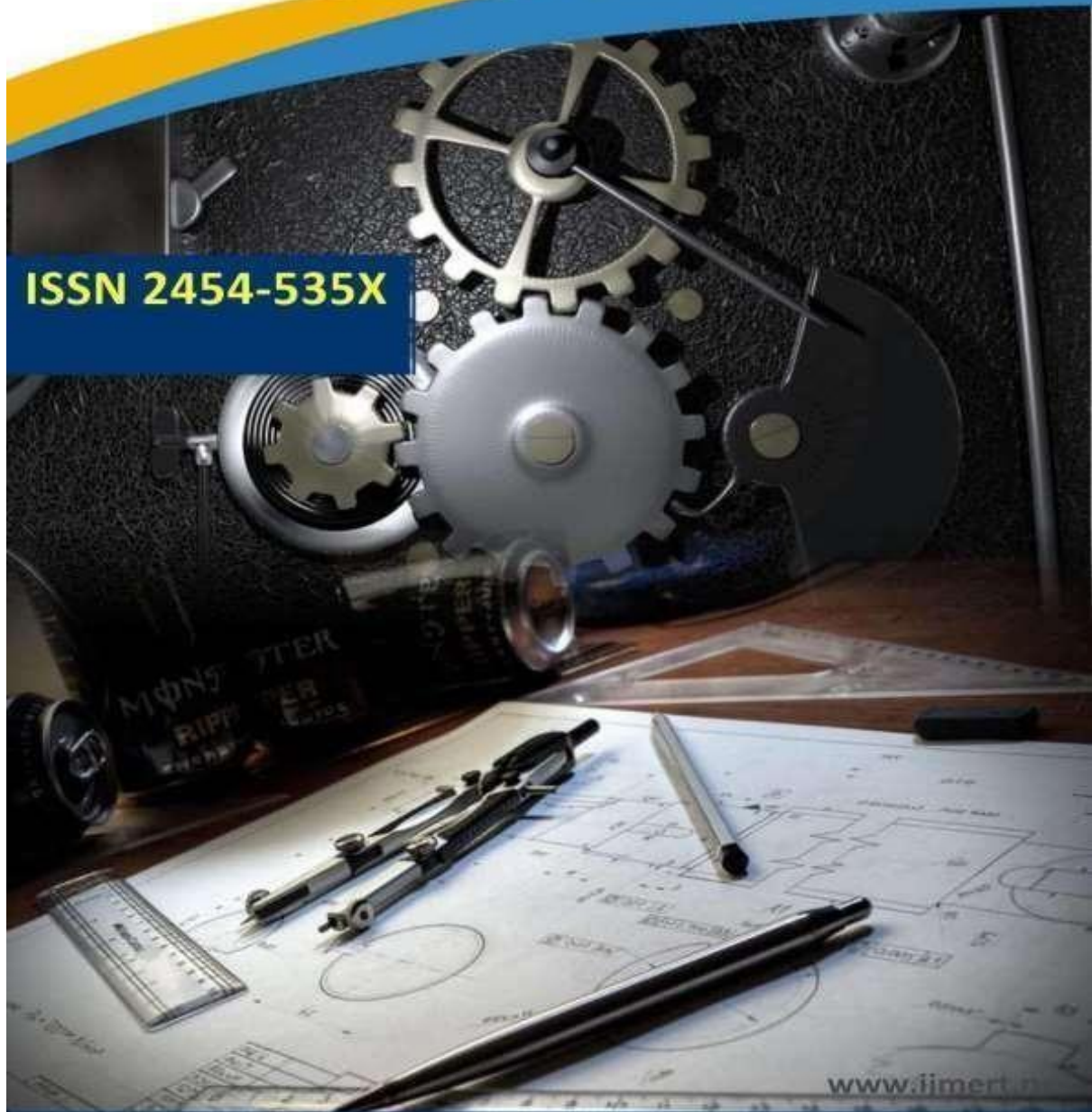




International Journal of Mechanical Engineering Research and Technology

ISSN 2454-535X



www.ijmert.in

Email ID: info.ijmert@gmail.com or editor@ijmert.net

INTEGRATION OF RAILWAY SYSTEM CONNECTED FED TO MICROGRID STATIONS

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ABSTRACT

This paper suggests a techno-economic process for the energy storage by using SCs in the train, with the aim to reduce the energy consumptions. The proposed design of railway station use PV and wind sources, and batteries for energy storage system (ESS). For the train, SCs are implemented to the ESS where they are alimented breaking phases and from stations by a pantograph installed in an air power line in each stop. SCs are distinguished by high characteristics power and a wide number of charge/discharge cycles, they provide low particular energy and a fast-charging time. An energy management approach is suggested to control the DC bus by voltage and the buck-boost converter by current. The Sizing of PI controller used for the stabilization of the DC bus of train and station is given. The whole system is modeled in MATLAB-Simulink. Simulations for the train and station show the suitability of the suggested powertrain and control strategy.

Keywords: Energy management, railway system control, energy storage system, Supercapacitors.

INTRODUCTION

In the last few decades, generally there are growing in energy using and pollutions. The growing number of citizen traveling between cities has implied the continuous development of mass transit systems as buses, taxies, and trains .However, the use of railway transportation systems other conventional means of transport is widely recognized due to the Carrying capacity of a large number of people. The development of rail transportation allows people to travel quickly. Thereby, growing environmental like climate change and CO2 emissions change issues dictate the requisite for ameliorate the performance energy regulation of railway systems. For these raisons, the electrified railway traffic has become a principal development management of current public transportation networks. The production of clean energy from renewable sources have become the hot topics of social development. However, railway system integrates different renewable energy sources, like photovoltaics (PV) and wind turbines. To ensure a continuous power supply and to respond to the charge power of train from station to the train, an energy storage system (ESS) is necessary. In order to manage the overload variation in railway power supply structure in the time of heights commuting hours, a wide number of ESS technologies are implemented in the railway system as a constructive means to improve load needs. The on-board storage augmented the weight and space of a vehicle that encourage the underground storage.

SCs represent an appear energy storage devices characterized with a high-power density, a long span life and a wide temperature range, has become the best appropriate storage element match with the functioning characteristics of train system. By comparing SCs to different energy storage devices like batteries and flywheels, SCs present fast charging and discharging time because of the high-power density, and important potential of energy recovery. n general, ESS with SC is considered like energy buffer accelerating mode of train and recycles the excess of power during the braking mode, realizing a good balance of charge and discharge. SCs are considered a best solution in systems which characterized with different fluctuations. SCs are also used in interruptible power systems to stabilized the power and bus voltage. The energy storage in railway system presents a challenge for researches.

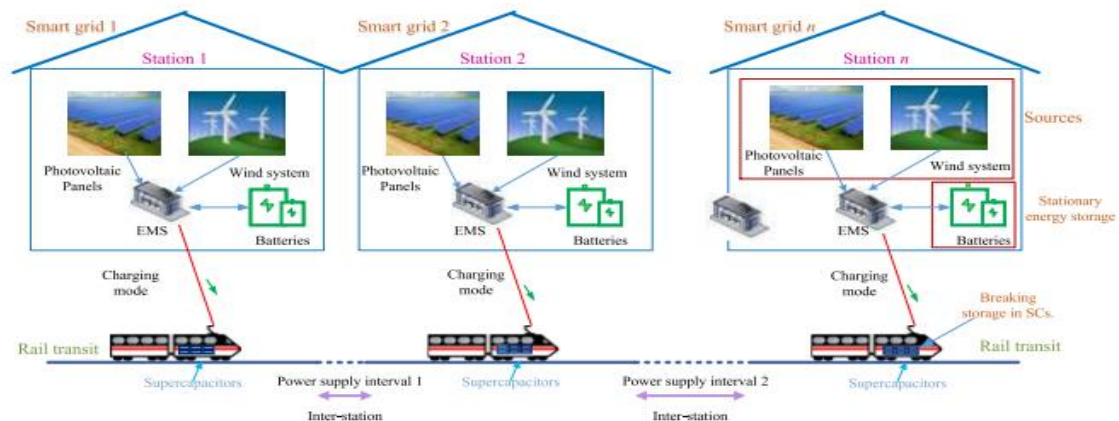


Fig 1. Proposed system configuration

The proposed system, is composed of two parts: the first one concern the stations, the second one is addressed to the control of trains. The stations are composed PV and wind fields where the energy storage is insured by batteries. The trains are composed by SCs and engine. SCs are used because of their high power. The innovative contributions given in this article are as follows. A design of train implementing SCs for energy storage alimented from stations and breaking phases. A new EMS is suggested to control the DC bus by voltage and the buck-boost converter by current. Sizing of PI controller used for the stabilization of the DC bus of train and station. A design of railway station using PV and wind sources, and batteries for energy storage.

LITERATURE SURVEY

The integration of railway systems with microgrid stations presents a promising approach for enhancing the sustainability, reliability, and efficiency of urban transportation networks. Microgrid stations, equipped with renewable energy sources, energy storage systems, and smart grid technologies, offer opportunities to power railway infrastructure while minimizing environmental impact and reducing dependence on fossil fuels. This literature survey explores existing research and developments in the integration of railway systems connected to microgrid stations, focusing on technical aspects, control strategies, performance evaluations, and future directions. Railway systems play a vital role in urban transportation, providing efficient, high-capacity, and environmentally friendly mobility solutions. However, traditional railway electrification systems are often reliant on centralized power sources, leading to grid congestion, energy losses, and vulnerability to disruptions. Microgrid stations, on the other hand, enable decentralized energy generation, storage, and distribution, allowing for greater resilience, flexibility, and sustainability in powering railway infrastructure.

Integrating railway systems with microgrid stations poses several technical and operational challenges. One key challenge is ensuring reliable and continuous power supply to railway electrification systems, including traction substations, signaling systems, and auxiliary equipment. Microgrid stations must be equipped with adequate energy generation and storage capacity to meet the dynamic power demands of trains, particularly during peak periods and in areas with limited grid connectivity. Furthermore, coordinating the operation of railway systems and microgrid stations requires advanced control strategies, communication protocols, and interoperability standards. Real-time monitoring, predictive analytics, and demand response mechanisms are essential for optimizing energy flows, minimizing grid congestion, and ensuring grid stability.

Several research studies have investigated the integration of railway systems with microgrid stations for enhanced energy management and sustainability. For instance, Wang et al. (2018) proposed a hierarchical control framework for microgrid-connected railway systems, incorporating renewable energy sources, energy storage systems, and demand-side management techniques. The hierarchical control strategy optimizes energy generation, storage, and distribution to meet the power demands of trains while minimizing grid impact and operational costs. Additionally, Li et al. (2020) developed a predictive control algorithm for microgrid-based railway electrification systems, leveraging real-time data analytics and machine learning techniques. The

predictive control strategy anticipates train schedules, passenger demand, and weather conditions to optimize energy dispatch, reduce energy wastage, and improve system reliability.

Furthermore, Zhang et al. (2019) investigated the use of advanced communication and control technologies, such as Internet of Things (IoT) devices and distributed energy management systems, to enable seamless integration and interoperability between railway systems and microgrid stations. The study demonstrated the feasibility of remote monitoring, predictive maintenance, and dynamic control of railway infrastructure through cloud-based platforms and data-driven algorithms.

Performance evaluation of integrated railway systems connected to microgrid stations involves simulation studies, laboratory experiments, and field trials. Simulation-based studies utilize software tools such as MATLAB/Simulink, PSCAD, and OpenDSS to model railway systems, microgrid components, train operations, and grid interactions. Laboratory experiments may involve the development of hardware-in-the-loop (HIL) setups or scaled-down prototypes of microgrid stations and railway electrification systems to validate control strategies and assess system performance under realistic operating conditions. Field trials may involve the deployment of integrated railway systems and microgrid stations in real-world urban environments to evaluate their efficiency, reliability, and impact on energy consumption and emissions. The integration of railway systems connected to microgrid stations offers significant opportunities for enhancing the sustainability, reliability, and efficiency of urban transportation networks. Through the deployment of decentralized energy generation, storage, and distribution infrastructure, microgrid stations enable resilient and environmentally friendly power supply to railway electrification systems. Simulation, laboratory, and field studies have demonstrated the feasibility and effectiveness of integrated railway systems and microgrid stations in improving energy management, reducing carbon footprint, and enhancing grid resilience. Continued research and development in this area are essential for advancing the integration of renewable energy sources with urban transportation systems and accelerating the transition towards a sustainable mobility future.

PROPOSED SYSTEM

Enhancing Railway System Efficiency and Sustainability through Integration with microgrid stations reduced energy consumption and reliance on the traditional grid improved grid stability and reduced power fluctuations and enhanced sustainability through the use of renewable energy sources. Cost-effective implementation and operation review existing models and research on integrating railway systems with microgrids, identifying key challenges and limitations. System Modeling and Simulation: Develop a comprehensive model that accurately represents the dynamics of train operations, microgrid components, and power flow between the railway system and the microgrid.

Control Strategy Development: Design and implement advanced control strategies to manage power fluctuations, ensure grid stability, and optimize energy exchange between the railway and the microgrid.

Economic and Regulatory Assessment: Evaluate the economic viability of the proposed integration, considering the cost of infrastructure upgrades, energy savings, and potential revenue streams. Analyze and address relevant regulatory and policy frameworks. Scalability and Interoperability Analysis: Investigate the challenges and potential solutions for scaling the proposed integration across large and complex railway networks and ensuring interoperability of different microgrid technologies.

Validation and Optimization: Validate the developed model and control strategies using real-world data and conduct simulations to optimize performance and address any identified issues.

Dissemination and Impact: Share research findings through publications, presentations, and collaborations with industry stakeholders to accelerate the implementation of sustainable railway systems powered by microgrids. A comprehensive and practical framework for integrating railway systems with microgrid stations. Optimized control strategies to ensure grid stability and efficient energy management. Economic and regulatory roadmaps for implementing the proposed integration. Recommendations for scaling and ensuring interoperability across diverse railway networks. A significant contribution to achieving sustainability and efficiency in the

transportation sector.

This project aims to bridge the gap between theoretical models and real-world implementation, providing a valuable roadmap for integrating railway systems with microgrid stations, leading toward a more sustainable and efficient future in the railway industry. The primary objective of the project on the control and management of railway systems connected to microgrid stations is to enhance the efficiency, reliability, and sustainability of railway operations.

By integrating advanced control systems with renewable energy sources available at microgrid stations, the project aims to optimize energy usage within railway networks. This includes maximizing the utilization of solar, wind, and other clean energy sources to power railway operations efficiently while reducing reliance on fossil fuels. Additionally, the project seeks to improve grid stability and reliability by incorporating energy storage capabilities, ensuring continuous power supply even in the face of grid disturbances or external disruptions. Through the implementation of smart technologies and data analytics, the project aims to increase operational efficiency, streamline maintenance practices, and drive continuous improvement in railway operations. Ultimately, the project aims to contribute to the advancement of sustainable transportation infrastructure, reduce carbon emissions, and promote environmental conservation in the railway sectors.

In order to increase the utilization rate of the regenerative braking energy (RBE), reduce the operation cost, and improve the power quality of traction power supply system (TPSS) in high-speed railway, a supercapacitor (SC)-based energy storage system (SCESS) integrated railway static power conditioner (RPC) is presented in this article. In this scheme, the SC is connected onto the dc link of the RPC via a bidirectional dc-dc converter. A hierarchical control strategy, with an energy management layer and a converter control layer, is presented. Four operation modes and transition conditions of SCESS-RPC are elaborated in detail in the energy management layer. To obtain rapid and stable control performance, in the converter control layer, a passivity-based control (PBC)-based nonlinear controller is designed for the RPC, and an optimal control strategy based on the linear quadratic regulator with integral action (LQRI) is adopted for the bidirectional dc-dc converter. By means of simulations and experiments, the feasibility of the proposed topology and control strategy are verified. The authors propose a control strategy based on the maximum kinetic energy recovery throughout braking operations of the running vehicles. The stored energy comes back to the vehicles during the accelerations. The strategy stays on the knowledge of the state of charge of LiC device and the actual vehicle speeds. In particular, the control algorithm evaluates, in real time, the actual value of LiC voltage and current references on the basis of the vehicles inertial forces and acceleration estimations, taking into account the power losses of the system. Experimental tests made on electromechanical simulator, equipped with a 136-V, 30.5-F LiC module, fully confirm the validity of the suggested control. Finally, experimental characterization of LiC module has been achieved.

The methods proposed for maximizing the recovered energy are presented together with their theoretical analysis. A novel optimization strategy, based on the linearization of the dc power flow equations, is analytically explained, while a successive approximation method is used. The proposed control strategy is evaluated through simulations on a modified version of the Thessaloniki metro railway network (Greece). Simulation results show that the system performance is significantly improved when reversible substations or energy storage are in operation.

The recent application of energy storage devices in electrified railways, especially batteries, flywheels, electric double layer capacitors and hybrid energy storage devices. The storage and reuse of regenerative braking energy is managed by energy storage devices depending on the purpose of each system. The advantages resulting from the use of energy storage devices are presented by observing the results of both verification tests and practical applications in passenger services. Several real installations of energy storage for railways are shown and compared by using the Ragone plot. The effect of the use of energy storage devices on electrified railways of the future is discussed. Finally, a discussion on the recent applications and developments of energy storage devices is presented in this study. The effective use of energy storage devices is characterised on the basis of the specific

applications and current trends of the research undertaken by public bodies and manufacturers.

Electric trains typically travel across the railway networks in an inter-provincial, inter-city and intra-city manner. The electric train generally serves as a load/source in tractive/brake mode, through which power networks and railway networks are closely coupled and mutually influenced. Based on the operational mode of rail trains and the characteristics of their load power, this paper proposes a coordinated optimal decision making method of demand response for controllable load of rail trains and energy storage systems. First, a coordinated approach of dynamically adjusting the load of the controllable rail train in considering the driving comfort and energy storage battery is designed. Secondly, under the time conditions that satisfy the train's operational diagram, the functional relationship between the train speed and the load power is presented. Based on this, in considering the constraints of the train's arrival time, driving speed, motor power, and driving comfort, the capacity of energy storage batteries and other constraints, an optimization model for demand response in managing the traction power supply system.

SIMULATION RESULTS

The control and management system for railway systems connected to microgrid stations boasts a suite of features designed to revolutionize energy distribution and optimize railway operations. At its core, real-time monitoring provides operators with instant insight into energy parameters, ensuring prompt responses to changing conditions. Remote control capabilities empower operators to adjust microgrid and railway system operations on the fly, maximizing efficiency. Integration of renewable energy sources like solar and wind power reduces reliance on conventional fuels, promoting sustainability and reducing carbon emissions. Energy storage management ensures stability by efficiently storing and releasing energy as needed, while automated fault detection mechanisms swiftly identify and diagnose issues, minimizing downtime. Emergency response protocols and backup power systems provide resilience during crises, ensuring uninterrupted railway operations.

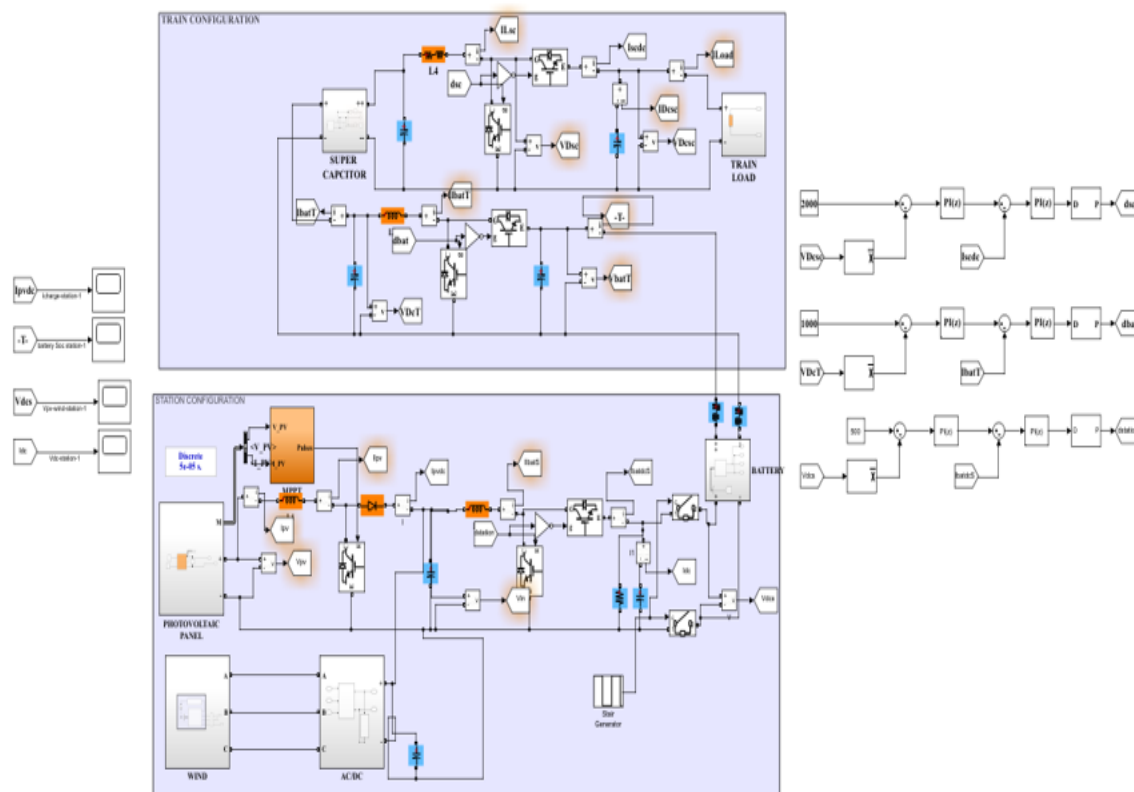
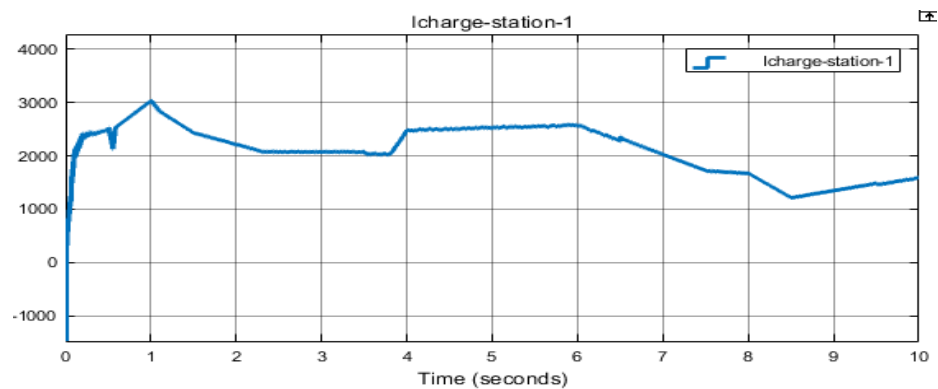
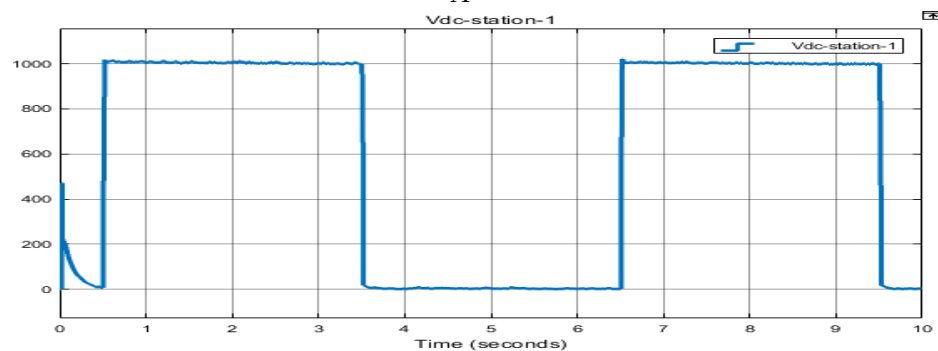


Fig 2. At station 1 with train-1 configuration

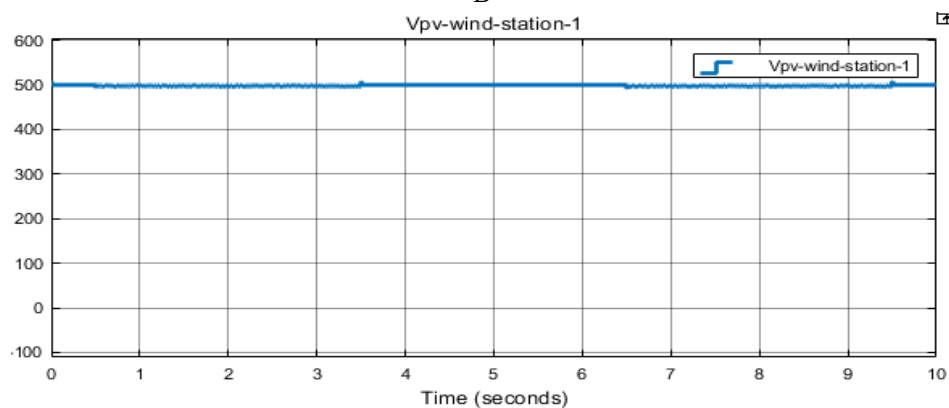
Smart grid technologies optimize energy flows and enable predictive maintenance, further enhancing efficiency. Scalability allows for seamless integration with existing infrastructure and future expansion. With a user-friendly interface and compliance with safety standards, this system promises to usher in a new era of efficient, reliable, and sustainable railway transportation. The control and management of railway systems connected to microgrid stations offers a wide range of applications across various sectors. Some of the key applications include. By optimizing energy usage and integrating renewable energy sources, the system enhances the overall energy efficiency of railway operations. This leads to reduced energy costs and a lower carbon footprint. Microgrid stations contribute to grid stability by providing localized power generation and storage capabilities. They can serve as backup power sources during grid outages or emergencies, ensuring uninterrupted railway operations. The system facilitates the seamless integration of renewable energy sources such as solar and wind power into railway infrastructure.



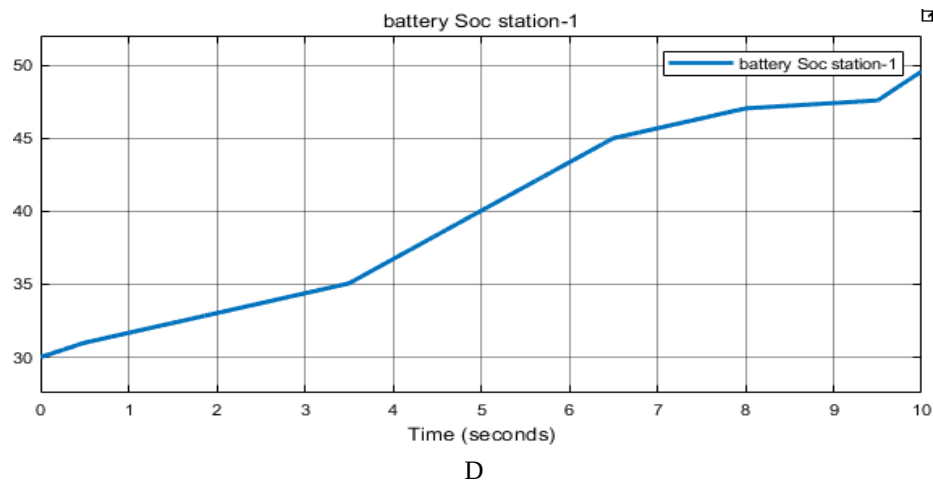
A



B



C



D

Fig 3. Simulation test of station 1. (a) PV and wind current of station 1. (b) Charge current from station 1. (c) DC bus voltage of station 1. (d) SoC of batteries of station 1

At station 1 and station-2 with train-1 configuration

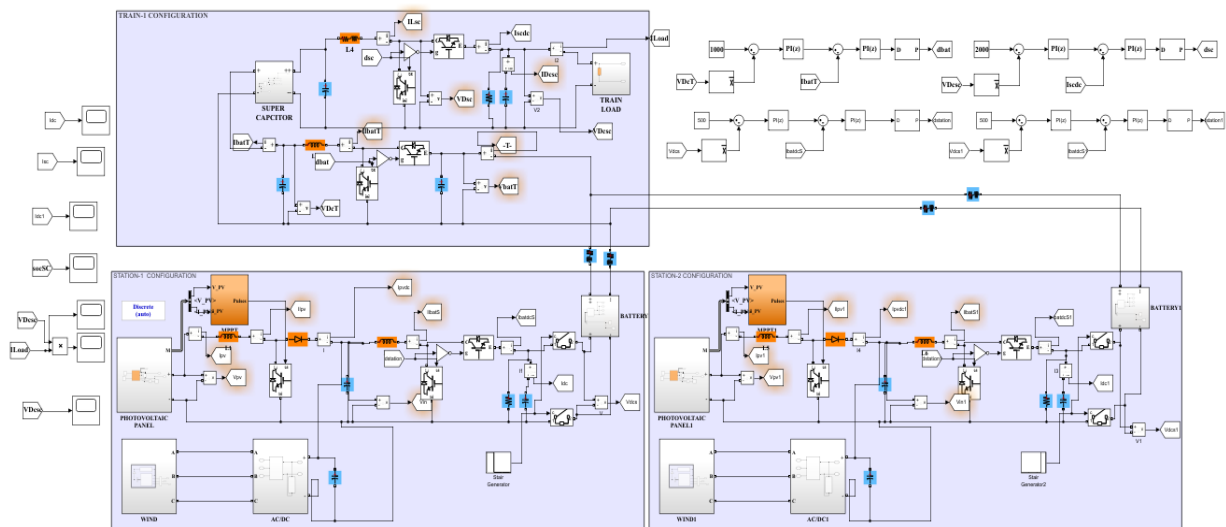
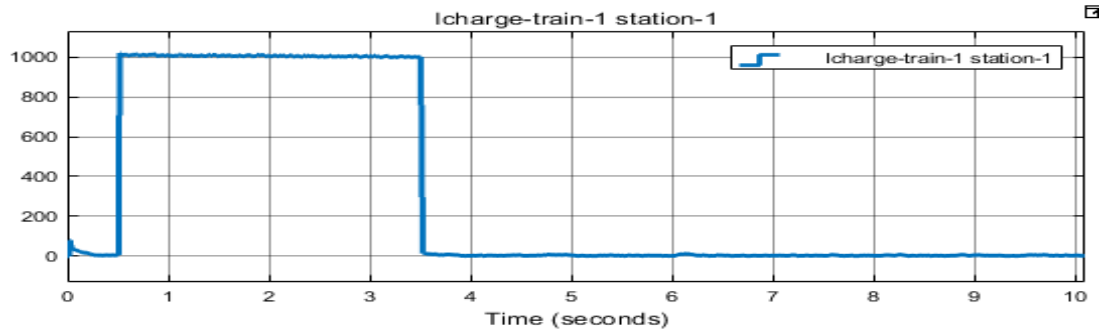
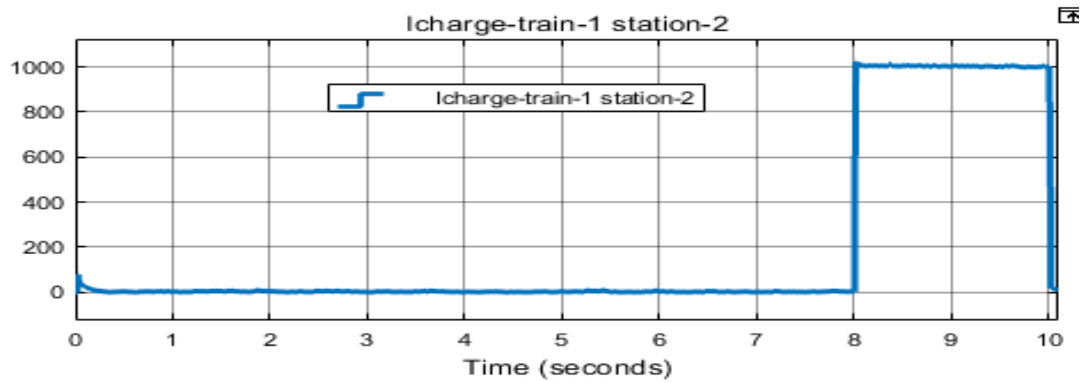


Fig 4. Schematic diagram

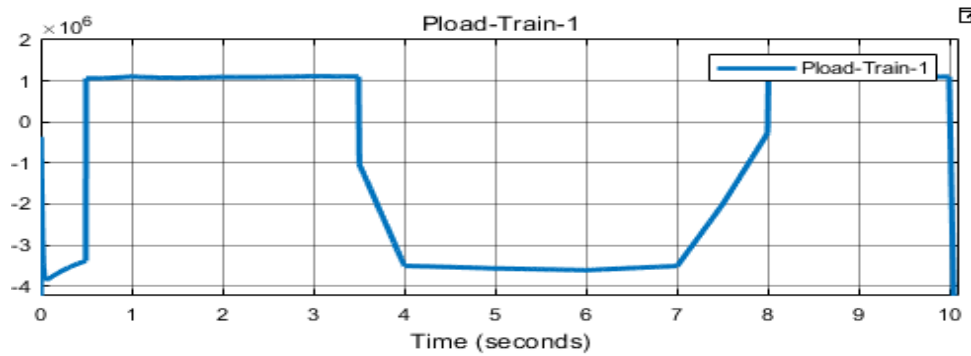
The ability to operate independently or in conjunction with the main grid enhances the resilience of railway systems. Microgrid stations with energy storage systems can continue to supply power during disruptions, minimizing downtime and maintaining critical operations. Operators can remotely monitor and control various aspects of the railway system, including energy generation, distribution, and consumption. This remote accessibility improves operational efficiency and enables rapid response to changing conditions. Real-time monitoring data can be used to implement predictive maintenance strategies, identifying potential issues before they escalate into costly failures. This proactive approach reduces maintenance costs and improves system reliability.



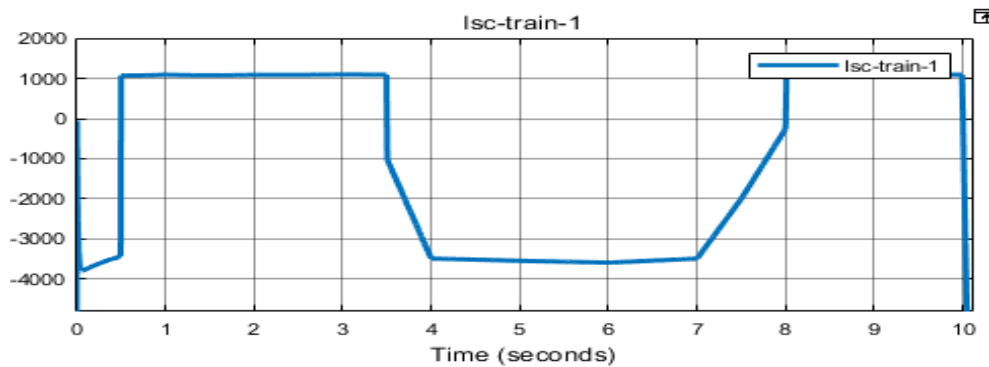
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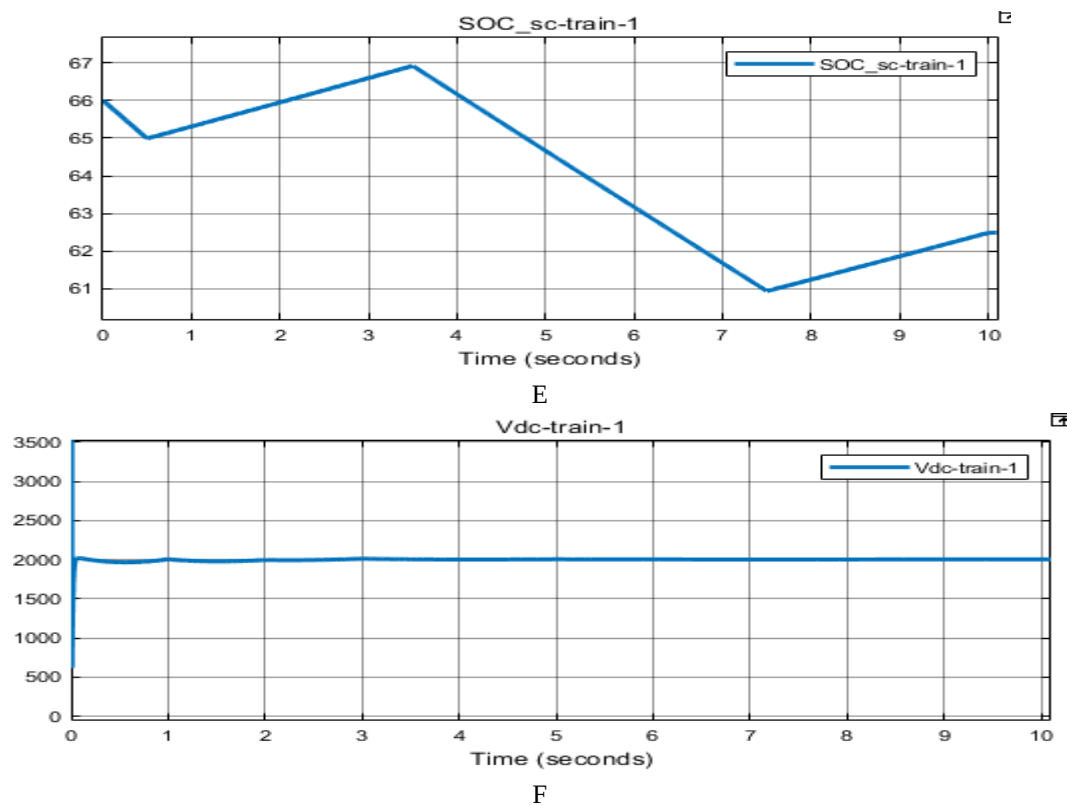


Fig 5. Simulation test of train 1. (a) Charge current of train 1 from station 1. (b) Charge current of train 1 from station 2. (c) Load power of train 1. (d) SCs current of train 1. (e) SoC of SCs of train 1. (f) DC bus voltage of train 1.

At station-1 with train-1 and train-2 configuration:

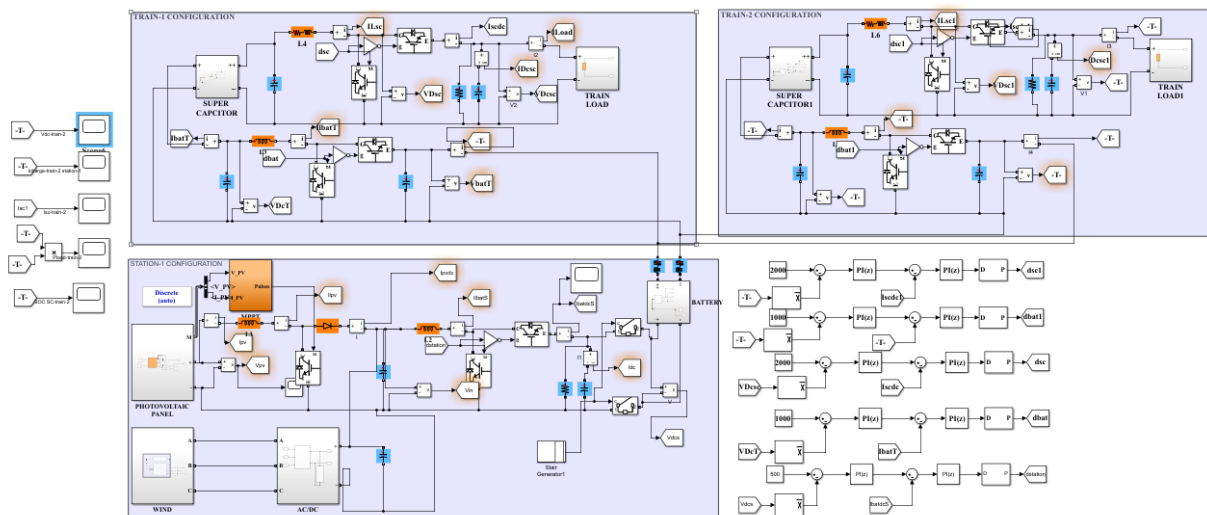
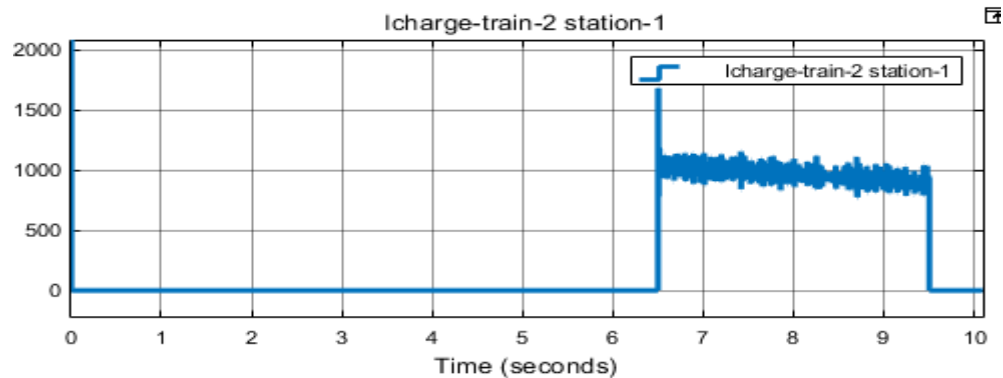


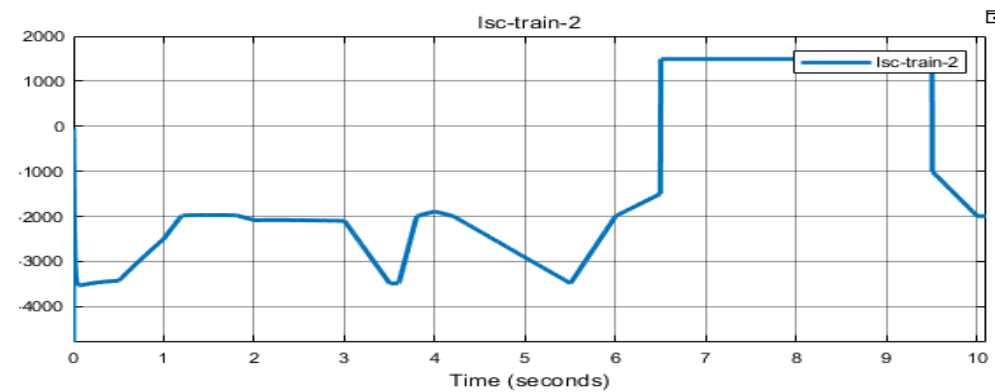
Fig 8. Schematic diagram

The system enhances emergency preparedness by providing backup power capabilities and facilitating quick response to emergencies. During natural disasters or other emergencies, the system can ensure the continued operation of essential railway services. Integration with smart transportation systems enables seamless coordination between railway operations and other modes of transportation. This promotes efficient multimodal

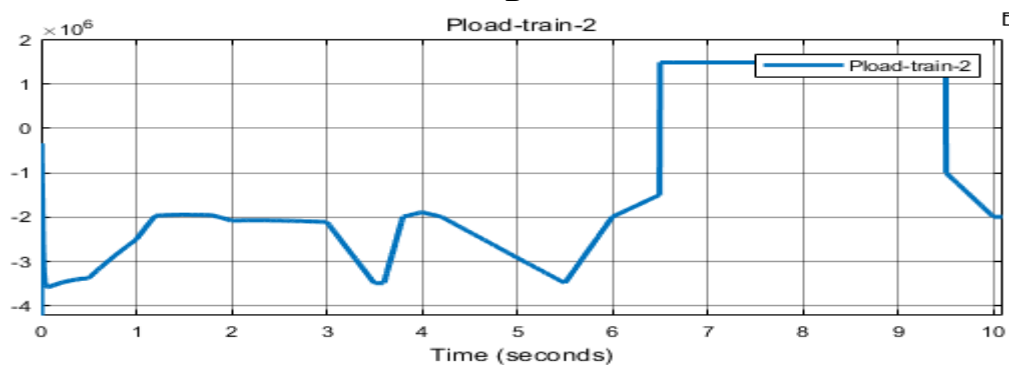
transportation networks and enhances overall urban mobility. Overall, the applications of control and management systems for railway systems connected to microgrid stations extend far beyond energy management, encompassing aspects of sustainability, resilience, efficiency, and innovation in transportation infrastructure.



A



B



C

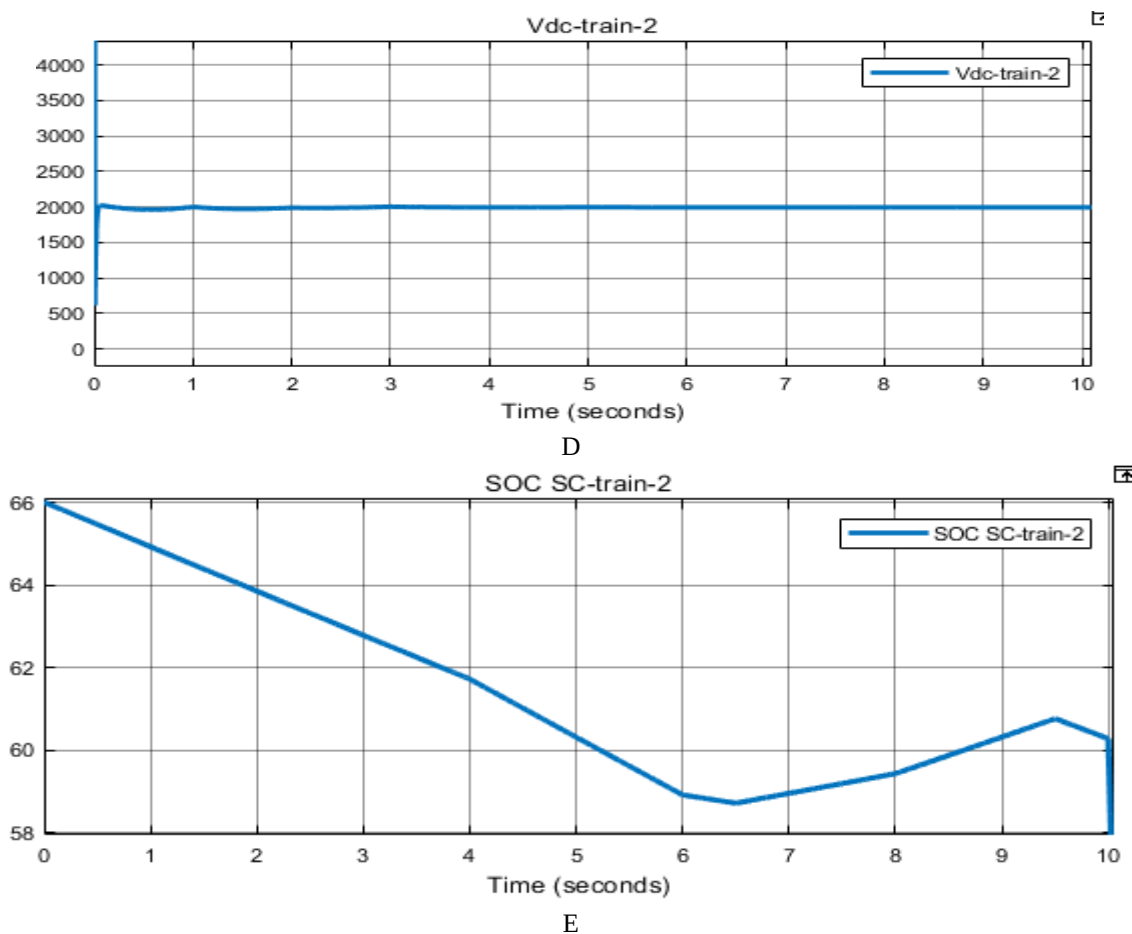


Fig 9. Simulation test of train 2. (a) Charge current of train 1 from station 1. (b) SCs current of train 2. (c) Load power of train 2. (d) DC bus voltage of train 2. (e) SoC of SCs of train 2

CONCLUSION

The proposed techno-economic method for the energy storage by using SCs in the train was presented in this paper. The studied system is devised on two parts: station and train. The design of railway station is presented by using PV and wind as principal sources, and batteries for ESS. The train is composed by engine and SCs. SCs are implemented to the ESS of the train, where they are alimented from the breaking phases and the stations by a pantograph installed in an air power line in each stop. SCs are used for their fast charge and discharge. An EMS is given in order to stabilize the DC bus. The calculation of parameters of the buck-boost converter are given. The Sizing of the integral and proportional gain controller used for the stabilization of the DC bus of train and station is given. A simulation test was proposed with one station and two trains. The trains recharge from the station in different times. The obtained results showed that the given EMS and system design give good results in order to stabilize the DC bus voltage and reply to the need of energy by the engine. The future work will be reserved to the application of this system with AC engine.

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