usage of rooftop area is a viable solution. A 2-kW plant requires 8 panels considering a rooftop area of 15 sq.m and a panel rated of about 250Wp. This micro grid generates approximately 9 kWh a day considering average irradiation in India, which is capable of delivering to bulky loads as electric vehicles. MATLAB is a powerful tool and can be used to analysis various performance parameter and the power flow across the network based on which decision commands are sent to the actuators to perform specified functions. Master controller plays a key role and should be able to handle large set of instructions based on priority. Solar generation depends on factors such as irradiation, inclination angle, temperature, etc. Type of solar panel to be used varies from application to application. Fault analysis of DC network is quite complex to analyze. Faults may lead to voltage reversal i.e. discharge of battery beyond certain limit which may lead to battery failure [9]. AC fault analysis tools can also be used to analyze faults on DC network.

VI. TRACTION CHARGING

Along with building EVCS at multiple locations, railways also is very keen on using solar energy as a battery backup to huge capacity batteries. Indian railways has already started on a major scale project of using renewables especially solar with the installation capacity of 1000MW by 2021-22. As much as 500MW of photovoltaic system is to be used on the railway coaches. Indian Railway Organization for Alternate Fuels (IROAF) is installing flexible solar panels on the coaches in such a way that it doesn't affect the aerodynamics and aesthetic of the train. This will also result in growth of solar and battery market at Compound Annual Growth Rate (CAGR) of 5.15%. The rise in demand for an energy efficient transportation system is due to issues such as air pollution caused by burning of fossil fuels. In countries such as France and China, the carbon footprints because of rail network is 14 to 15 more than the other mode of transports. Though the batteries of locomotives do get charged by regenerative braking, but it's not enough to fully charge them, solar integration may imply much more reliable power supply. Electric locomotives, though a convenient choice for commute with frequent stops, but has a huge potential for long distance travel if solar array installed on coaches. High infrastructure costs due to third rail, overhead lines, and substations can be lowered.

VII. CONCLUSION

The proposed hybrid energy system, comprising hydrogen fuel cells, solar PV, and battery storage, successfully demonstrates an efficient and sustainable solution for powering electric locomotives. The simulation results in MATLAB/Simulink validate the coordinated operation of the energy sources, ensuring optimal power distribution, stable DC-link voltage, and precise control of the BLDC motor under varying load conditions.

By integrating clean energy technologies, this model addresses the challenges of conventional grid dependency and limited charging infrastructure, making it particularly suitable for urban environments and future autonomous transportation systems. The use of rooftop solar panels for energy generation and the inclusion of fuel cell technology further enhances the system's feasibility for both domestic and commercial deployment.

Overall, the proposed system aligns with India's ambitious electric mobility goals and provides a scalable and environmentally friendly approach to modern transportation. Future work may involve real-time implementation and performance validation using hardware-in-the-loop (HIL) testing to further refine the control strategies and improve system resilience under dynamic conditions.

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RESULT

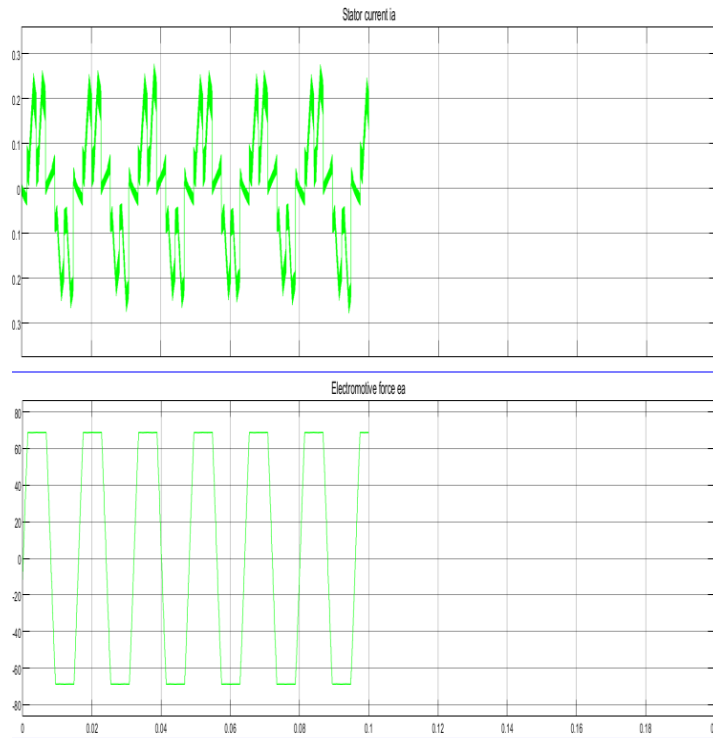


Fig:10.9 STATOR CURRENT AND ELECTROMAGNETIC FORCE

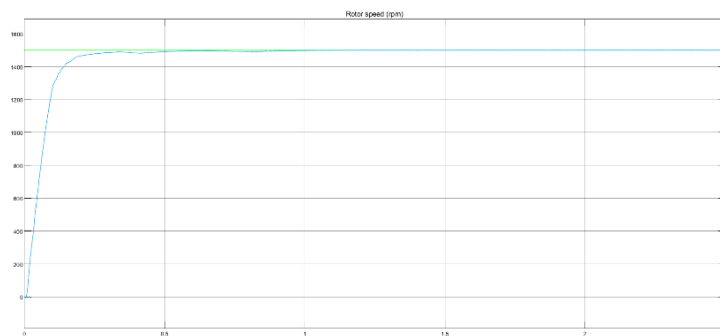


Fig:10.10 ROTOR SPEED