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A Pulse Charging Technique for Fast Charging of Electrical Vehicle

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Abstract: *Electric vehicles (EVs) have become integral to the automotive industry due to two primary factors: diminishing reliance on oil and mitigating air pollution, thereby fostering an environmentally friendly environment. When purchasing EVs, consumers evaluate various factors such as overall vehicle mileage, recharge time, mileage per charge, battery charging/discharging safety, longevity, charging rate, capacity, and temperature regulation. A novel pulse charging technique has been proposed, incorporating proportional integral derivative (PID) control and neural network mechanisms to enhance battery charging efficiency. This design utilizes a PID controller within the charging unit, with feedforward neural networks determining PID control parameters. Additionally, a battery management system (BMS) ensures swift and efficient charging while maintaining battery health. The system is implemented using MATLAB/Simulink.*

Keywords: Electric vehicles

I. INTRODUCTION

Li-ion batteries used to have low levels of self rate and a high energy density. For electric vehicle (EV) sectors, Improvements in lithium-ion battery technology are imperative to enhance power management, energy density, control, and security, particularly in the context of electric vehicles (EVs) [1]. However, challenges such as low ambient temperatures affecting Li+ ion diffusion and complications during fast charging can lead to degradation and safety concerns [2]-[4]. Battery management systems (BMS) are crucial for monitoring and ensuring the safety of batteries by detecting over-current, over-voltage, or over-charging/discharging scenarios, thus preventing potential safety hazards like wildfires [5]-[7]. The BMS also includes automatic cut-off features to disconnect the battery under extreme conditions [8]-[10].

Manufacturers face challenges in introducing electrified solutions, including range, motor configurations, and customer acceptance of EVs. Researchers discuss various electrical drives like SRM, BLDC, PMSM, and induction motor drives for EV applications [11]-[14]. Over-modulation techniques in modular multilevel cascaded converters and voltage balancing strategies are explored [15]-[17]. Power quality enhancement techniques using FACTS controllers for EV applications are also investigated [19]-[22].

Long charging times and range anxiety hinder EV adoption compared to petrol vehicles [23], [24]. Advanced charging algorithms and hardware techniques can improve battery runtime and characteristics [25]-[27]. This paper proposes a pulse charging technique with a PID controller in the charging unit to minimize charging time, with PID parameters determined by a neural network. The aim is to enhance battery performance by monitoring and controlling charging state parameters. The contributions of this paper include designing a pulse charging technique to reduce charging time while minimizing temperature rise and switching losses. It also improves charge current settling time and battery charging capacity, reducing total harmonic distortion (THD) values compared to existing technologies. The manuscript is organized into sections covering introduction and literature review, proposed system architecture, simulation results, performance parameter comparisons, and conclusions.

II. PROPOSED SYSTEM ARCHITECTURE

This paper describes the design of an intelligent battery management system based on pulse charging, utilizing PID control and artificial neural networks (ANN). The primary objective is to optimize the frequency and duty cycle of

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charging pulses using electronic design automation (EDA) tools. MATLAB is employed for designing, implementing, and validating the system's performance.

The pulse charging technique is emphasized due to its recent popularity, focusing on controlling charge current pulses to optimize charging time while considering factors such as battery heating, polarization, state of charge, and variable battery impedances. The use of PID control is justified for designing the charging unit, with a MOSFET circuit employed for pulse width modulation (PWM) control. This MOSFET circuit acts as a current booster and rectifier, enhancing charging speed.

However, PID controller tuning presents challenges such as overshoot and increased response time. To address this, parameter tuning using PID control and ANN is proposed. A feed-forward neural network is utilized to distribute charge pulses among connected battery packs, enabling faster charging. The battery management system (BMS) is designed to manage the distribution of charge pulses, employing digital and chemical batteries for communication and control, respectively.

The neural network assists in monitoring coulomb flow, estimating battery capacity based on fixed rated capacity, and reducing total harmonic distortion (THD) by filtering high-frequency components. Overall, the proposed system aims to prolong battery life, reduce costs, increase charging efficiency, and minimize charging time for lithium-ion batteries.

2.1 Implementation of single-phase electric vehicle battery charger

A unique single-stage dynamic rectifier design is created for the use of integrated charging devices. The proposed dynamic rectifier, with a lessened range of semiconductors, was created by four MOSFETs and4 diodes. There are two types of chargers, semi conductive and inductive: i) semi-conductive chargers: this type of charger has a hard-wired that is associated with the supply ability and ii) inductive chargers: as the same charges do not require a hard-wired that is related with the capacity to give manoeuvre vigour to the EV's battery structure. They employ the alluring time rule for essential (transmitter) and supplementary (collector) curls for power move.

This is a current boosting circuit, basically a current booster and rectifier circuit. This circuit is mainlyused to boost the current and in turn the power of the charging unit. This factor plays a vital role in increasingthe charging speed of the battery and hence reduces the required charging time. Figure 1 shows the five-stage lively rectifiers used for electric vehicle battery chargers. S_1, S_2, S_3, and S_4, resemble the 4 MOSFET switches. D_1, D_2, D_3, and D_4 resemble the 4 diodes while C_1, C_2, are the 2 capacitors having voltages V_{dc1} and V_{dc2}, respectively.

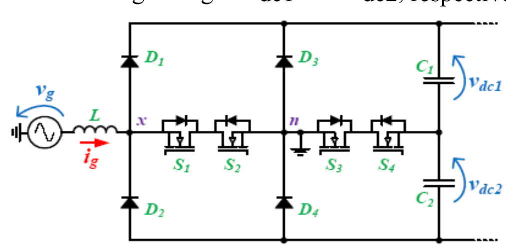

Figure 1. Five-level active rectifiers for EV battery chargers

V_g and I_g are the voltage, and the contemporary of the grid l is the inductor a grade-by-grade operation of the said five level lively rectifiers is illustrated in Figure 2 (in Appendix). And subfigure operationare explained below as Figures 2(a) to (h).

The stages of operation of the proposed single phase five-level active rectifier are given:

V_{ar}=0 V: Whenever the generated voltage changes from 0 V to+V_{dc}/2;

V_{ar}=+ V_{dc}/2 V: Whenever the generated voltage changes from 0 V to+V_{dc}/2;

V_{ar}=+V_{dc}/2 V: Whenever the generated voltage changes from+V_{dc}/2 to+V_{dc};

V_{ar}=+V_{dc} V: Whenever the generated voltage changes from+V_{dc} /2 to = + V_{dc};

V_{ar}=0 V: Whenever the generated voltage changes from 0 V to -Vdc/2;

V_{ar}=- V_{dc}/2 V: Whenever the generated voltage changes from 0 V to - V_{dc}/2;

V_{ar}=- V_{dc}/2 V: Whenever the generated voltage changes from -V_{dc}/2 to -V_{dc};

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V_{ar}=- V_{dc} V: Whenever the generated voltage changes from -V_{dc}/2 to -V_{dc}.
The corresponding pulse pattern of all MOSFET switches used in the project is shown in Figure 3.

2.2 Charging process:

Figure 4 depicts the charging process layout, which consists of five major components: the intelligent metre, unit interface, master controller, charging converter modules, and battery management system (BMS). By examining the various connections, connection notifications, connection acknowledgments, PWM-rated capability, rated current estimations, rated voltage, current, charging ready and emergency stop points, battery information, charging ready/indication equipped, charging commencement, charging completion, and connector disconnection are the numerous steps involved in thedesigned charging process [25]-[27].

Figure 3. MOSFET switch pulse pattern

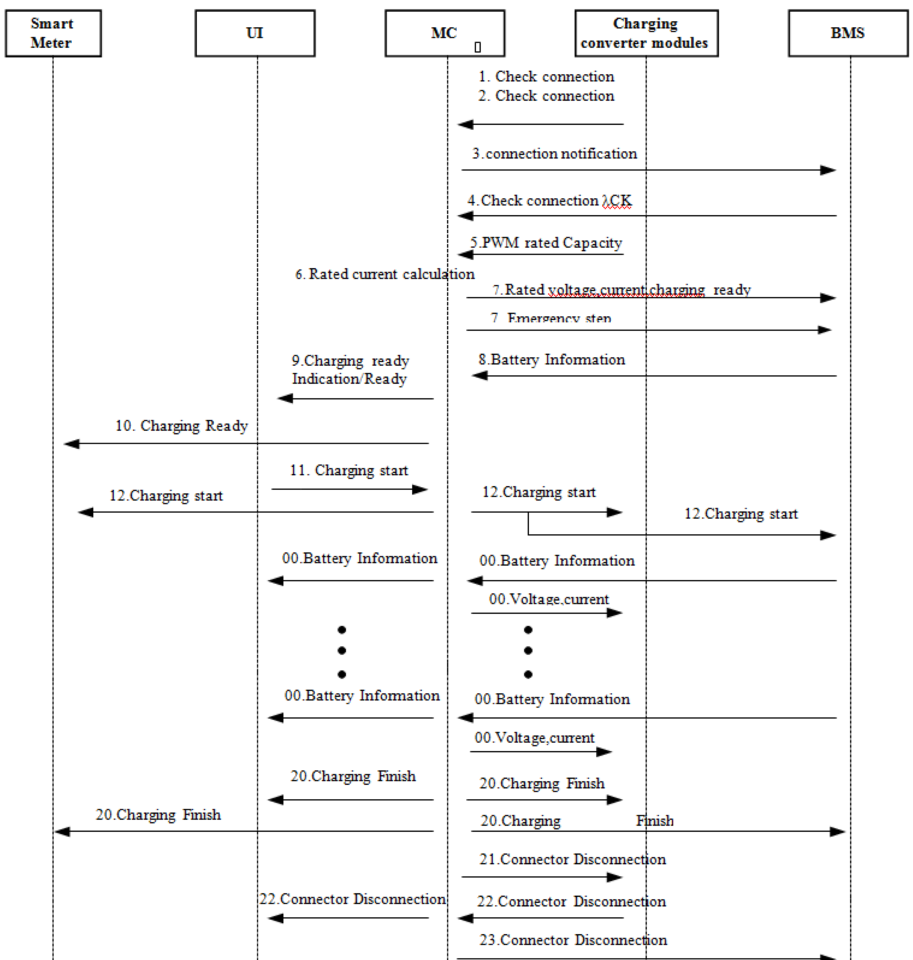

Figure 4. Charging process

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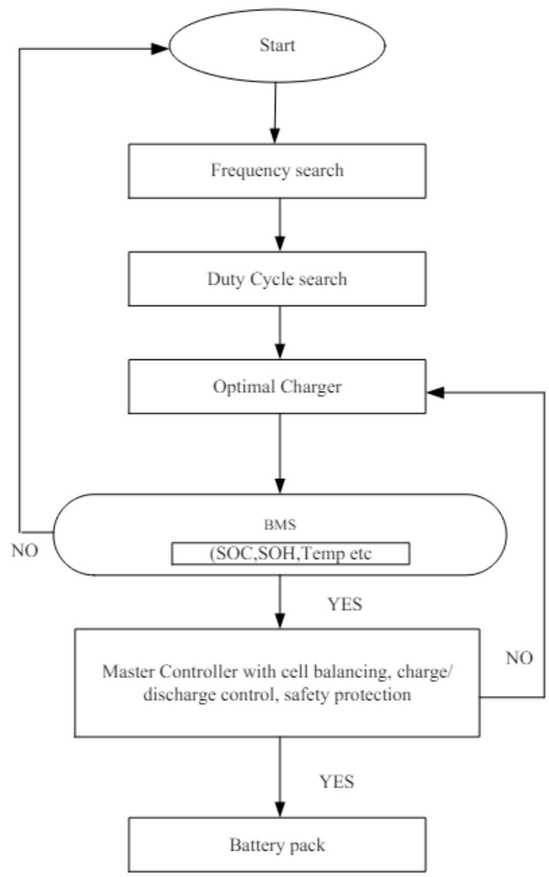
2.3 Flowchart

The pulse charging approach controls and monitors charge current pulses while charging the battery in great detail. It optimises charging time by automatically adjusting the frequency of charge pulse occurrence. Lower charging times and higher charge rates, in addition to energy efficiency gains, are the main advantages of pulse charging, that are both desired features by local customers. The flowchart of the proposed system design is illustrated in Figure 5.



2.4 PID controller

PID control is one of the earliest advanced control techniques. It has many blessings, inclusive of easy algorithms, high reliability, and precise robustness, and has been broadly carried out within the area of commercial method management. Figure 6 resembles the PID control configuration used in this design.

The PID controller block output is a weighted sum of the entering signal, the imperative of the input sign and by-product of the input signal. The weights are the proportional, critical and by-product benefit parameters. A first-order pole filters the spinoff motion. Sign 'u' is the input sign while sign 'y' is the output signal. The transfer characteristic of the PID controller is given through in (1).

$$(s) = p\,[1 + I\,(\frac{1}{s}) + D\,(\frac{N_s}{s+N})]$$

The advantages of PID control are no offset is present, there are no oscillations with less settling time and the improvement can be seen together in transient and steady-state replies

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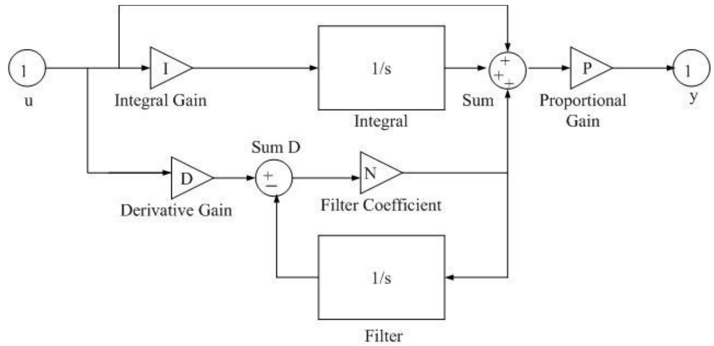

Figure 6. PID controller

2.5 Neural network

Artificial intelligence allows us to clear up complex problems. Neural networks are a traditional case in synthetic intelligence in which a system is tuned to analyze complex tactics. The usefulness of the synthetic neural community has been verified in several programs like speech synthesis, diagnostic troubles, business and finance, robot manipulation, sign processing and many other troubles that fall below the class of pattern recognition. The new advanced and adaptive artificial intelligence systems are Kalman clear out, machine gaining knowledge of algorithms along with fuzzy logic and aid vector machines, diverse neural networks such as radial foundation function neural network, feed ahead neural internet, returned propagation neural internet, and so forth. Adaptive systems mean structures that are self-designed as well as those that mechanically modify themselves subjected to changing systems.

The first step of the prediction model is to educate the network. The prediction error among plant output and neural community output is used because of the neural network training signal. The technique is illustrated in Figure 7. The internal shape of the model is illustrated in Figure 8 sign 'u' is the input sign and 'y' is the output sign, 'w' represents the weights and 'b' is the prejudice of the community.

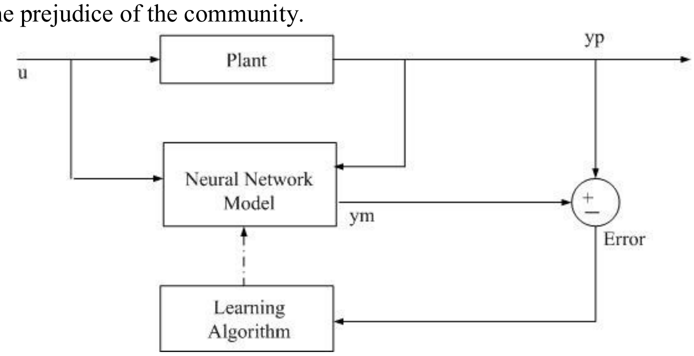

Figure 7. The training process for the network

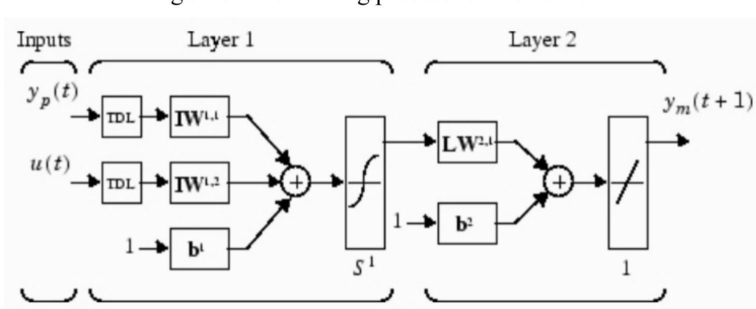

Figure 8. The internal structure of neural network model

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The numerical optimization is given in (2),

$$j = \sum_{j=N_1}^{N_2} (y_r\,(t+1) - y_m\,(t+1))^2 + p \sum_{j=1}^{Nu} (u'\,(t+1-1) - u'\,(t+1-1))^2 \quad (2)$$

Here n_1, n_2, and n_u represent horizons for evaluating tracking errors as well as manipulating steps. u' is indeed the managed sign, y_r is indeed the intended response and y_m is the networking version response. The sum of the squares of control increments' impact to the performance metric is determined by cost.

Figure 9 depicts the entire manipulation operation. A neural community version as well as an optimisation block comprises the controller. The optimisation block identifies the variables of u' that limit j, and then the most trustworthy 'u' is entered into the community version as an input.

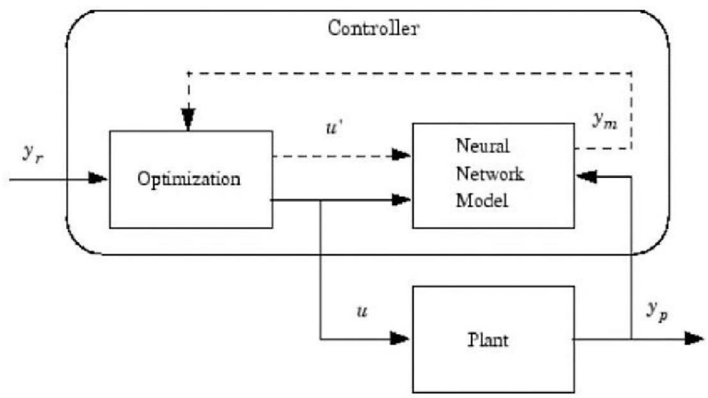

Figure 9. Control process in the network model

III. SIMULATION RESULTS

The proposed active rectifier for producing the pulses is established thru the software simulation with the use of MATLAB 2015 a software program. The consequences obtained are as mentioned under. The simulation model of the proposed design is shown in Figure 10. As mentioned theoretically, the simulation model is also built for the usage of four MOSFET switches, 4 diodes, capacitors, and one inductor for that reason.

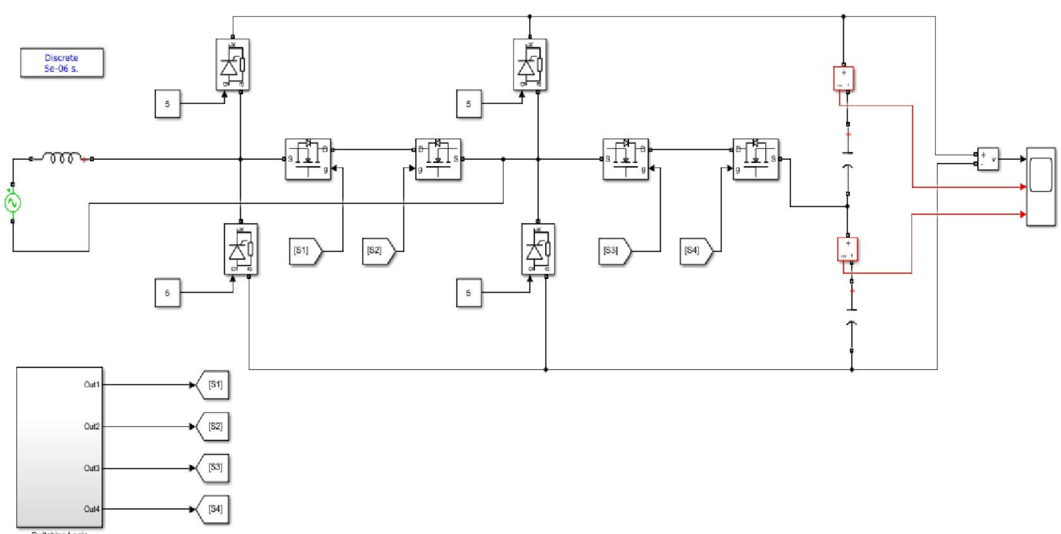

Figure 10. Simulation model of the proposed design

3.1 Power grid voltage (Vg) and current (ig)

The graph of electricity grid voltage in volts towards time in seconds is depicted in Figure 11. It is determined that clean +/- 230 v is obtained and maintained. The graph of current in amperes and time in seconds is depicted in Figure

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12. In advance, there are +/- 60/70 spikes within the system in the transition segment. Afterward the modern-day settles downs to +/- 50a. the settling time of the machine in the transitionphase is sort of about 0.025 s, that's a way extra less which makes the gadget greater reliable and green.

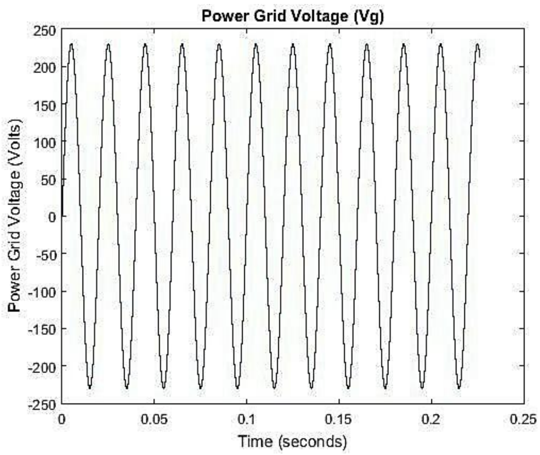

Figure 11. Power grid voltage waveform

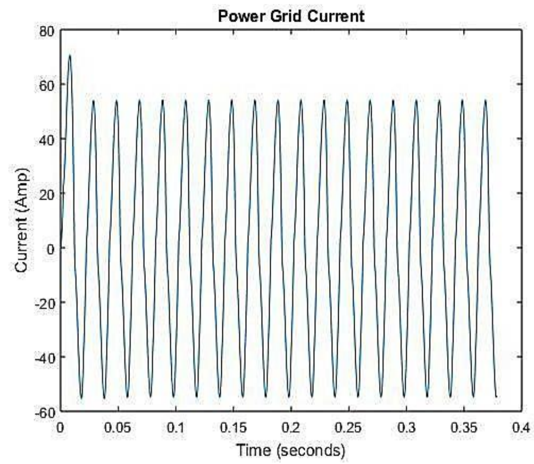

Figure 12. Power grid current waveform

3.2 DC output voltage, power factor and total harmonic distortion

The obtained output DC voltage is nearly 240 V as shown in Figure 13. The obtained power factor reading of the proposed system is about 0.934, the same is depicted in Figure 14. A bar chart of obtained THD as compared with a few existing technique authors' THD is shown in Figure 15. Additionally, a table i.e., Table 1, of the same is referred to. It miles discovered that the acquired THD from the proposed systemis 2.8 which is a long way greater much less than in advanced strategies having THD equal to 8.3, 4.9, and
2.9. In our proposed gadget, we've protected a low skip filter that filters out a maximum of excessive frequency components. This helps lessen the full harmonic distortion from the desired output.

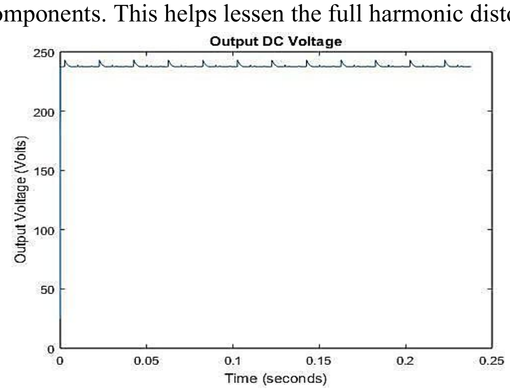

Figure 13. Output DC voltage

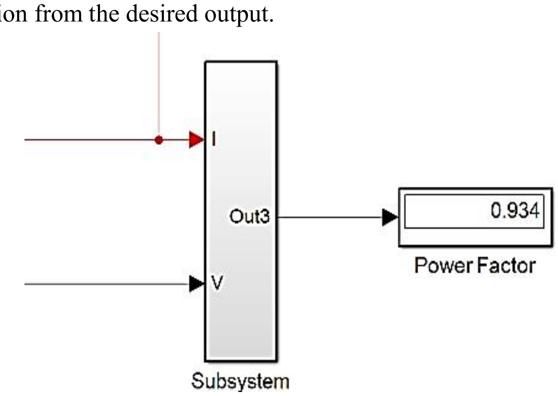

Figure 14. Power factor

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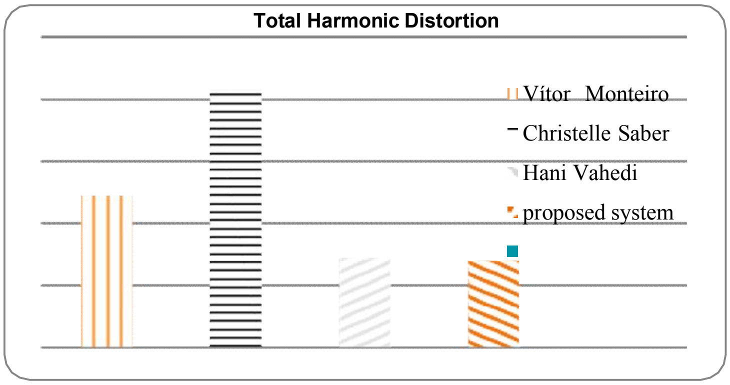

Figure 15. Obtained THD compared with existing technique authors THD

Table 1. Comparison of various THD values

Authors	Total harmonic distortion
V. Monteiro *et al*. [8]	4.9
C. Saber *et al*. [13]	8.3
H. Vahedi *et al*. [17]	2.9
Proposed system	2.8

3.3. Circuit model and various battery parameters waveforms

The inner circuit diagram of the designed model in simulation is proven in Figure 16. MATLAB simulation without a doubt illustrates the charging and discharging cycles of the battery. The source switch selects the operation kind of charging or discharging. MOSFETs have been deployed with altered charging cycles to it. There seem to be two PID control operations: the first controls voltage and the second controls current.

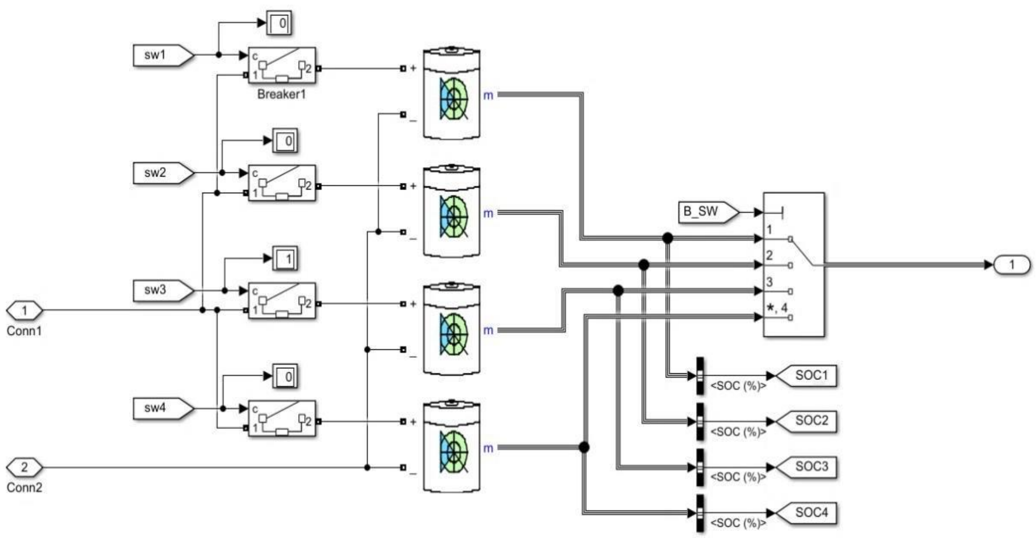

Figure 16. Simulation model

The PID modification activity is employed to handle pulse price accusing. Those PID impediments have been removed from ANN. The waveforms indicate that the battery voltage is constantly growing during the charging period. The situation of price increases for the duration of the charging cycle. The simulation waveforms of various battery parameters considered i.e., state of charge (SOC), battery voltage, battery current, and load voltage depicted in Figure 17.

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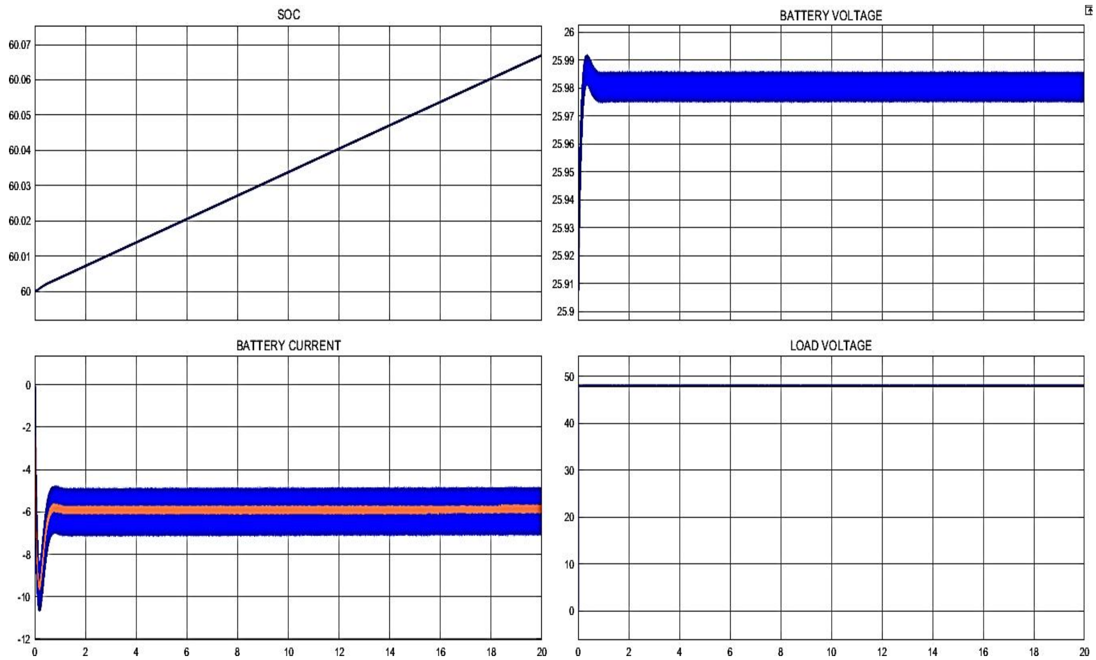

Figure 17. Simulation waveforms of various parameters

IV. COMPARISON OF PERFORMANCE PARAMETERS

Table 2 illustrates a comparative evaluation of performance analysis between those from previous research and those proposed in this study. The various parameters, such as voltage, charge efficiency, charge time, state of health, state of charge, temperature rise, settling time, and life span, have been evaluated in comparison with the ideal, the results of previous research, and the system that has been proposed. It has been observed that the outcomes of a current proposal are superior to those of earlier research.

Table 2. Comparison of performance parameters

Sr. No.	Parameters	Ideal case	Earlier research	Proposed system
1	Voltage	12 V	10/11 V	11.95 V
2	Charge Efficiency	99% ideally	75-80%	90%
3	Charge time	3-10 hours	140 min [16]; 110 min [17]	35 min
4	SOH	100%	89.87% [18]	91%
5	SOC	50% (Practically)	90% [19]	93%
6	Temperature rise	22°	21.5°	20°
7	Charge current settlement time	80 ms	20 ms [16]	18 ms
8	Life span	8 yrs	25% more [16]	35% more

V. CONCLUSION

Concerns about limited energy sources, as well as the environmental impact of petroleum-based transportation infrastructure, have increased interest in electric transportation infrastructure. Thus, throughout the latest days, EV, hybrid electric vehicles (HEV), and plug-in HEV have received a lot of attention. Battery technology and related systems continue to be a central challenge in vehicle electrification. Many manufacturers have targeted fast charging capability as a key design characteristic for EV battery packs to decrease anxiety as well as meet customer requirements. Proposing an optimal charging design such that provides benefits such as reduced charging time and increased efficiency while preserving battery life is critical.

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The pulse charging technique handles the detailed control and monitoring of charge current pulses while charging the battery. It automatically adjusts the frequency of charge pulse occurrence to optimize charging time. Lower charging time and greater charge, as well as energy efficiencies, are the key benefits provided by pulse charging, which are both desired features by today's customers. After considering all of the factors and research gaps, one such document designs and proposes an improved fast-charging technique based on PID control action monitored by neural networks. The software implementation is completed in MATLAB/Simulink. Simulation results show that the proposed design is successful and the same design concept handling activities the primary objective is to decrease the recharge time of the battery.

APPENDIX

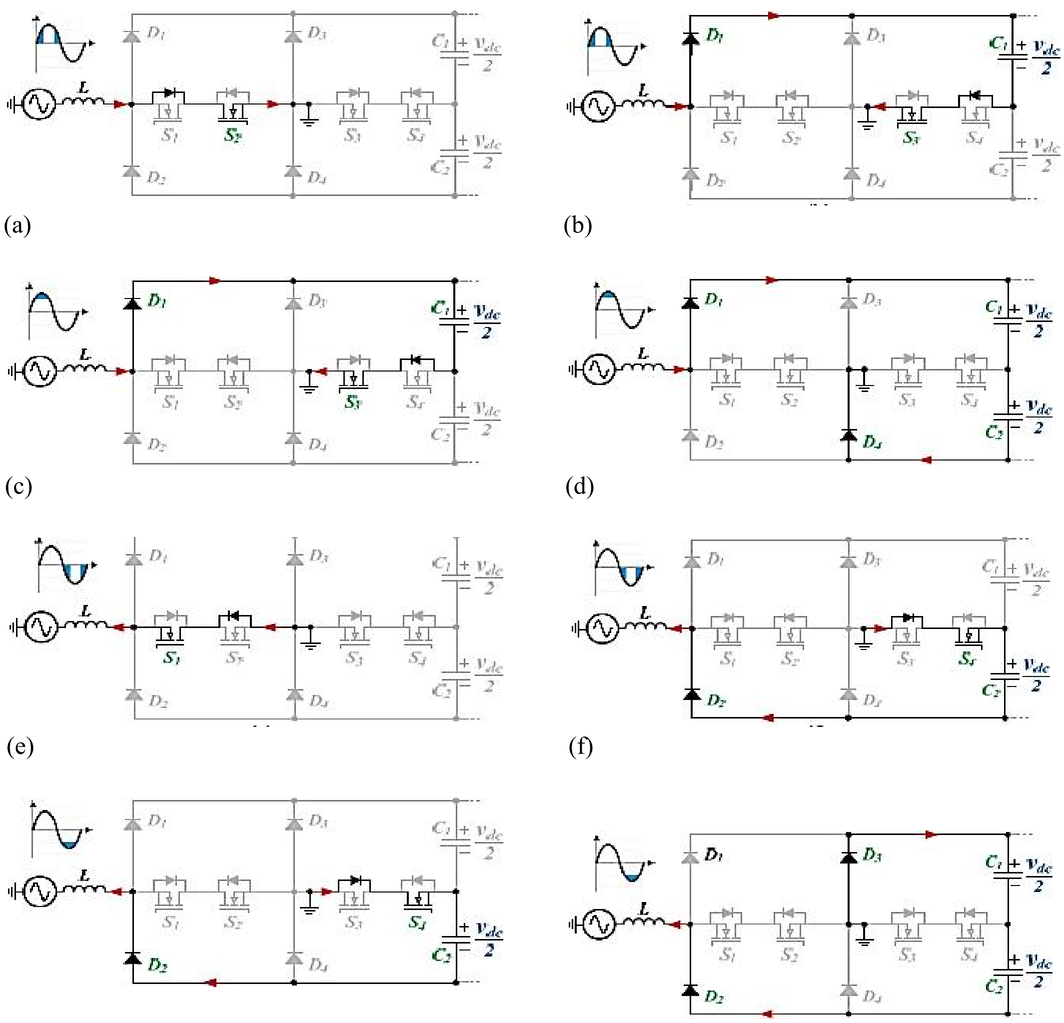

Figure 2. The step-by-step operation of the proposed five-level active rectifier (a) stage output 0 V to$V_{dc}/2$, (b) stage output 0 V to+$V_{dc}/2$, (c) stage output +$V_{dc}/2$ to+V_{dc}, (d) stage output +$V_{dc}/2$ to+V_{dc}, (e) stage output0 V to -$V_{dc}/2$, (f) stage output 0 V to -$V_{dc}/2$, (g) stage output -$V_{dc}/2$ to -V_{dc}, and (h) stage output -$V_{dc}/2$ to -V_{dc}

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