Neural network based novel controller for hybrid energy storage system for electric vehicles

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Article Info

Article history:

Received Jun 16, 2022
Revised Dec 20, 2022
Accepted Dec 23, 2022

Keywords:

Battery charger
Electric vehicles
Full bridge IGBT converter
Magnetic circuit
Neural network
Three phase bridge rectifiers

ABSTRACT

This manuscript deals with the various control strategies of storage system for an electrical vehicle. High demands in the electrical systems in the field of transportations leads to various challenges and more precise control and regulations techniques. Apart from the conventional grid system now a days the integration of renewable energy systems like solar, wind and fuel cell system leads to more complex system but these system shares the load from conventional generating system. This paper deals with the study and control aspects of the electrical vehicles associated with hybrid energy storage (HES) systems. In general, when systems are integrated with the main grid there are more distortions and ripples in the system. To reduce these distortions various control techniques are used. This paper proposes a neural network-based PI (NNPI) controller for HES system for electric vehicles for better distortion less outputs.

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1. INTRODUCTION

Owing to the pollution created by conventional sources several green energy sources have been explored for power generation [1], [2]. Pollution in various forms is a matter of concern for the whole world. It has toxicological and hazardous impact on mankind and the environment. Now a days the major contribution in air pollution is by the motor vehicles which operates on the conventional fuels. To reduce this emission from motor vehicles various manufacturers are moving on Li-ion batteries because they have high energy per unit volume (energy density) and serve extended range for electrical vehicles than the super capacitors systems. Kale Burd ID, Barelli *et al.* [1] focused on dynamic analysis of hybrid energy storage (HES) system connected with PVsystem. Energy storage system with optimistic highlight like broadening device range, complementing base movement, multiple–activity hybridization. This paper give motivation of using HESS system. Mohamed *et al.* [2] discussed about wireless charging of hybrid type electric vehicles. This paper also discussed about charging related issue and transient analysis of HEV system. Terzi *et al.* [3] reviewed the commercial electric vehicle charging method. This paper also discussed about various issues related to charging system. Al-Otaibi [4] discussed about the self charging system of electric vehicles. This manuscript elobrated the concept of inductive wireless charging system for instant charging the electric vehicle (EV). Xia *et al.* [5] detailed and discussed about the HES system for electric vehicle. This manuscript discussed about optimization based control strategy designed using Li-ion battery with super capacitor for HESS for electric. Optimization technique reduced the battery size and power quality is improved. But battery current ripple and super capacitor current ripple is more [5]. Elangovan *et al.* [6] paper is about the solar energy operated electric vehicle based super lift converter with battery. This paper discussed about sun oriented energy based transportation alternative for transportation system. Reduced charging time using solute carrier (SLC). But solar radiation necessary for vehicle. Selvakumar *et al.* [7] paper is based on design of solar electric hybrid vehicle. This paper discussed about hybrid system is designed using electrical charging and solar charging. But speed limit and cost is main problem. Smith [8] paper is based on the development of an electrical vehicle charging station. This paper discussed that the photovoltaic module is also alternative for charging. Moreover, EVs and plug-in hybrid electric vehicles (PHEVs) are introduced for improving energy profitability but cost and maintances is main problem [8]. Mikkelsen *et al.* [9] paper covered the comparison of PT, fuzzy logic, NN type control strategy of doubly-fed induction generator (DFIG) in wind energy conversion system. This discuss the transient, Ripple with various controller like PI, fuzzy logic and neural network. The work done by various researchers in the area of electric vehicles is detailed in Table 1 (see Appendix).

2. LITERATURE AVAILABLE

The work done by various researchers in the concerned field alongwith their objectives, their findings and techniques adopted are detailed in Table 1 [10]-[27] (see Appendix). After going into the insight details of the existing literature very few papers have suggested and implemented the AI techniques in the concerned area of EV. This paper deals with the control strategy which includes Neural networks in integration with PI controller. As the computing speed of the neural networks are very fast the neural network-based PI (NNPI) controller optimizes the energy uses as well, which leads to the minimal losses due to reduced ripples and hence increasing the operating and performance range of the vehicles compared to electrical vehicles. As the control scheme leads to reduced losses the life expectancy of the battery also increases.

This paper is systematized as follows: section 3 details about the circuit diagram and its analysis. Section 4 details about the proposed NNPI based novel control strategy. Section 5 acquaints the simulated outcomes and section 6 extracts some conclusion and directs about the scope for the further work in the concerned area in place of area/k in the future.

3. CIRCUIT DIAGRAM AND IT'S ANALYSIS

Figure 1 shows a Hybrid energy system and a DC-DC converter, the capacitor used here is a super capacitor and a Lithium ion battery. The DC-DC topology consists of four insulated gate bipolar transistor (IGBT) T_1-T_4 and their corresponding body diodes and a Battery with a magnetic structure containing self inductances L_1, L_2 and their corresponding mutual inductances M. The battery unit furnishes power to the DC motor. Super capacitor used here controls the instantaneous peak power supply. To manage the power flow accordingly to the demand one power management system is developed for the electrical vehicle.

The above-described converter has five operating stages. These charging modes shows different working modes like when the vehicles is in PC mode, CS mode, A mode, B mode and SCC mode. The Table 2 depicts various modes with their power sources and the power flow direction corresponding to the operating modes. All modes are implemented and verified for desired result in MATLAB/Simulink environment.

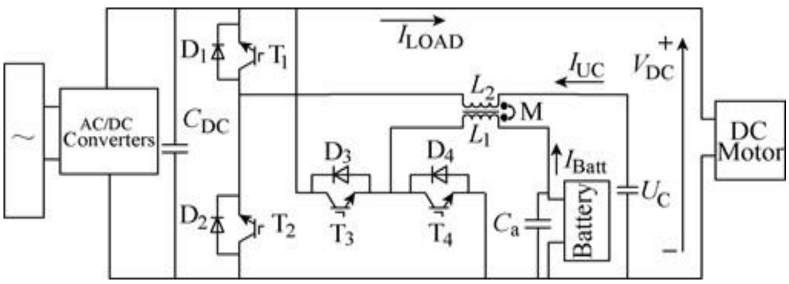

Figure 1. Circuit diagram of the HES system aong-with converter (DC-DC) [5]

Table 2. Modes of operation [5]

Working mode	Energizing source	Power flow direction	Operationg mode
Parking charging (PC)	AC Source	Battery and super capacitor	Buck
Constant speed (CS)	Battery	DC voltage	Boost
Acceleration (A)	Super capacitor	DC motor	Boost
Braking (B)	Regenerative energy (K.E and P.E energy stored in wheels)	Battery and super capacitor	Buck
Super capacitor charging (SCC)	Battery	Super capacitor and DC motor	Boost or Buck

3.1. Elements of the converter (DC/DC) alongwith magnetic structure

Any system which is mainly associated with converters, the magnetic elements are the main components when it comes for energy conversion, electrical isolation, energy storage and filtering of ripples. Electrical isolation is a main phenomenon which is very useful for the protection of the system. But when dealing with the magnetic components their proper sizing is to done. In this topology the E-type magnetic cores is used. Here inductors L_1 & L_2 are used as coupling inductors, also inductor L_2 acts as a output filter and the inductor L_1 is used as an external inductance, C_a is the extra capacitor used. In Steady state condition the voltage across capacitor C_a is equal to the output voltage across the inductor L_2 and L_1 despite the ripples in the capacitor voltage. Figure 2 shows a DC-DC converter which contains four IGBT switches and their associated body diodes [5]. Now for this system to work in boost converter mode it must contain the components L_1, T_4, D_4, or L_2, D_1, T_2. For buck operation the switches/components come in the operation are L_1, T_3, D_4 or L_2, T_1, D_2.

In the electric vehicle, DC-DC converters with properly designed magnetics can reduce the size, weight and the most important is the heat generation in the energy storage (ES) system. Moreover, these integrated magnetic circuits can lower the ripple content in the output current. In section 5 related with simulated outcomes and discussion, the feasibility of this magnetic circuit is validated with the aid of simulations. The various parameters used in the proposed control strategy are mentioned in Table 3.

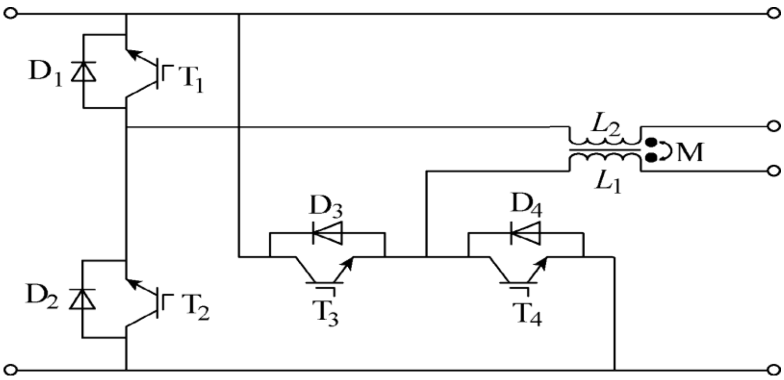

Figure 2. Topology of magnetic circuit [5]

Table 3. Various parameters used in control strategies [5]

DC voltage/V	Vdc = 300
Base value of battery pack voltage /V	V batt. =144
Cdc/uF	4400
Base value of the super capacitor voltage /V	Vuc =125
L1/mH	10.12
L2/mH	580
Switching frequency/kHz	Fs=15
Sampling time/us	Tst=5

4. PROPOSED NNPI TYPE NOVEL CONTROL STRATEGY

For making the system stable an efficient closed loop system controller is used. The main concept behind the controller is that it compares the output values like the voltage, current, torque values with a pre defined reference values, the differences between the output values and the compared values gives the error values. Now these error values are given to a controller like PI, Fuzzy as an input, their output is then used to generate the Gate pulses for the converters. In this paper a new strategy which implements a control techniques in which a neural network is used in parallel with a PI controller. Neural networks has a wide class of control stretagy. For function approximation multi layer perceptron (MLP) and radial basis function (RBF) networks are mostly useful. In this paper, implementation of MLP networks is done. Figure 3 depicts the Simulink model of the proposed NNPI type novel controller for HES system for electric vehicles Figure 4 depicts the block diagram representation for NNPI and PI type control strategy. The proposed network contains three layers: i) an input layer, ii) several hidden layers and iii) an output layer. Node i, represents a neuron, in a MLP network. It contains a summer and a activation function g_{af}. The activation function g_{af} is expressed as,

$$g_{af} = a(n) + \sum_{i=1}^{n} xi \times wij + \theta$$

the inputs 1,..., k x k; K = neuron multiplied by weights wij and summed up together with the constant bias term θ which finally results into the activation function g_{af}.

Output voltage V_{dc} is compared with the reference voltage of 300 V and an error in voltage is generated which is fed to the NNPI controller as input In1 as shown in Figure 5. Value of i depend upon type of input and weight value substituted in (1). Value of activation function (g_{af}) is calculated and again fed to second layer i.e. a (1) as shown in Figure 6. Processed output of layer 2 of MLP network is compared with PI controller output with the aid of compartor. The comparator wil generate a net error in voltage or currnet i.e. out 1. Net error is converted into pulse with logical comparator. These pulses are fed to the SR latch circuit which generates the gate pulse for the converter.

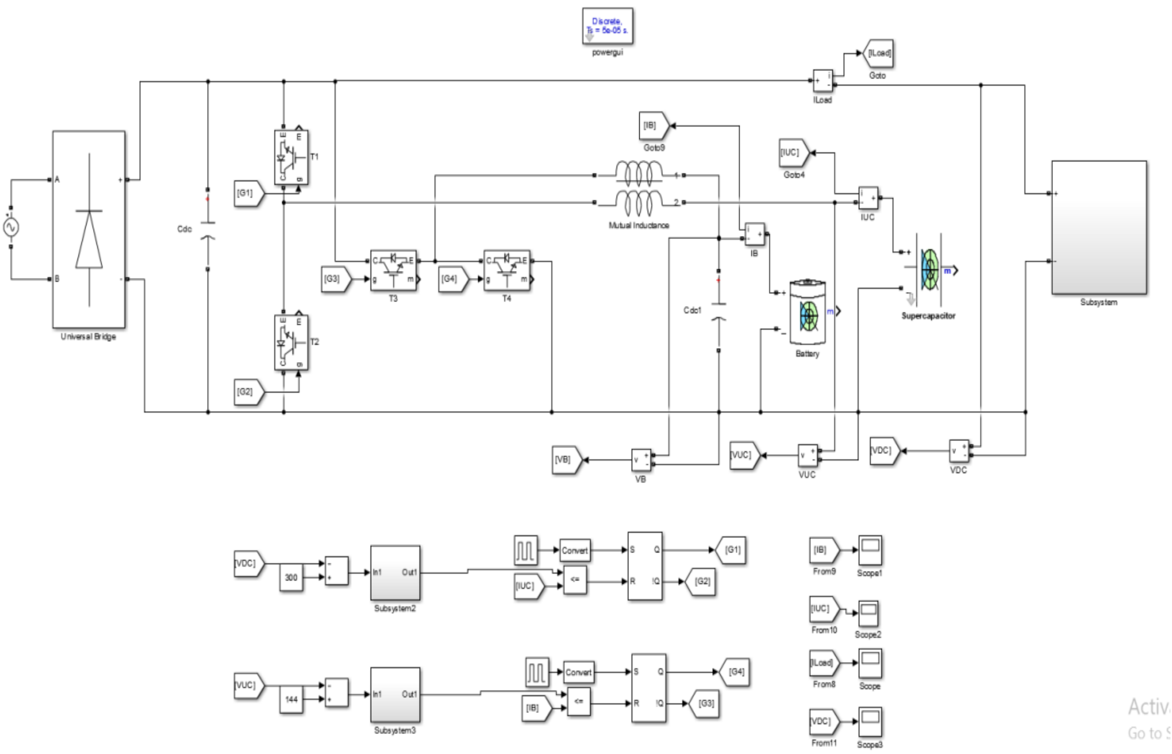

Figure 3. Simulink implementation of the proposed NNPI type novel controller for HES system for electric vehicles

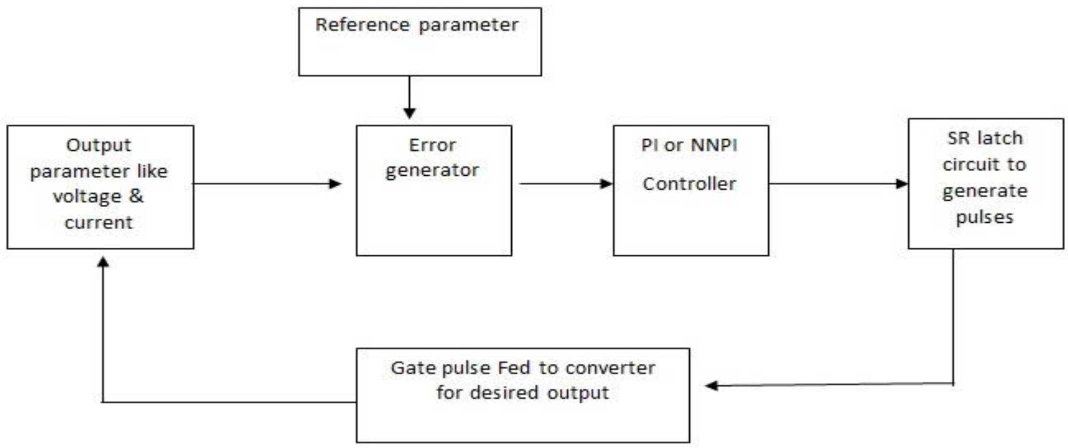

Figure 4. Block diagram for NNPI and PI type control strategy for battery voltage and current (V_{dc} and I_b) and super-capacitor current (I_{uc})

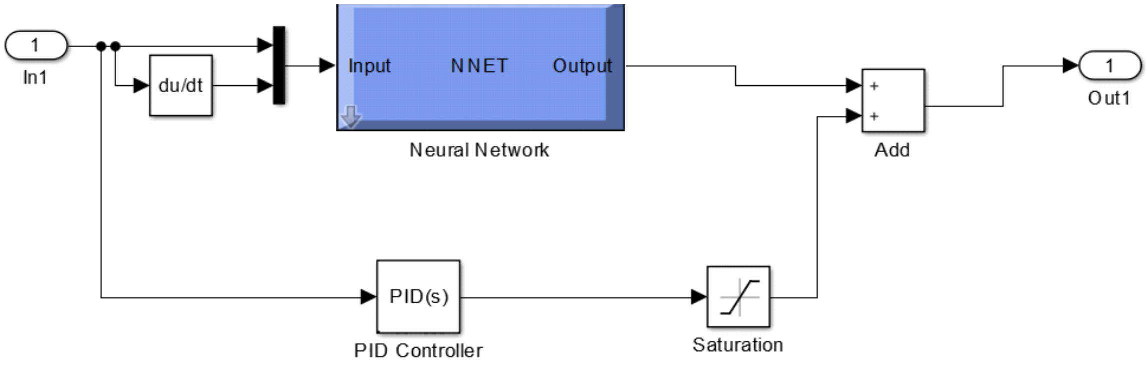

Figure 5. Simulink Implementation of NNPI type control strategy for output voltage and current control

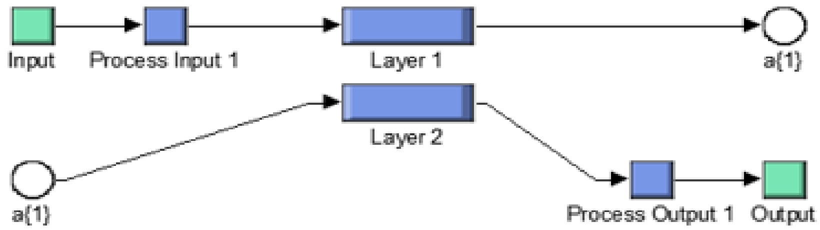

Figure 6. Representation of multi-layer perceptron (MLP) network

5. SIMULATED OUTCOMES AND DISCUSSIONS

Figure 3 depicts the proposed NNPI type novel controller for HES system for Electric Vehicles. Here the artificial neural network (ANN) is combined with the PI type controller. Figures 7-12 illustrates the various simulated outcomes that are obtained and analyzed for various parameter like battery voltage (V_{dc}), battery current (I_b), super capacitor current (I_{uc}) using both PI and NNPI based controller.

Figure 7 illustrates the simulated outcomes for the battery voltage V_{dc} using both PI type controllers. It is observed that the battery voltage is having more ripples which may create heat issues and finally reduces the efficiency of the motor. But with the aid of NNPI type controller, the ripples and the heat effect can be minimized and hence increases the efficiency of the motor. Better and improved performance in terms of ripples, noise and efficiency is attained using NNPI type controller than PI type controller and is represented in Figure 8 and Table 4.

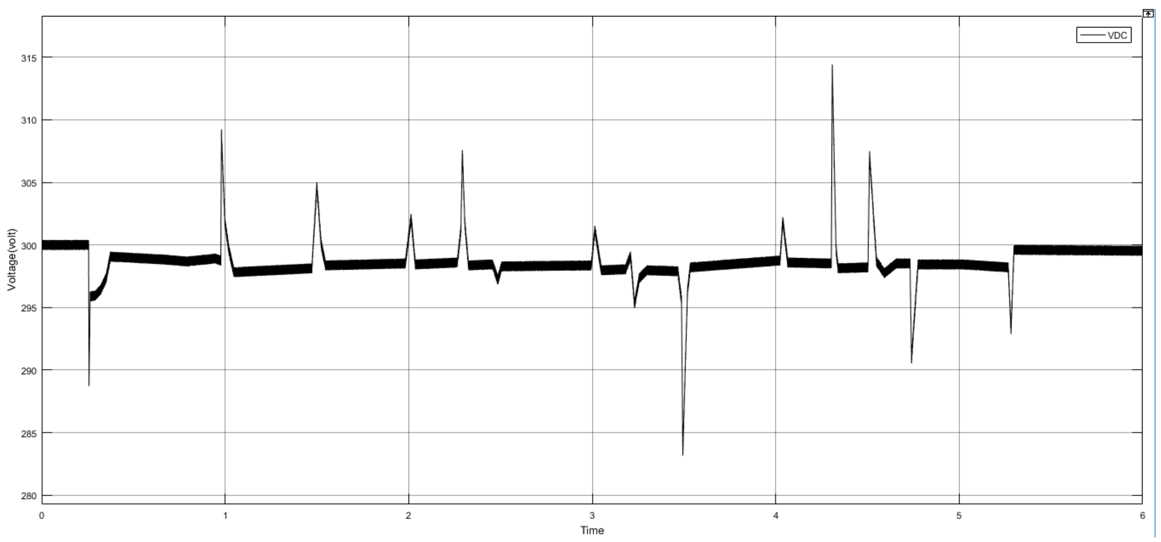

Figure 7. Simulated outcomes of PI type controller for the battery voltage V_{dc}

Figures 9 and 10 illustrates the simulated outcomes for the super-capacitor current I_{uc} using both PI type and NNPI based controller. Super capacitor current shows fewer ripples with NNPI controller than PI controller. Percentage reduction in ripples with NNPI controller is tabulated in Table 4.

Figures 11 and 12 illustrates the simulated outcomes for the battery current I_b using both PI type and NNPI based controller. It is observed that ripple free and more smooth output battery current is attained in case of NNPI based controller than PI based controller. Figures 13-15 illustrates the comparison of Simulated outcomes of PI and NNPI type controller for the battery voltage V_{dc}, super capacitor current I_{uc} and battery current I_b.

Different running conditions of electrical vehicles are discussed in this paper as per different driving conditions requirements like A mode, CS mode, B mode. For each mode the source of power, power flow, operating mode, circuit behavior are different. Considering the case of constant speed mode source of power is battery and the circuit behavior is boost mode of operation that is for constant speed mode slightly more voltage is required. In the same fashion considering the acceleration mode, power source is through super capacitor and mode of operation is boost mode. In different operating condition the running condition of the battery also vary in terms of the current and voltage drawn through the battery. This variation in the battery operation is shown below. Results are compared using both PI and NNPI type controller and the variation in the ripple content is shown in Table 4.

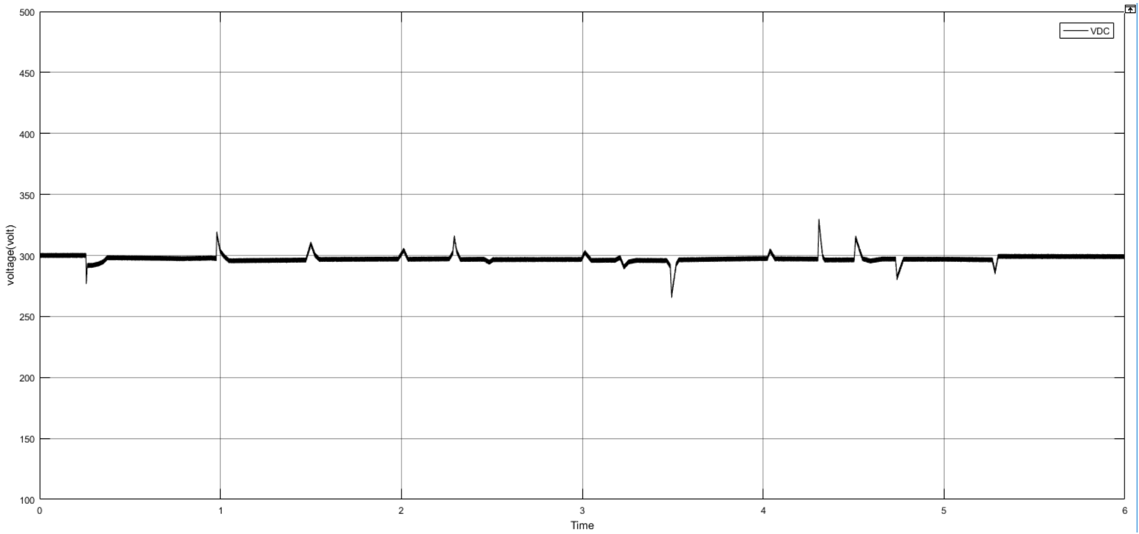

Figure 8. Simulated outcomes of NNPI type controller for the battery voltage V_{dc}

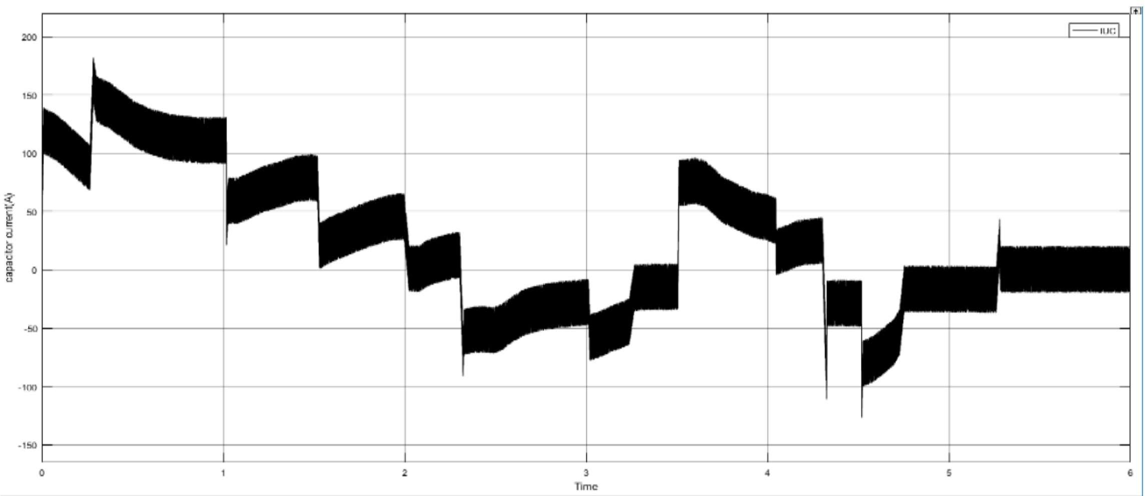

Figure 9. Simulated outcomes of PI type controller for the super-capacitor current I_{uc}

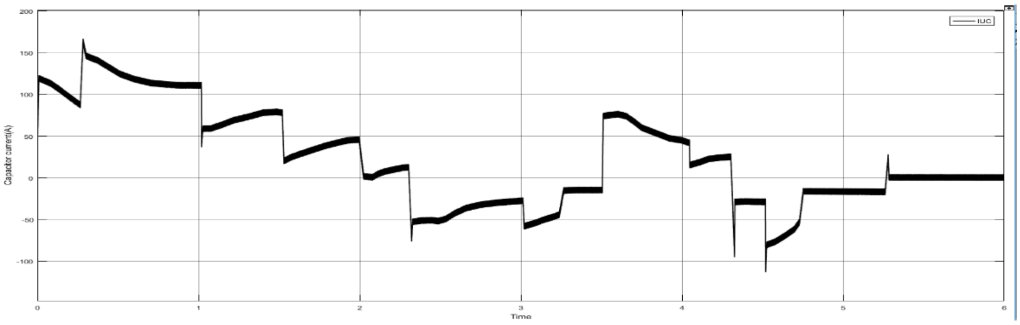

Figure 10. Simulated outcomes of NNPI type controller for the super-capacitor current I_{uc}

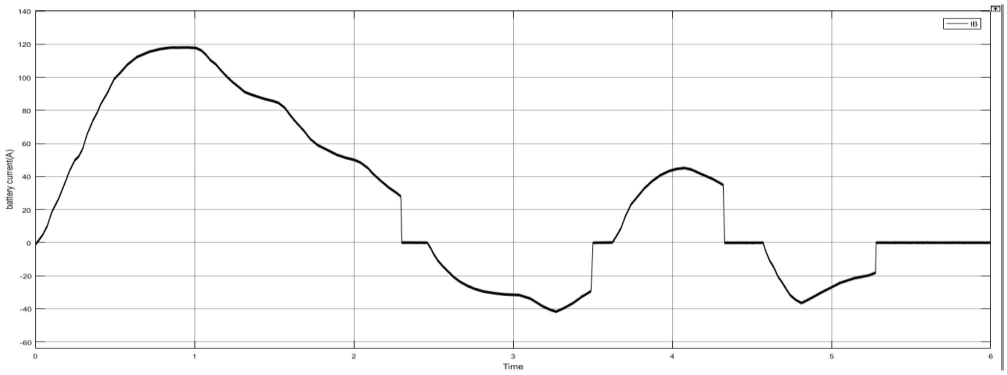

Figure 11. Simulated outcomes of PI type controller for the battery current I_b

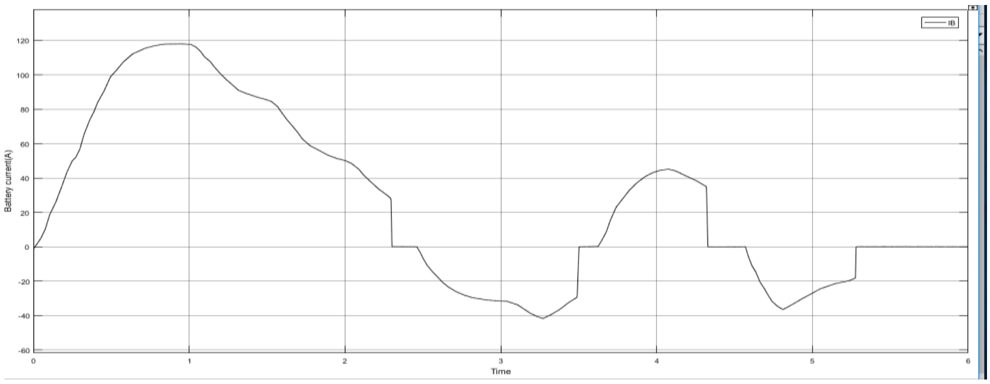

Figure 12. Simulated outcomes of NNPI type controller for the battery current I_b

Figure 13. Comparison of simulated outcomes of PI and NNPI type controller for the battery voltage V_{dc}

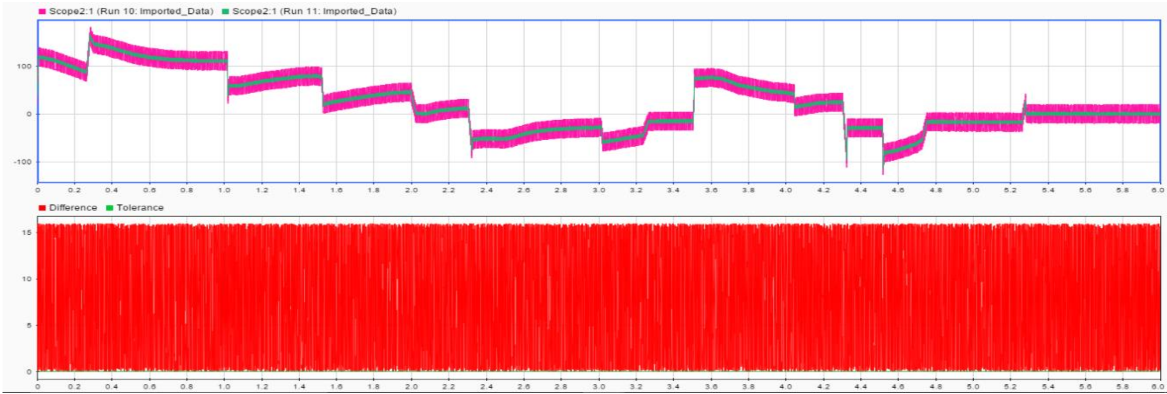

Figure 14. Comparison of simulated outcomes of PI and NNPI type controller for the super-capacitor current I_{uc}

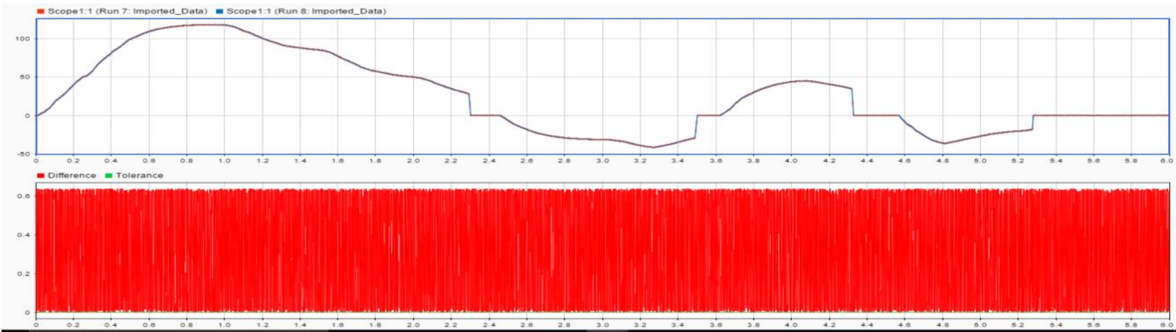

Figure 15. Comparison of simulated outcomes of PI and NNPI type controller for the battery current I_b

Table 4. % reduction in ripple with the proposed NNPI type controller for different operating modes and during different operating simulated times

Operating simulated time	At simulated time of 1 Sec		At simulated time of 2 sec		At simulated time of 3 sec		At simulated time of 4 sec		At simulated time of 5 sec	
% Ripples in different operating modes	% Ripples in Parking mode		% Ripples in Constant speed operating mode		% Ripples in Accelerating operating mode		% Ripples in Braking operating mode		% Ripples in Charging of Super-capacitors operating mode	
Parameters	I_{uc}	V_{dc}	I_{uc}	V_{dc}	I_{uc}	V_{dc}	I_{uc}	V_{dc}	I_{uc}	V_{dc}
PI Controller	40.17	23.392	42.811	11.696	41.91	9.355	37.4	10.284	33.38	4.678
Proposed NNPI Controller	9.06	10.78	10.232	4.293	8.183	3.22	6.956	0.959	9.414	0.914
% Reduction in Ripple with proposed NNPI Controller	77.44%	53.91%	76.09%	63.29%	80.47%	65.57	81.41%	90.67	71.79%	80.66%

6. CONCLUSION AND DISCUSSION

In this paper, the performance of the electrical vehicle during various operating modes like P mode, CS mode, A mode, B mode and SCC mode is discussed with the aid of both PI and proposed NNPI type controller in MATLAB/Simulink environment. The proposed system performance in terms of load side voltage (V_{dc}), charging current (I_{uc}) are observed. The percentage reduction in ripples during different operating mode at different operating simulated times are examined. It is observed that the proposed NNPI type controller gives a smoother and fewer ripples without any instantaneous battery current. Due to this the life of the battery is increased and the heating effect in the vehicle batteries is reduced. Reduction in the ripple content leads to stable operation of the operating motor and also leads to less vibration and losses in the motor used. Thus, the proposed NNPI type controller is shown to be efficient in reducing the ripples in load side dc voltage and charging current. Electric vehicles (EVs) are emerged as a viable option than the conventional IC Engine as it emits low carbon emissions, most energy diversified and energy recovery during braking operating mode despite of its high initial cost.

APPENDIX

Table 1. Work done by various researchers in the concerned area of electric vehicles

Ref No	Objectives	Findings/Outcomes	Technique opted
[10]	The paper elaborated in detail the HES type system based on batteries and ultra capacitors for the performance enhancement in terms of efficiency, reliability and battery maintenance of storage devices adopted in EV.	Analyzed different topologies from the viewpoint of their efficiency, cost and reliability. optimal sizing of the HES type system components e.g. ultra capacitors.	An optimization-based algorithm for optimizing various parameters is implemented.
[11]	This paper detailed about development photovoltaic based EV charging station at some Solar based Laboratory (LABSOLAR) by the Federal University of Juiz de Fora (UFJF).	The motive of the proposed system is to accomplish the charging of a Carryall 6 EVs which are used at UFJF. The proposed system is tested and validated experimentally.	Perturb and Observe (P&O) Microcontroller DSC TMS320F28335.
[12]	This paper focused on the implementation of the various control strategies based on PI, fuzzy and ANN for DFIG system used in WECS. In a DFIG, the dual control from grid side and the rotor side is done and analyzed using MATLAB/Simulink software.	It is noticed from the simulated outcomes that ANN based controller are quite efficient as compared to PI and fuzzy based controllers. Less steady state error and more stable output is attained using ANN based controller. Also no need of any mathematical model is requisite for ANN so it proves to be computationally efficient also.	PI, Fuzzy and ANN
[13]	This paper covered the designing criteria of a hybrid type renewable energy system (RES) with PV and Biogas system using optimization software (HOMER) for different types of batteries: advanced lead acid batteries, Li-ion batteries and zinc-bromine and flow batteries.	A comparative study is carried out based on size, economical/technical aspects, and stability. The same study is practically validated for an electrification of a rural village of the Madhya Pradesh.	Optimization software HOMER
[14]	This paper suggested and designed a hybrid energy storage system (HESS) to compensate the effect of power variations of micro grid. The proposed control strategy is implemented by considering the attributes of the various components used for the HESS. Moreover, the battery charging and discharging is not related directly with the power disturbances but is the function of the SMES current.	The process of charging/discharging of battery helps in attaining the desired level of SMES current. The battery is prevented from the stinging currents due to inductive nature of the SMES coil. Hence the lifetime of the battery can be increased by decreasing the cycling frequency	HIL test platform
[15]	A novel hybrid energy storage (HES) system is implemented with the aid of battery pack and ultra capacitors module connected with a 3-Level Neutral-Point Clamped Converter (NPCC). A Surface Mounted Permanent Magnet Synchronous Machine (SMPMSM) is preferred for propulsion purpose in EV.	The proposed HESS based control strategy enables its proper exploitation and prevents battery pack from handling sudden power fluctuations, preserving its rated performances and extending its life.	NPC modulation approach No need of any DC-DC converter.
[16]	This paper implemented a sliding mode controller for a HES type system with a 4 leg three level inverter. To permit the inverter to operate under unbalanced load situation, a 3-dimensional space vector modulation technique along with sequence decomposition-based control strategy is suggested for control from ac side provided a balanced ac voltage is kept at the common cooping point.	The proposed technique for the HES type system for the purpose of power flow control is compared with PI controller. The proposed technique is validated both through simulations and experimentally on a prototype developed in the laboratory.	Sliding mode controller +PI controller
[17]	This paper elaborated the detailed design criteria of a HESS hardware prototype to illustrate various aspects related with energy efficiency, its scalability and flexibility. It is proved in this paper that by using the proposed design criteria improved energy efficiency is accomplished.	The proposed controller is validated through experiments for load-leveling purpose and for improving energy efficiency.	A LM3S2965 microcontroller based novel control strategy with voltage- and current-regulating power converter. Of customized type.
[18]	This paper implemented a new and novel energy management technique for improving the performance of an EV in terms of size, efficiency, and cost of the whole system and finally the life span of the battery. In addition, one of the most important advantages of this novel strategies	By using the proposed EM technique the battery and super capacitor power constraints can be controlled. This suggested EM technique finally helps in increasing the life span of the battery and hence lowers the overall cost of HESS. The proposed strategy is validated through simulations and experimental setup in the laboratory.	PI Controller+ a dSPACE DS1104 controller
[19]	In this paper, an ANN type control is suggested and implemented for the angular position control of a DC motor for driving a robot operated arm.	It is shown through simulations in this paper that the ANN based controller is easy to implement and proves to be less costly also for industrial control applications	PID+ANN Controller

Table 1. Work done by various researchers in the concerned area of electric vehicles (continue)

Ref No	Objectives	Findings/Outcomes	Technique opted
[20]	This manuscript suggested a HVDC system for the power flow control between two converters. Current control is accomplished from the rectifier side. Both current control and extinction angle control is accomplished from the inverter side.	In this paper, the performance is compared using both PI and ANN controller using MATLAB/Simulink software.	PI and ANN controller
[21]	This paper explored a optimization based new strategy for the benefit of distribution company name Discos with the aid of proper selection and use of charging station CSs that helps in reducing the losses, voltage dips and load demand during peak hours conditions. In problem formulation various parameters i.e. increase in load, electricity tariffs and SOC of the batteries with passage of time are taken into consideration while solving optimization problem.	With the aid of the proposed technique, the operating cost of the grid is reduced. The proposed technique is validated with the aid of Monte-Carlo simulations and proves to beneficial for both Disco's and owners of CSs.	Genetic algorithm (GA) method using Monte-Carlo simulation and MCS optimization method.
[22]	This paper is related with the smart charging of Pug-in Electric Vehicle (PEV) which helps in efficient delivery of energy and at the same time controls the unbalance in three-phase systems. The proposed strategy is based on interaction between the aggregator and PEV owners on real time basis.	It provides wide options for the charging to PEV and this strategy also ensures that the existing grid operates safely within the defined voltage unbalance bounds. The proposed strategy is tested and validated by executing simulations in MATLAB/GAMS software.	MATLAB/GAMS simulation
[23]	This paper proposed an algorithm (Archimedes optimization algorithm) based on optimization technique for the purpose of optimal location and its sizing of an EV-CS for a IEEE 33 bus system in order to mitigate loss and for voltage support	In this paper, the proposed optimization algorithm AOA is compared with various existing methods like CS and PSO to show its effectiveness in reducing the power loss.	Archimedes optimization algorithm (AOA)
[24]	This manuscript covered the modeling aspects of the Li-ion battery and its parameter estimation. Trust Region-Reflective and Levenberg-Marquardt algorithms are tested.	The proposed system is testified by comparing simulated outcomes with the error MSE (mean square error)	Trust-Region-Reflective and Levenberg-Marquardt algorithms.
[25]	This paper detailed about the integration of ANN for the state of charge (SOC) estimation of the Li- ion battery and the control of the bidirectional DC-DC type converter. The robustness of the proposed ANN technique is testified using MATLAB software.	The effectiveness of the proposed controller is shown through simulated outcomes in terms of speed of convergence, voltage error in dc voltage.	ANN
[26]	This paper proposed a heuristic optimization approach for a battery model for its parameter estimation	A comparison of the proposed GA based algorithm with various existing techniques like PSO, Gravitational search algorithm has been made for parameter estimation of the battery. The proposed algorithm provides more accurate and best results.	GA algorithm
[27]	This paper covers the modeling aspects of the Lithium battery and its SOC calculation and estimation. ANN is adopted for obtaining the desired dc voltage of the battery and its SOC.	The proposed ANN method suggested and implemented for Li-Ion battery cell and its SOC estimation shows very good accuracy and fast convergence rate.	ANN

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