MANAGING RAILWAY SYSTEM CONNECTED TO MICRO-GRID STATIONS WITH INTELLIGENT CONTROLLERS

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ABSTRACT:

The modern railway system operates as a complex microgrid, combining various elements such as distributed active loads, renewable energy sources, and storage devices. The active loads refer to the trains, while the energy sources consist of renewable energy-based microgrids. The proposed railway station design incorporates photovoltaic (PV) panels, wind energy sources and batteries for the energy storage system (ESS). Super capacitor (SC) are integrated into the energy storage system in the train, being charged during braking operation and when the train is stopped, the pantograph connects to the overhead transmission line to charge the super capacitor in the train. Now a days super capacitors are selected for their high-power characteristics, extensive charge/ discharge cycles, low specific energy and rapid charging capability. An energy management system strategy is suggested to control the buck-boost converter by current and the DC bus by voltage. This paper explores the replacement of the Proportional integral (PI) controller with the Fuzzy Logic Controllers (FLC) and Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers are used to stabilization of the DC voltage in the train and station. The existing method, when employing a proportional integral (PI) controller, it shows significant peak overshoot and increased harmonic distortion as its drawbacks. The entire railway system is modelled in MATLAB-Simulink.

Keywords: Energy management, railway system control, energy storage system, supercapacitors, renewable energy sources.

I. INTRODUCTION

Travelling has risen alarmingly over the years, and hundreds of individuals now make daily trips between cities. The public transit has drawn the interest of many. Public transit options abound and include trains, buses, taxis, and aeroplanes. Because trains go quicker than other modes of transportation and offer more reasonably priced tickets, they are becoming more and more popular among the public. Performance of railway transportation system can be impacted by environmental changes and CO2 emissions. Among all the public transport options now in use, the electrified train is now one of the most popular.

The advantages of microgrid technology integration with railway systems have made it a more and more popular strategy in recent years. This include higher energy efficiency and dependability. With sources, storage devices, and distributed active loads, the contemporary railway network represents a vast infrastructure linking tiny grids. Here, trains serve as the active load while microgrids run by renewable energy serve as the sources. The storing mechanisms are batteries and super capacitors.

The fundamental issue with an Electric train are not able to recover energy during regenerative breaking times. Another problem is that the electrical train takes a very long time to charge from the stops.

Based on a Proportional and Integral (PI) controller, the current system is employed in energy management system is to stabilize DC voltage for both trains and stations. Higher harmonic distortion and increased peak overshoot errors are the main shortcomings of the current approach.

In this paper, we suggest to overcome these shortcomings by using two different controllers such as Fuzzy logic controller (FLC) and Adaptive neuro fuzzy inference system (ANFIS) are used in our work.

The railway system has been successfully studied in numerous articles by researchers such as: Ciccarelli, poullikkas at. el [1,2] presents "improvement of energy efficiency in light railway vehicles based on power management control of wayside lithium-ion capacitor storage" and storage technologies of for electric power. Kleftakis at. el [3] gives the power conversion and conditioning systems for stationary electrochemical storage. The work done by cabrane and divya at. el [4,5] energy storage through the batteries and supercapacitor. Kleftakis - khayyam at. el [9-12] Research on Wayside storage devices to stabilize voltage and enhance energy effiency in metro railway systems and energy management. Kim - Le at. el [13,17] energy management strategies and dc bus voltage stabilization and controlling with fuzzy controllers. Jung at. el [18] Rapid inspection method, Railway panorama, for monitoring high-speed railway infrastructure. Yoo and Feng at. el [19,20] A novel energy management strategy using fuzzy logic supervision that control the power plants and enhancing power quality. Yang and Cabrane at. el [21,22] presents A Supercapacitor energy storage systems and Models of Supercapacitor. Dabri at. el [23] gives the Integration of timetables, passenger flows, and train speed profiles. Zhang at. el [24] A critical review on the vertical stiffness irregularity of railway ballasted track.

II. METHODOLOGY AND OPERATION

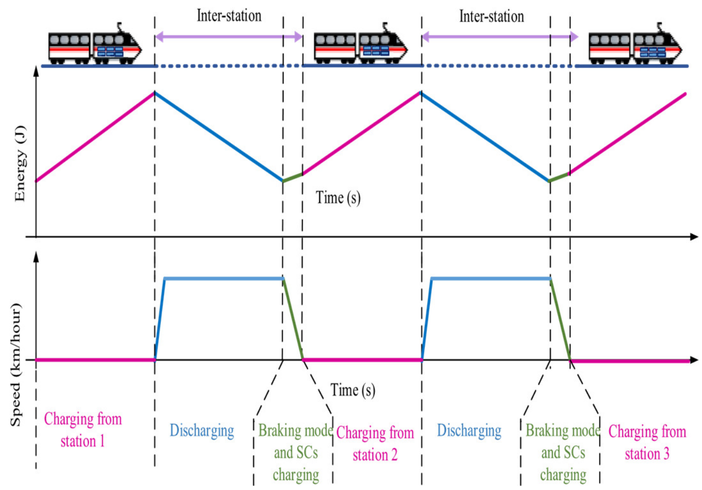

Fig. 1. Power and speed change between train and stations

The Railway station consists of many numbers of stations are considered for the analysis of proposed method and is shown in fig. 1. The distance between the two stations is 10 km and train stop at each station every 5 to 15 minutes. At this time the train motors are quietly operated and super capacitors are charged from the batteries with the connection of the pantograph connects to the overhead power line through a buck-boost converter, after the train stops it ensures their charging and it discharges while the train in traction mode or running condition. By applying of braking system of the train, at this condition the super capacitor will charge automatically by occurring of friction and heat on the rail tracks.

III. THE MANAGEMENT OF ENERGY AND SYSTEM MODELLING

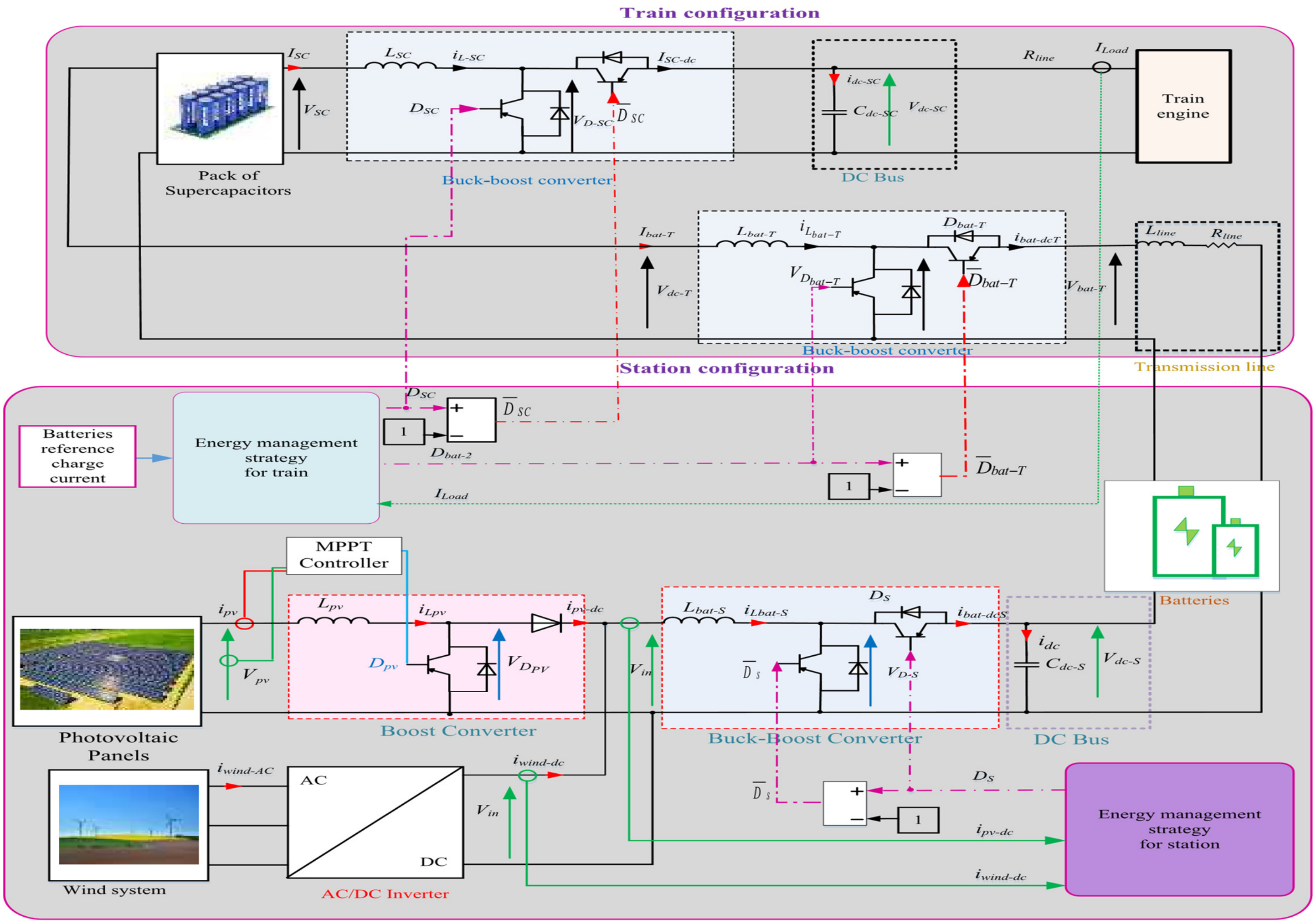

Fig. 2. Configuration of the station and train model.

The configuration of train and station along with DC bus connection is shown in fig. 2. The control of the energy management of the railway station is the first component and to control the energy management of the train is the second component of the railway system. The total railway system will work by using Renewable energy sources, batteries and super capacitors. The renewable energy sources used in our work is solar and wind sources. The entire railway system operates with DC system. The PV system will generate a DC electricity but the wind system will generate an AC electricity and it will convert to DC by AC-DC converter and further connected to the dc bus bar. Boost converter is used to control the dc voltage, it connects the pv system to the same bus. The maximum power point tracking system is used to track the maximum voltage from the pv system, it is connected between the photovoltaic panel and boost converter. To charge the batteries from the renewable sources through a buck-boost converter and to stabilize the dc voltage of the railway station. The pantograph connects to the overhead transmission line to charge the super capacitor from the railway station batteries trough buck-boost converter. A line transmission provides a resistance and inductance, these two parameters acts as a filter. A buck-boost converter is used in the train to link the train engine to super capacitor and to stabilize the train voltage at 2000V dc. The converters are controlled by the energy management system of the total railway system. The train power is 3.5 MW. The energy is delivered by the super capacitors is estimated approximately 210MJ (corresponding to 3.5MW for 60 sec).

IV. DC VOLTAGE CONTROL OF RAILWAY SYSTEM WITH TWO INTELLIGENT CONTROLLERS

A. By implementing with fuzzy logic controller (FLC) for to control the stabilization of the DC voltage of the railway system of the railway station, train and super capacitor.

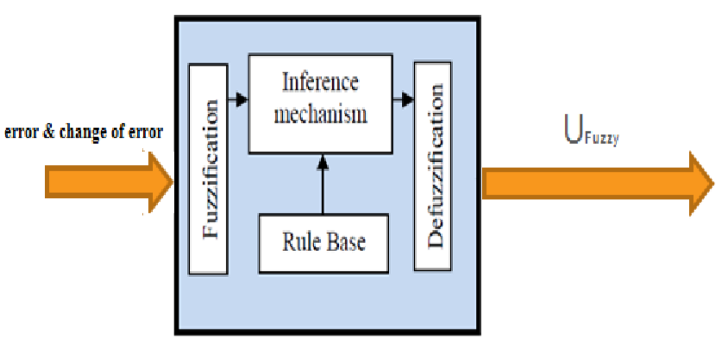

Fig. 3. Block diagram of fuzzy logic controller (FLC).

A typical fuzzy logic controller consists of three stages to complete this total process.

1. Fuzzification:
   - In this controller we have to taken two input variables one is voltage, another one is change in voltage for these two inputs we have to given the six membership functions.
2. Inference mechanism (Rule base):
   - The operation of the fuzzy controller is determined using the max-min composition rule. This means that for each rule in the rule base, the minimum value of the antecedent is taken, and the maximum value of the consequent is applied. This method ensures that the most relevant rules are considered in the decision-making process.
3. Defuzzification:
   - For the defuzzification step, the centroid method is used. The centroid method, calculates the center of the area under the fuzzy set to produce a crisp output. This method is chosen because it provides a balance between accuracy and computational efficiency, making it a popular choice for many fuzzy control systems.

The fuzzy controller is designed with two inputs (voltage and change in controller), each with six membership functions. It uses the max-min composition rule for operation and the centroid method for defuzzification to produce a precise and effective control output.

B. By implementing with Adaptive neuro fuzzy inference system controller (ANFIS) for to control the stabilization of the DC voltage of the railway system of the railway station, train and super capacitor.

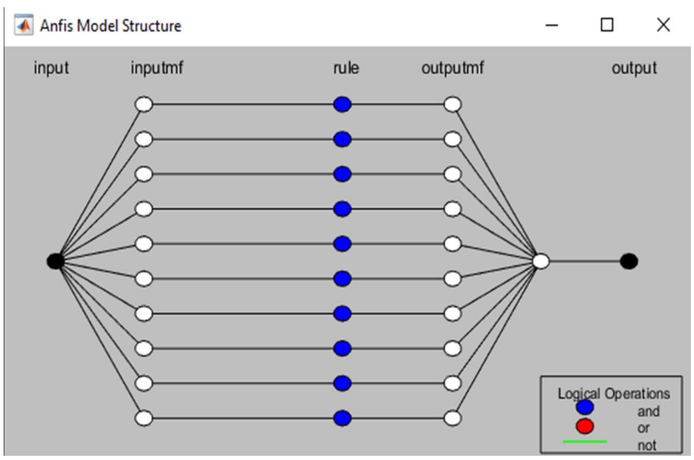

Fig. 4. Structure of Adaptive neuro fuzzy inference controller

In fig. 4. We have to observed the five layers. The five layers represent the fuzzification, rule layer, normalization layer, defuzzification and output layer.

Using an ANFIS controller for voltage control with input involves collecting data, training the ANFIS model, validating it, and then implementing it in the control system. The ANFIS model uses the input (current voltage) to generate a control signal that stabilizes the dc voltage of the railway station, train and super capacitors. This approach combines the strengths of neural networks and fuzzy logic, providing an effective solution for complex control problems.

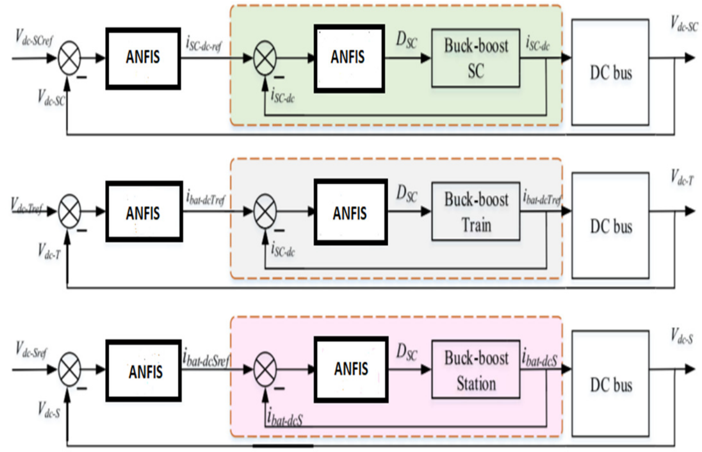

fig. 5. Block diagram of energy management controlling with Adaptive Neuro Fuzzy Inference System (ANFIS) controller.

The fig. 5. Is represents the energy management system is used to stabilize the dc voltage of the railway system. In these energy management systems is totally controlled by using of fuzzy logic controller (FLC) and Adaptive neuro fuzzy inference system (ANFIS) controllers to overcome the peak over shoots of the current in the railway station, train and super capacitor and also to overcome the increased harmonic distortions of the railway station, train and super capacitor. And this is the drawbacks, which are occurred in propotional integral (PI) controller.

By using of three controllers to control the dc voltage of railway station, train and super capacitors. In these three controllers the Anfis controllers will gave the better results or performance of the railway system is good. In another two controllers are proportional integral and fuzzy logic controllers are not give the better results or performance of the railway system than the Anfis controller.

V. SIMULATION RESULTS

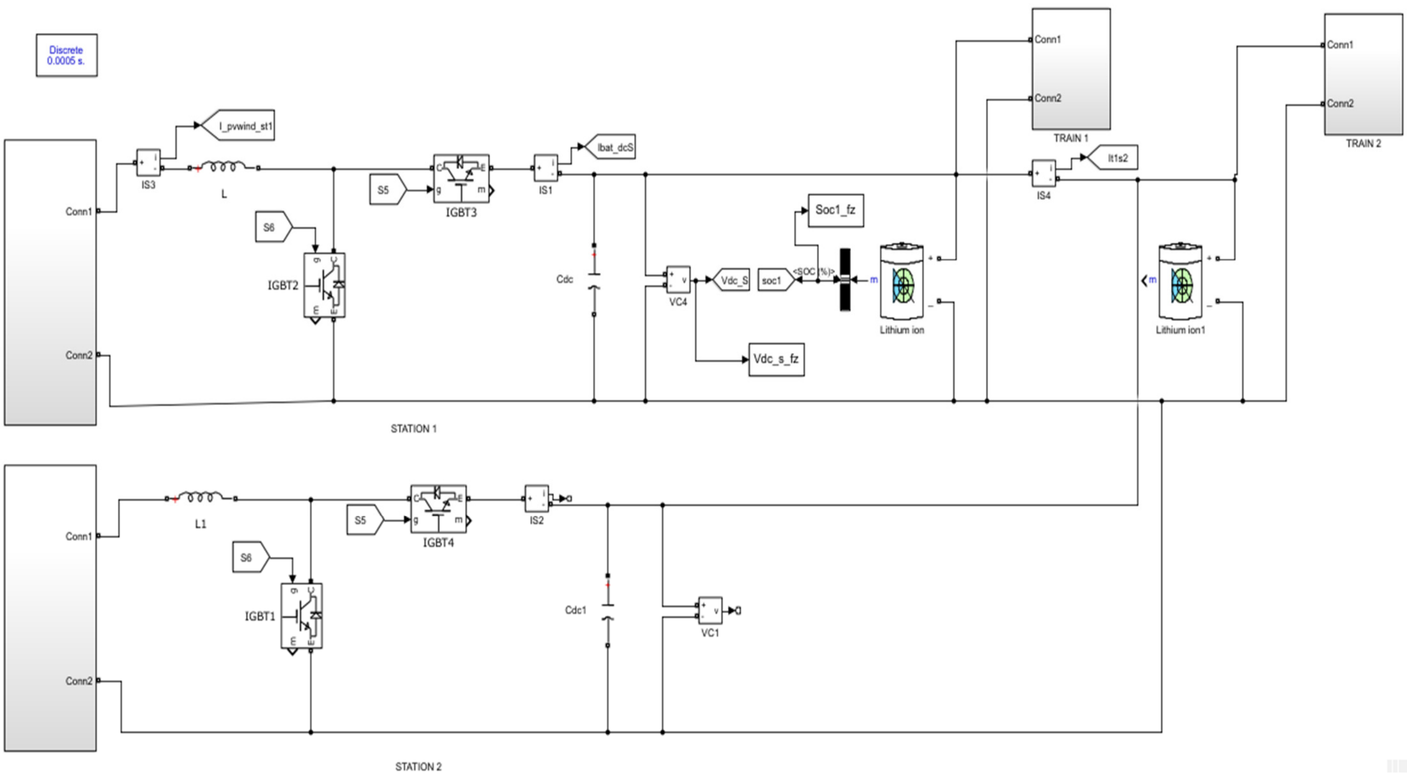

Fig. 6. Simulation Block Diagram of Train and Station Configurations.

In fig. 6. Explains the simulated block diagram of railway system. The railway system consists of renewable sources, converters, batteries and super capacitors. In the railway station uses the photovoltaic panels and wind energy as the main sources and it includes batteries for energy storage. In the train consists as super capacitor and engine. The super capacitor is charged during breaking operation and during stop condition super capacitor are charged through a pantograph connects to the overhead transmission line to charge the super capacitor in the train. The super capacitors are chosen because it can charge and discharge very quickly. The total railway system is connected to the energy management system. The energy management system is controlled by using of intelligent controllers such as fuzzy logic controllers and Adaptive neuro fuzzy inference controllers.

By using of the intelligent controllers comparing with proportional integral (PI), the simulated railway system results are shown in below graphs.

Fig. 7. represents a detailed analysis of station current by using of different controllers. The current are increases of its required current. It varies between 1200A and 3000A with pi controller. Using with fuzzy controller the current is controlled a little bit compare

with pi controller. The current is controlled a better using anfis controller compared with another two controllers. The current varies from 1300A and 2700A.

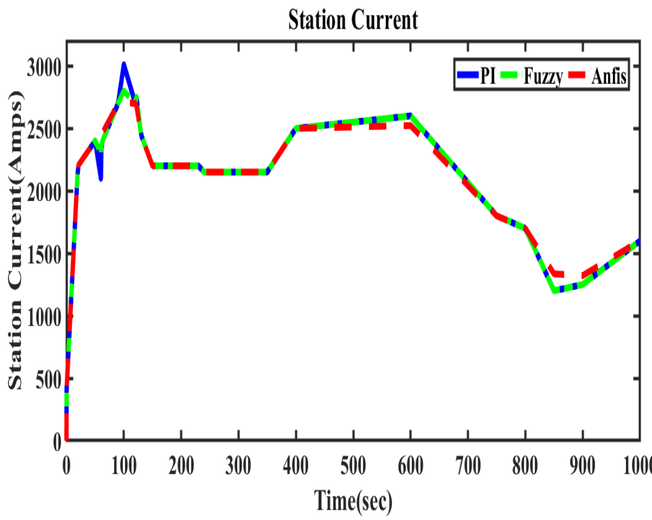

Fig. 7. PV and Wind Current of Station 1.

Fig. 8. is an insightful graph that illustrates the dc voltage of the station. By implemented with three controllers the dc voltage is not changed. The station dc voltage will be fixed at 500v dc. Because the solar and wind irradiation and temperature not stable at station. It is changes at different temperatures so, at station the dc voltage is constant.

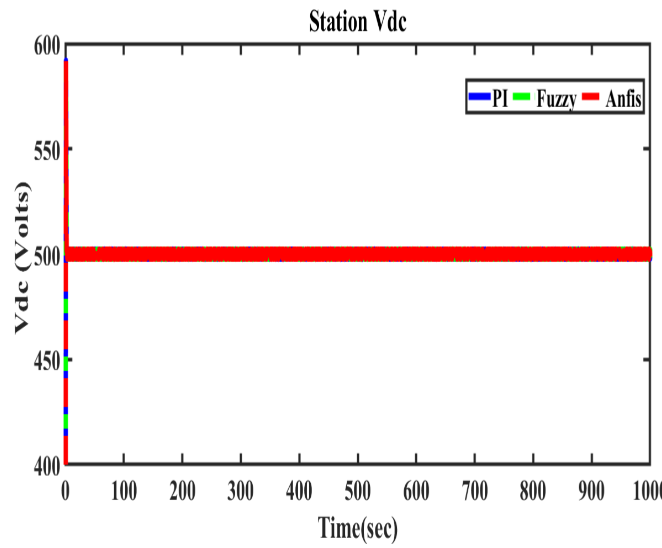

Fig. 8. DC voltage of Station 1.

Fig. 9. is observed that the state of charge of the batteries at station. By using of PI controller, the state of charge of batteries of station 1 the percentage between 30% and 50% while the trains are in charging condition they occur some harmonic distortions. So, we have to reduce these harmonic distortions using fuzzy and anfis controllers in the replacement of PI controller. By using of these controllers, we have to increase the smoothness of the battery condition.

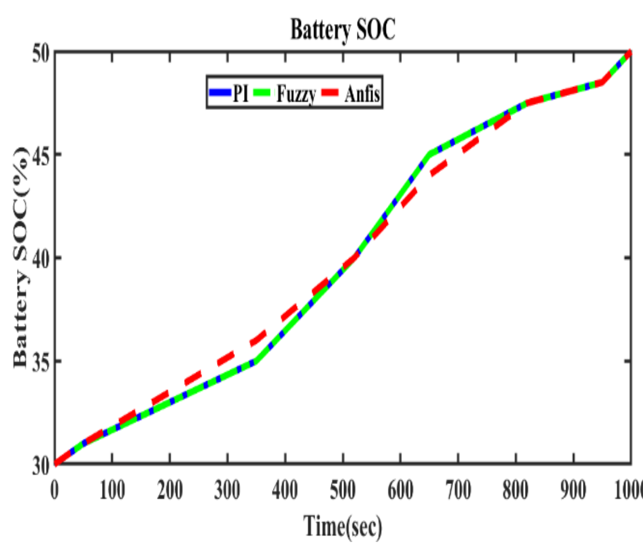

Fig. 9. State of charge of Station 1.

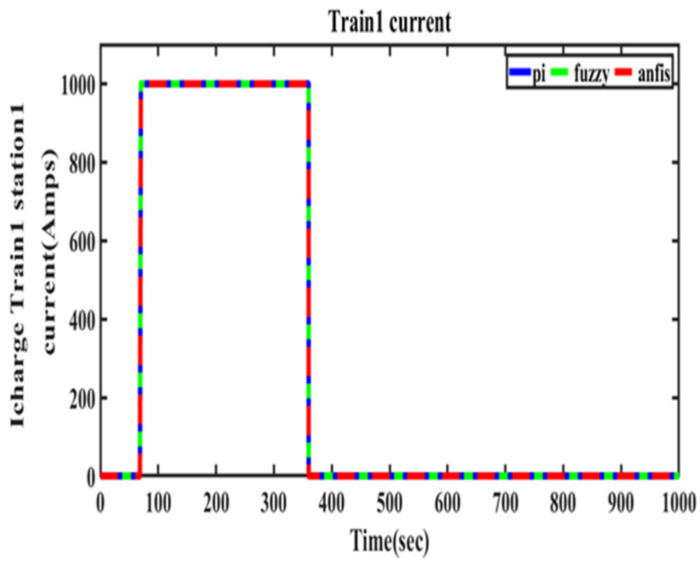

Fig. 10. Charge current of train 1 from station 1.

Fig. 10. illustrates, the train 1 is charging condition from station 1. The required constant current of the train 1 charge is 1000A. By using of three controllers they didn't occur any changes in the graph. Train 1 charge from station 1 between t=50sec and t=350sec. Because the current will be constant.

Fig. 11. represents, the train 1 is charging condition from station 2. The required constant current of the train 1 charge is 1000A. By using of three controllers they didn't occur any changes in the graph. Train 1 charge from station 2 between t=800sec and t=1000sec. Because the current will be constant.

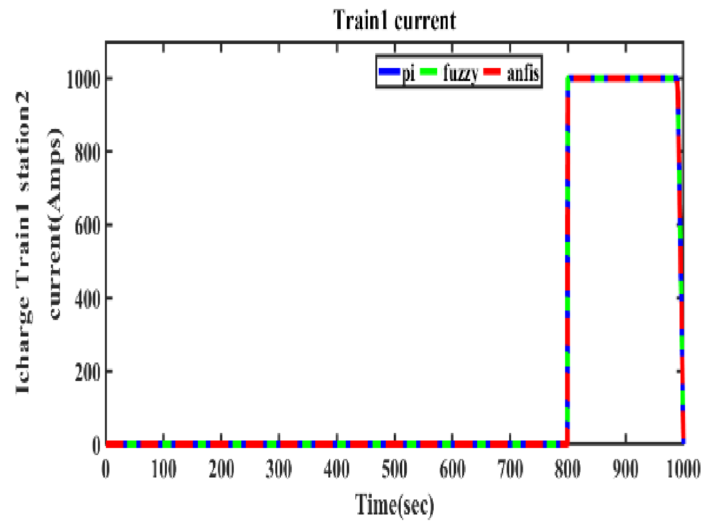

Fig. 11. Charge current of train 1 from station 2.

Fig. 12. depicts the power of the train 1, with the time intervals. By using of fuzzy and anfis controllers, in the replacement of PI controllers it didn't occur any changes in the graph. Because the power of the train 1 is good condition. The above graph the train 1 power will be constant at charging condition. The train 1 power will be discharging at traction mode or running condition.

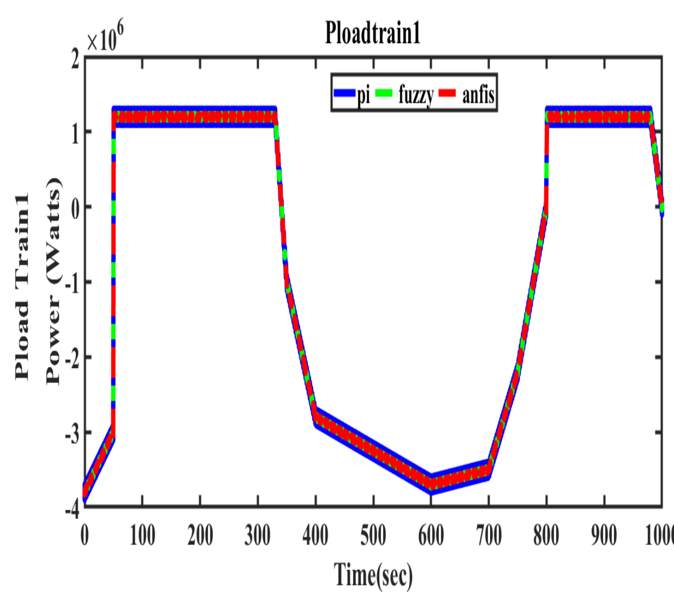

Fig. 12. Load power of train 1.

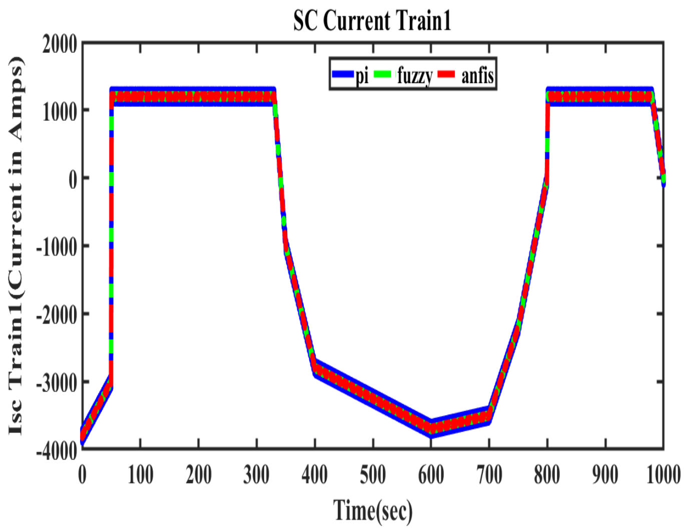

Fig. 13. Super capacitor current of train 1.

Fig. 13. obtained the super capacitor current of the train 1. By using of fuzzy and anfis controllers, in the replacement of PI controllers they didn't occur any changes in the graph. Because the Super capacitor current of the train 1 is in good condition. In the graph the train 1 current will be constant at charging condition. The train 1 current will be discharging at traction mode or running condition.

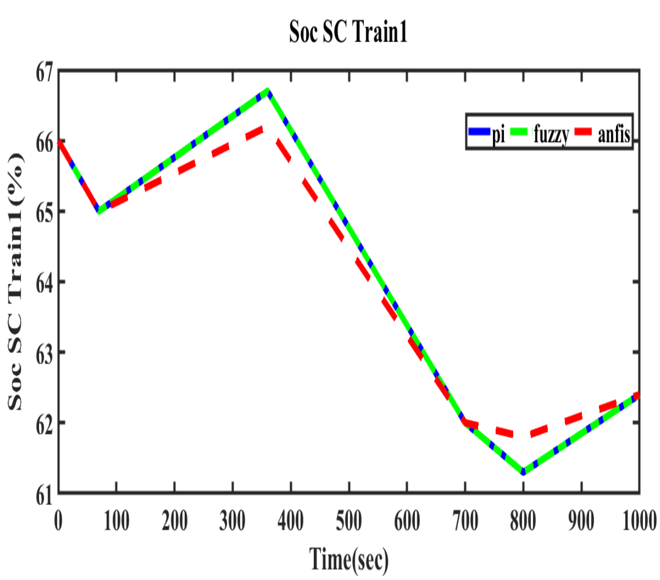

Fig. 14. State of charge of Super capacitor of train 1.

Fig. 14. illustrates the state of charge of super capacitor of train 1. We have to compared with three controllers the anfis controller will gives the better results. The train 1 is in traction mode the energy will decreases. The train 1 in charging mode the energy will consumes. The state of charge of super capacitor of train 1 it varies between 61% and 67%.

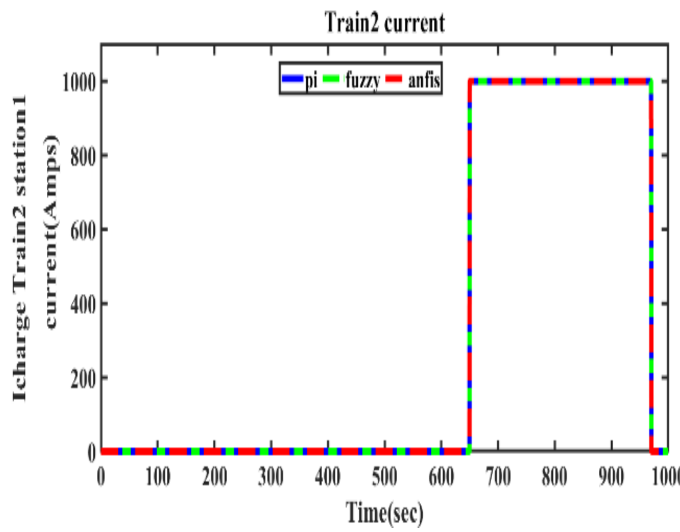

Fig. 15. Charge current of train 2 from station 1.

Fig. 15. represents, the train 2 is charging condition from station 2. The required constant current of the train 1 charge is 1000A. By using of three controllers they didn't occur any changes in the graph. Train 1 charge from station 2 between t=650sec and t=980sec. Because the current will be constant.

Fig. 16. detailed show cases the load power of the train 2. Because the power of the train 2 is not in good condition. Because the DC voltage occur harmonic distortions or unwanted spikes. The train 2 power will be constant at charging condition. The train 2 power will be discharging at traction mode or

running condition. By using fuzzy and anfis controller to decrease the negative current of the train 2.

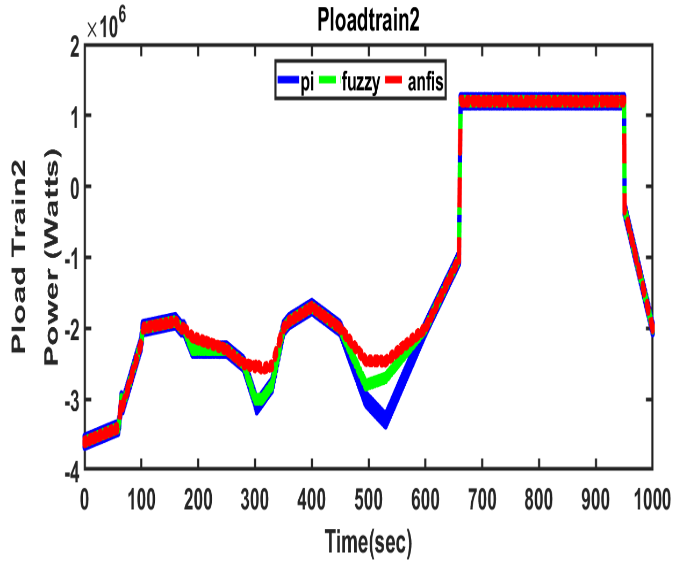

Fig. 16. Load power of train 2.

Fig. 17. represents the Super capacitor current of train 2. By using of fuzzy and anfis controllers, in the replacement of PI controllers they occur negative currents. Because the current of the train 2 is not in good condition. Because the DC voltage occur harmonic distortions or unwanted spikes. The train 2 current will be constant at charging condition. The train 2 current will be discharging at traction mode or running condition. By using fuzzy and anfis controller to decrease the negative current of the train 2.

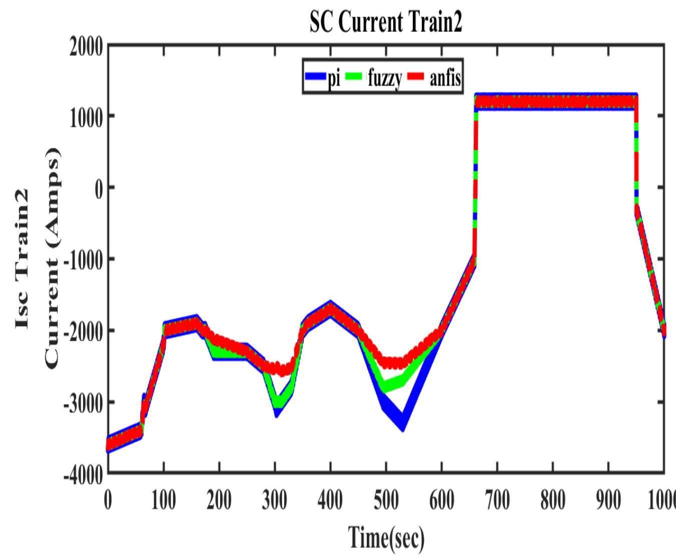

Fig. 17. Super capacitor current of train 2.

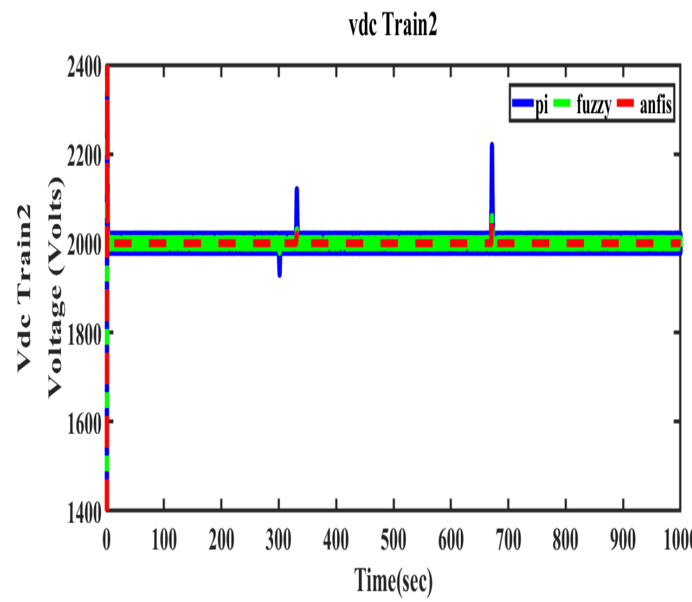

Fig. 18. DC voltage of the train 2.

Fig. 18. represents the dc voltage of the train 2. The replacement of PI controller using with fuzzy and anfis controllers we reduce the harmonic distortions or unwanted spikes of dc voltage of train 2. The voltage will be fixed at 2000V DC voltage of train 2. The train 2 the voltage spikes occur more. So, the DC voltage of train 2 will be stabilized by using fuzzy and anfis controllers.

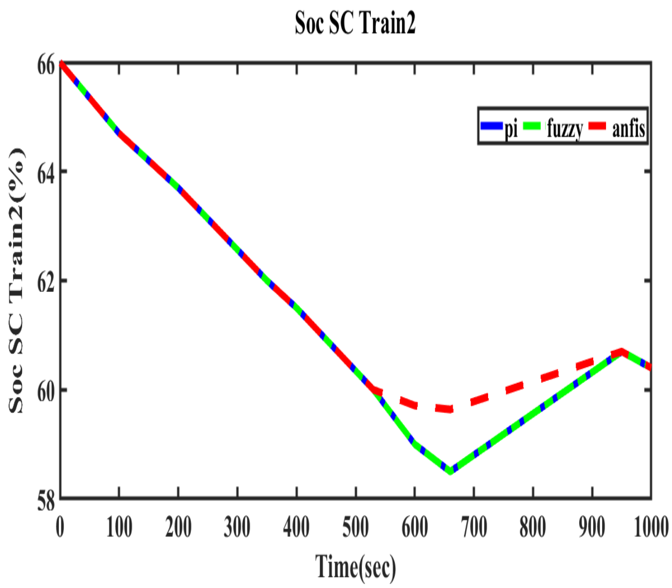

Fig. 19. State of charge of Super capacitor of the train2.

Figure. 19. depicts the state of charge of super capacitor of train 2. We have to compared with three controllers the anfis controller will gives the better results. The train 2 is in traction mode the energy will decreases. The train 2 in charging mode the energy consumes. The state of charge of super capacitor of train 2 it varies between 59% and 66%.

VI. CONCLUSION

This project evaluates the performance of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) and fuzzy logic controller (FLC) based microgrid station connected to a railway system. In the modern railway system, the train consists of an engine and supercapacitors (SCs), with SCs integrated into the train's energy storage system (ESS). The rapid charge and discharge capabilities of SCs make them highly efficient for this application.

To stabilize the DC bus, an Energy Management System (EMS) is utilized. This study proposes replacing the conventional Proportional-Integral (PI) controller with advanced controllers such as Fuzzy Logic Controllers (FLC) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS). These controllers are better suited to handle the complexities and uncertainties occur in railway energy systems. Adaptive control systems, such as Adaptive model predictive control MPC and self-tuning regulators, offer significant advantages for managing the complexities of railway microgrids. They can improve energy efficiency, enhance reliability, and ensure stable operation under varying conditions, making them a promising area for future research and development.

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