Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 4, August 2023, pp. 1947~1959
ISSN: 2302-9285, DOI: 10.11591/eei.v12i4.4564

Pulse charging based intelligent battery management system for electric vehicle

Sunil Somnath Kadlag[1], Pawan Tapre[2], Rahul Mapari[3], Mohan Thakre[4], Deepak Kadam[5], Dipak Dahigaonkar[6]
[1]Department of Electrical Engineering, Amrutvahini College of Engineering, Savitribai Phule Pune University, Sangamner, India
[2]Department of Electrical Engineering, S.N.D. College of Engineering and Research Center, Yeola, India
[3]Department of Electronics and Telecommunication Engineering, Pimpri Chinchwad College of Engineering and Research, Pune, India
[4]Department of Electrical Engineering, SVERIs College of Engineering, Pandharpur, M.S. India
[5]Department of Electrical Engineering, MET's Institute of Engineering, BKC, Nashik, India
[6]Department of Electronics and Communication Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur, India

Article Info

Article history:

Received Aug 15, 2022
Revised Nov 2, 2022
Accepted Nov 27, 2022

Keywords:

Battery management system
Electric vehicles
Neural network
PID controller

ABSTRACT

Electric vehicles (EVs) are now an important part of the automotive industry for two main reasons: decreased reliance on oil and reduced air pollution, which helps us contribute to the development of an environmentally friendly environment. EV buyers examine overall vehicle mileage, recharge time, vehicle mileage after every charge, batteries charging/discharging security, lifespan, charged rate, capability, and temperature increase. A new improved pulse charging technique is proposed, in which the battery is charged using proportional integral derivative (PID) control action and a neural network. A PID controller is used to develop the charging unit in this design. The feed forward neural network was used to determine the values of the PID control parameters. The battery management system (BMS) ensures that this designed battery charging system takes less time to charge the battery efficiently. The system is built with MATLAB/Simulink.

Corresponding Author:

Sunil Somnath Kadlag
Department of Electrical Engineering, Amrutvahini College of Engineering
Sangamner, Maharashtra, India
Email: asunilkadlag5675@gmail.com

1. INTRODUCTION

Li-ion batteries used to have low levels of self rate and a high energy density. For electric vehicle (EV) sectors, lithium-ion batteries must improve power management, energy density, control, security, and charger [1]. Low ambient temperatures in EV markets impede Li+ ion diffusion at electrolytes and electrodes, slowing complication kinetics. It is hard to eliminate proficiently and uniformly which leads to degradation and concerns into safety-related problems due to the heat generated while doing fast charging of the battery [2]-[4]. The improvement of batteries technology with battery-management systems, that include surveillance, security, and monitoring of battery variables that serve as the battery platform's brain, has critical to the evolution of electric vehicles. Since incorrect actions such as over-current, over-voltage, or over-charging/discharging may cause serious safety concerns to the cells, significantly accelerate the ageing process or even wildfires if left unattended [5]-[7]. As a result, battery management system (BMS) plays a vital role in guaranteeing battery reliability and safety. It also has an automatic cut-off feature, which disconnects the battery from the electrical circuit and loads the side when charging and discharging levels exceed the set limits [8]-[10].

There are many challenges to manufacturers to introduce electrified solutions with their ranges, motor configuration, and converters acceptance by the customer of EVs and battery electric vehicles that are not hybridized with ICEs. The researchers discuss the various electrical drives, such as SRM, BLDC, PMSM, and induction motor drives, as well as their limitations and proposed configurations with performance analysis for EV applications [11]-[14]. Compares the investigative uses of over-modulation techniques in modular multilevel cascaded converters for harmonic elimination in three-phase two-level voltage source inverters [15], [16]. A modular multilevel converter with a simplified nearest-level control (NLC) strategy was proposed for voltage balancing [17]. Describes the evaluation and control perceptions of a VSM-based multilevel PV-STATCOM for a distributed energy system for harmonic reduction [18]. Demonstrate a variety of power quality enhancement techniques using flexible AC transmission systems (FACTS) controllers and EV applications [19]–[22].

Long charging times and range anxiety as compared to petrol vehicles are the main issues that make it difficult to adopt electric vehicles. Depending on the various electric vehicle requirements of the energy storage system may vary significantly [23], [24]. With the help of various software and hardware techniques, battery runtime can be improved. Characteristics of the batteries can be improved by advanced charging algorithm and improving the output performance [25]-[27]. Hence this paper focuses to reduce the battery charging time by implementing a PID controller in the charging unit of the battery, wherein the values of required P, I, and D parameters will be decided by the neural network which will be trained accordingly. The main aim of the paper is to design, develop and implement a pulse charging technique that minimizes the charging time of the battery and simultaneously monitors and controls the charging state of the battery parameter to improve battery performance.

Therefore, pulse charging techniques with intelligent battery management are designed and the developed circuit is to monitor the battery parameters and subsequently control them to enhance battery performance that also simulates and analyses the developed system to evaluate the performance. Hence the main contributions of the manuscript are design and development help to lower the charging time with negligible effect on temperature rise during charging and switching losses are minimized. Also helps in reducing the charge current settling time and also increases the battery charging capacity. The total harmonic distortion (THD) value is reduced up to 2.8, which is much lower than the THD values obtained using existing technologies as shown in the comparison table. This paper is described into five sections as; section 1 presents an introduction to battery management and a literature review based on a research area. section 2 represents the proposed system architecture in detail. Section 3 gives the simulation results with simulation waveforms. Section 4 depicted comparisons of various performance parameters with the work already done and section 5 followed by the conclusion.

2. PROPOSED SYSTEM ARCHITECTURE

This paper refers to the design of a pulse charging-based intelligent battery management system. The system mainly uses PID and artificial neural networks (ANN). The key idea of the proposed design is to adjust the optimal frequency and duty cycle of the charging pulses. This is achieved by using the electronic design automation (EDA) tool. ANN is used to monitor and control various parameters of the battery. MATLAB is used to design, implement and verify the performance of the designed battery management system. The details of the proposed design are briefed. The charging unit plays a vital role in this model. The pulse charging technique, being recently in high demand, is preferred here. This method mainly depends on controlling the charge current pulses sent to the battery while charging. Here, the pulses of charge are sent to the battery in such a way that the charging time is well-optimized. Along with time optimization factors such as battery heating, polarization, state of charge, variable battery impedances, are also considered. In the resting time of every charge pulse, ions are diffused through the electrode materials.

This contributes to an increase in the efficiency of charging. By appropriately selecting the parameters of charge current pulses, one can also assure the extended life span of the battery along with its optimum performance. Considering these points, PID control is preferred as the best-suited control action to design the required charging unit. A MOSFET circuit is used to control the pulse width modulation i.e., PWM of the charge pulses. By controlling the PWM of charge pulses, we are controlling the charging and discharging cycles of the battery. This is a current booster and rectifier circuit used to boost the power which in turn will speed up the charging operation and hence reduce the time. The MOSFET circuit is triggered by PID. The PID controller performance is dependent on the controller parameters i.e., setting Kp, Ki, and K_d. The ideal setting of parameters is however not possible, as there are certain drawbacks such as overshoot and increased response time of the system.

Accurately designing and controlling the charge voltage and current, certain advantages such as prolonged life span, reduced cost, increase in efficiency of battery charging, and most importantly reducing reduced time to charge the battery can be added up to the performance of Li-Ion batteries. Hence parameter tuning i.e., designing, monitoring, and controlling, using PID control and ANN is proposed in this research. A feed-forward neural net is preferred. The distribution of incoming charge pulses among the connected battery a pack is another important aspect to be considered. BMS is hence designed to decide how, where, and when the charge pulses are to be provided to the battery packs so that they help charge the battery at a faster rate. BMS uses digital as well as chemical batteries for its working.

A digital battery is used to communicate with the user whereas imprints of chemical batteries are taken for the charging and discharging process. Chemical battery resembles the battery packs used for charging and digital battery symbolizes the program developed to control the monitoring and distribution of charge pulses. In this research neural network is used to serve this purpose. The measurement of the inward and outward flowing of coulombs is related to the capacity of the battery where BMS is specifically programmed according to the fixed rated capacity. Corresponding increase or decrease in the coulomb count estimates the battery capacity. The filter used eliminates the high-frequency components thus contributing to reducing the THD value of the proposed design.

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 and 4 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 mainly used to boost the current and in turn the power of the charging unit. This factor plays a vital role in increasing the 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.

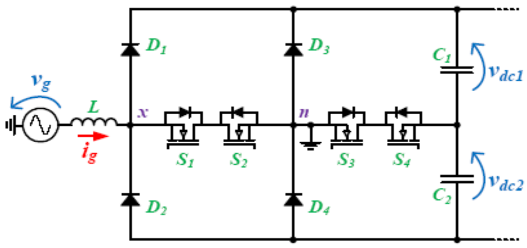

Figure 1. Five-level active rectifiers for EV battery chargers

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 operation are explained below as Figures 2(a) to (h).

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

(a) V_{ar}=0 V: Whenever the generated voltage changes from 0 V to+V_{dc}/2;
(b) V_{ar}=+ V_{dc}/2 V: Whenever the generated voltage changes from 0 V to+V_{dc}/2;
(c) V_{ar}=+V_{dc}/2 V: Whenever the generated voltage changes from+V_{dc}/2 to+V_{dc};
(d) V_{ar}=+V_{dc} V: Whenever the generated voltage changes from+V_{dc} /2 to = + V_{dc};
(e) V_{ar}=0 V: Whenever the generated voltage changes from 0 V to -Vdc/2;
(f) V_{ar}=- V_{dc}/2 V: Whenever the generated voltage changes from 0 V to - V_{dc}/2;
(g) V_{ar}=- V_{dc}/2 V: Whenever the generated voltage changes from -V_{dc}/2 to -V_{dc};
(h) 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 the designed charging process [25]-[27].

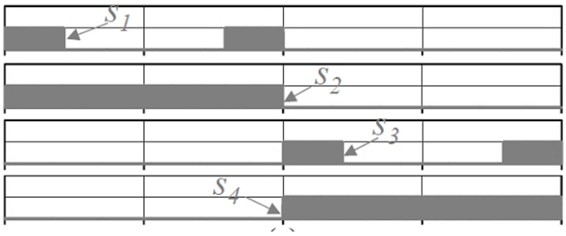

Figure 3. MOSFET switch pulse pattern

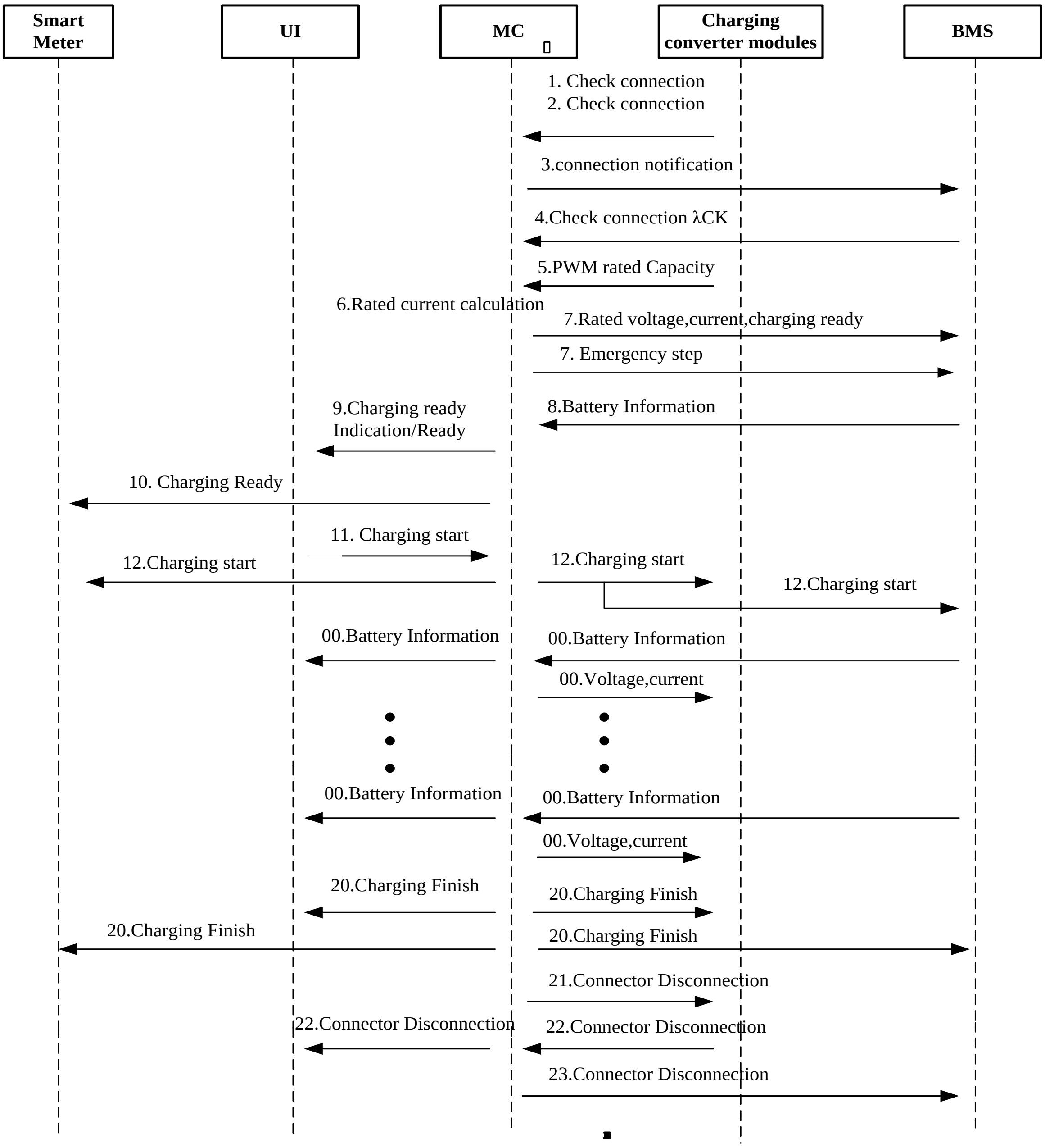

Figure 4. Charging process

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.

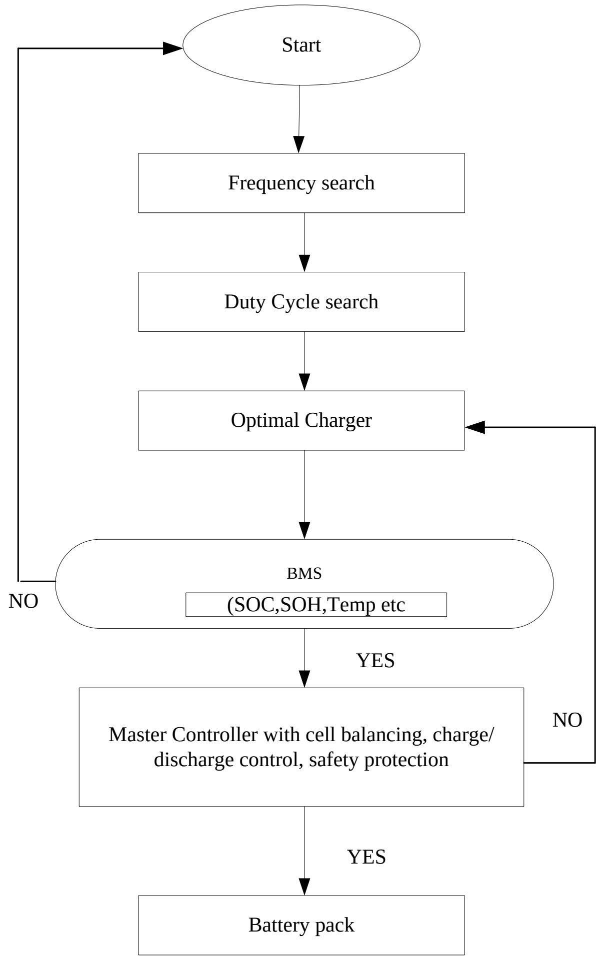

Figure 5. Flowchart

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).

$$C(s) = p\left[1 + I\left(\frac{1}{s}\right) + D\left(\frac{N_s}{s+N}\right)\right] \quad (1)$$

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.

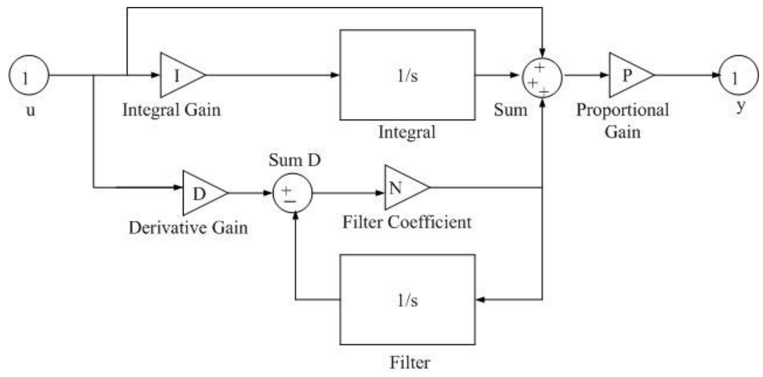

Figure 6. PID controller

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.

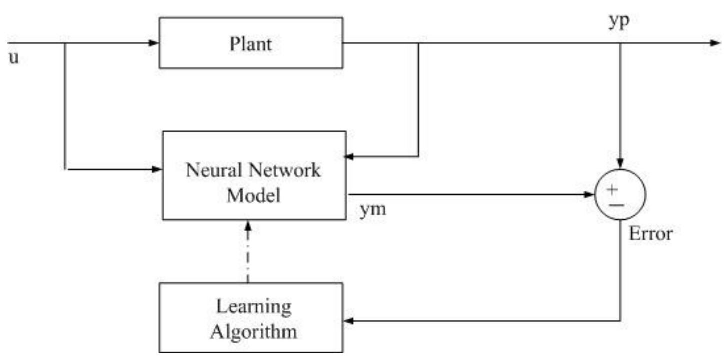

Figure 7. The training process for the network

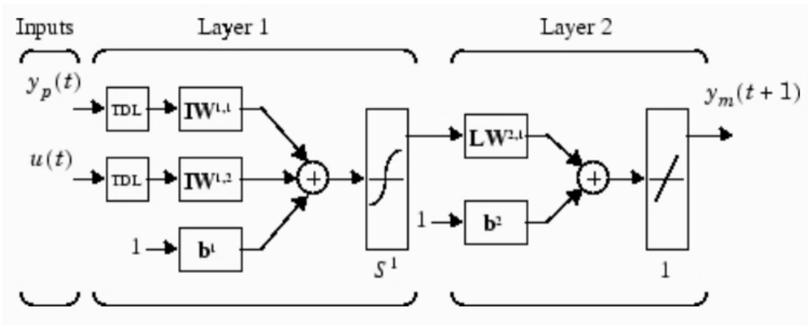

Figure 8. The internal structure of neural network model

The numerical optimization is given in (2),

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

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.

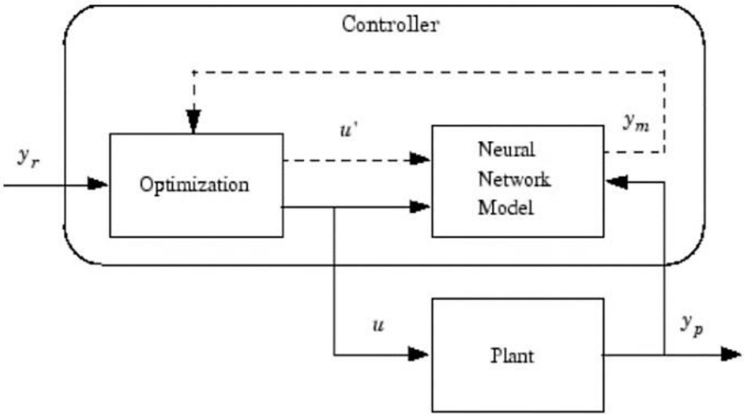

Figure 9. Control process in the network model

3. 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.

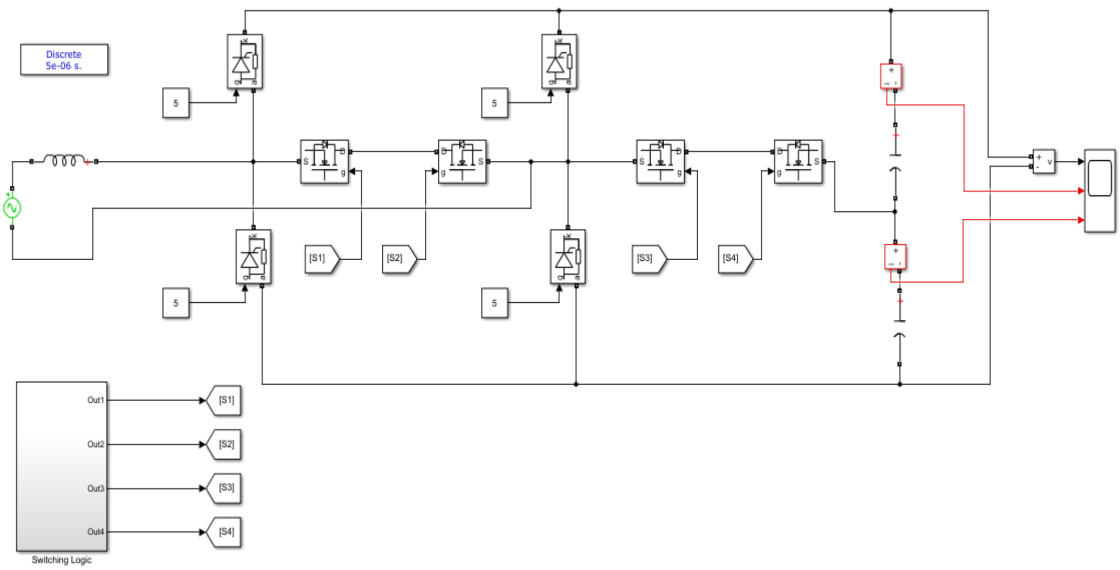

Figure 10. Simulation model of the proposed design

3.1. Power grid voltage (V_g) and current (i_g)

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 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 transition phase is sort of about 0.025 s, that's a way extra less which makes the gadget greater reliable and green.

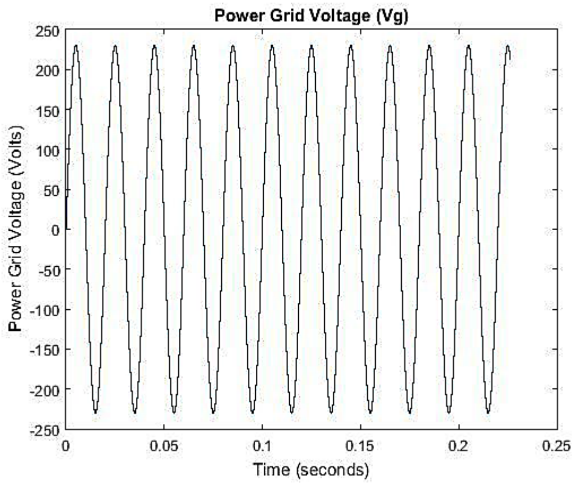

Figure 11. Power grid voltage waveform

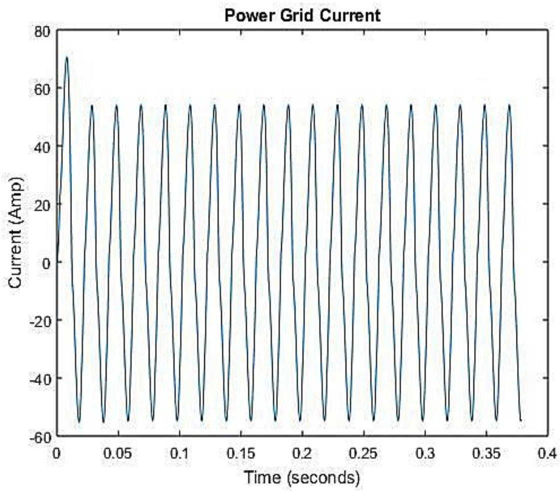

Figure 12. Power grid current waveform

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 system is 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.

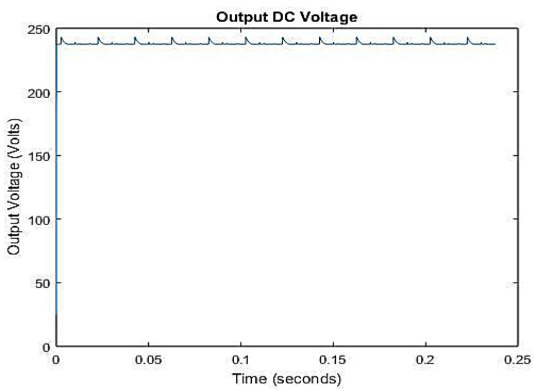

Figure 13. Output DC voltage

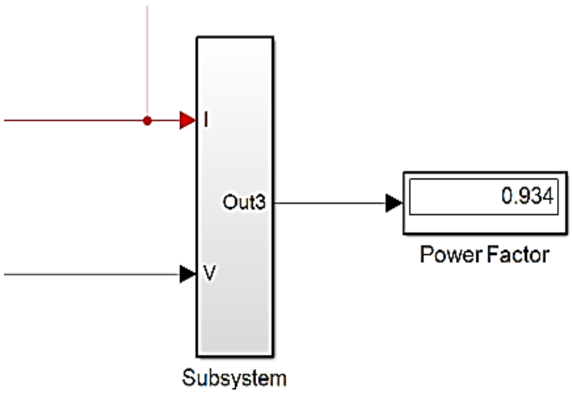

Figure 14. Power factor

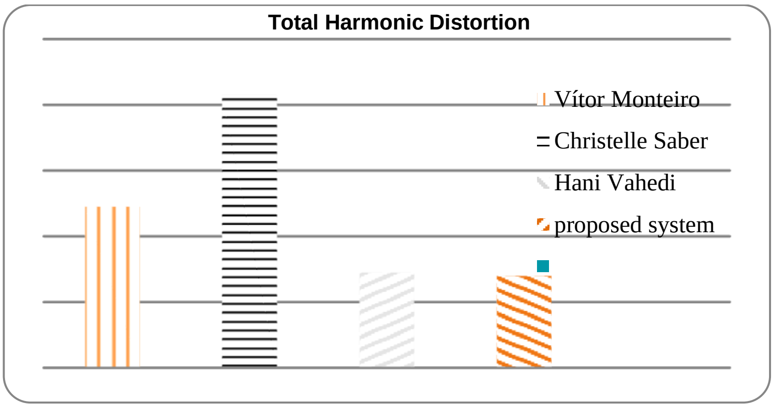

Figure 15. Obtained THD compared with existing technique authors THD

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.

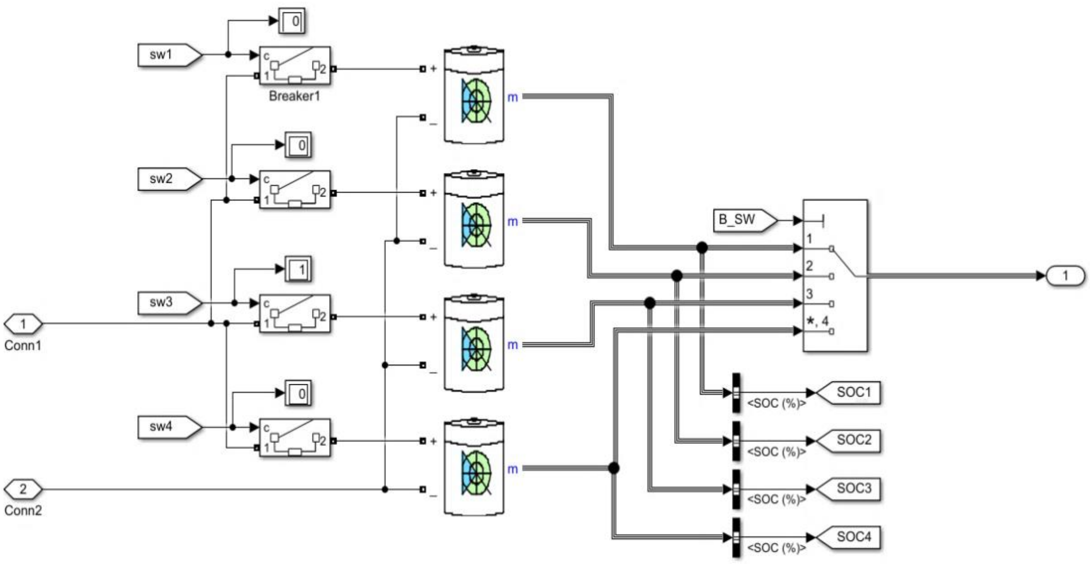

Figure 16. Simulation model

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.

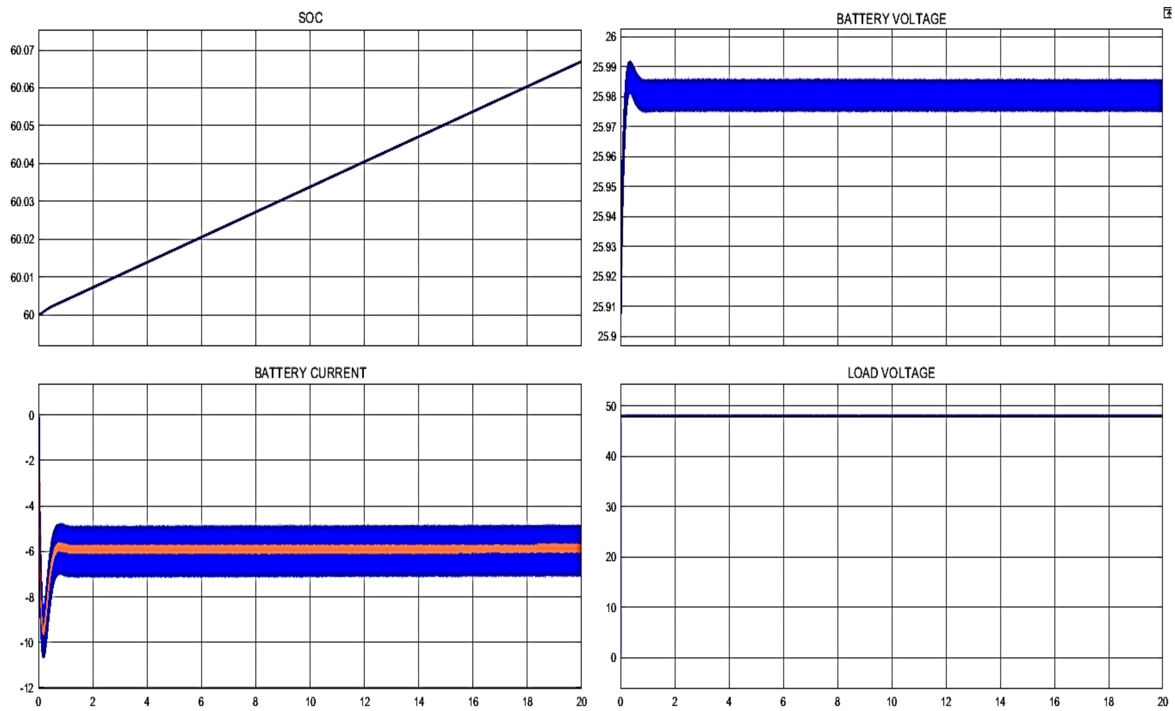

Figure 17. Simulation waveforms of various parameters

4. 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

5. 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.

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

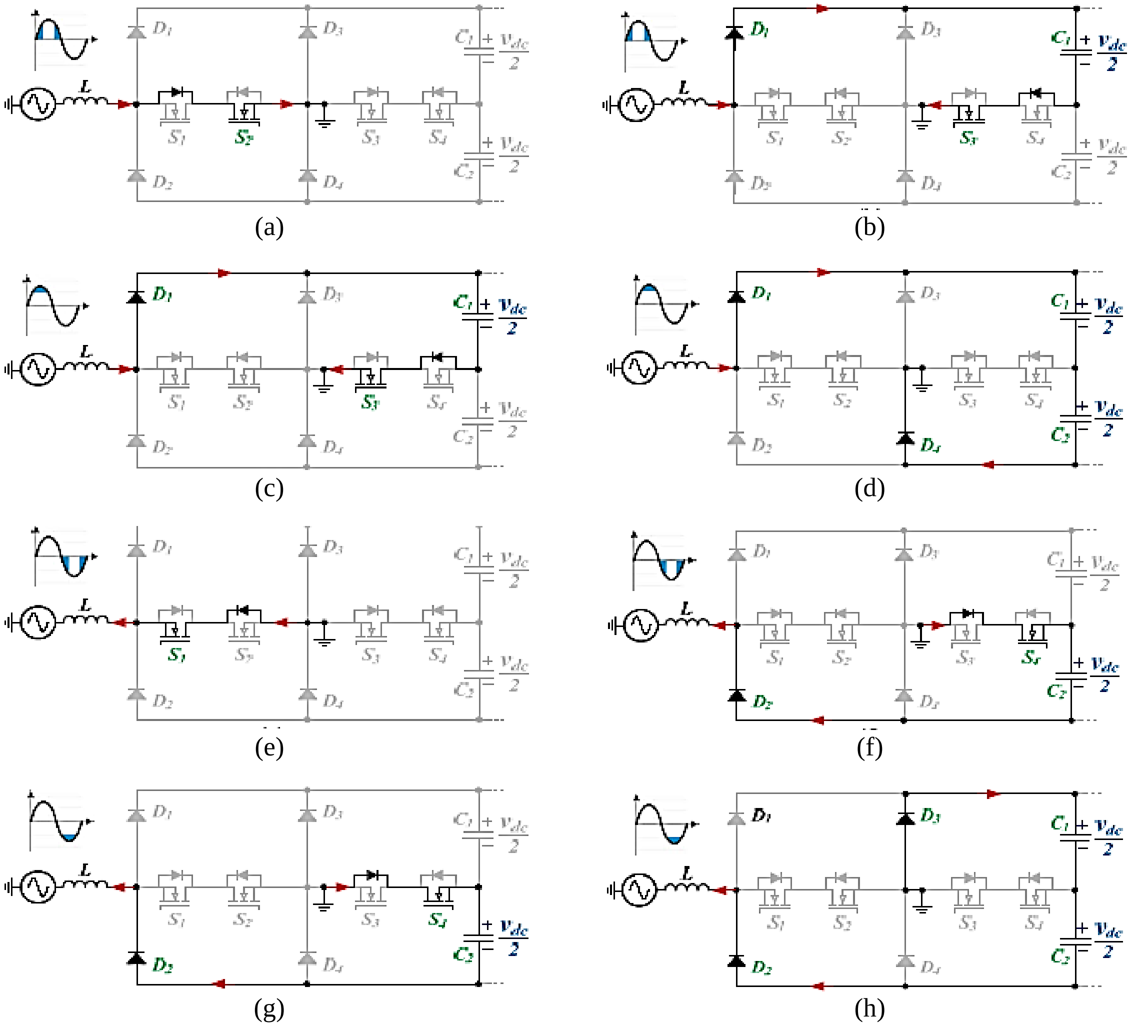

Figure 2. The step-by-step operation of the proposed five-level active rectifier (a) stage output 0 V to$V_{dc}/2$, (b) stage output 0 V to+$V_{dc}/2$, (c) stage output +$V_{dc}/2$ to+V_{dc}, (d) stage output +$V_{dc}/2$ to+V_{dc}, (e) stage output 0 V to -$V_{dc}/2$, (f) stage output 0 V to -$V_{dc}/2$,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

REFERENCES

[1] S. Abada, G. Marlair, A. Lecocq, M. Petit, V. S-Moynot, and F. Huet, "Safety focused modeling of lithium-ion batteries: A review," *Journal of Power Sources*, vol. 306, pp. 178–192, Feb. 2016, doi: 10.1016/j.jpowsour.2015.11.100.
[2] X. Gong, R. Xiong, and C. Mi, "A data-driven bias correction method based lithiumion battery modeling approach for electric vehicle applications," *IEEE Transactions on Industry Applications*, pp. 1–1, 2015, doi: 10.1109/tia.2015.2491889.
[3] C. Zhang, J. Jiang, Y. Gao, W. Zhang, Q. Liu, and X. Hu, "Charging optimization in lithium-ion batteries based on temperature rise and charge time," *Applied Energy*, vol. 194, pp. 569–577, May 2017, doi: 10.1016/j.apenergy.2016.10.059.
[4] H. E. Perez, X. Hu, S. Dey, and S. J. Moura, "Optimal Charging of Li-Ion Batteries With Coupled Electro-Thermal-Aging Dynamics," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 9, pp. 7761–7770, Sep. 2017, doi: 10.1109/tvt.2017.2676044.
[5] Y. Miao, P. Hynan, A. von Jouanne, and A. Yokochi, "Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements," *Energies*, vol. 12, no. 6, p. 1074, Mar. 2019, doi: 10.3390/en12061074.
[6] A. Tomaszewska *et al.*, "Lithium-ion battery fast charging: A review," *eTransportation*, vol. 1, p. 100011, Aug. 2019, doi: 10.1016/j.etran.2019.100011.

[7] G.-L. Zhu *et al.*, "Fast Charging Lithium Batteries: Recent Progress and Future Prospects," *Small*, vol. 15, no. 15, p. 1805389, Mar. 2019, doi: 10.1002/smll.201805389.

[8] V. Monteiro, J. G. Pinto, B. Exposto and J. L. Afonso, "Comprehensive comparison of a current-source and a voltage-source converter for three-phase EV fast battery chargers," *2015 9th International Conference on Compatibility and Power Electronics (CPE)*, Costa da Caparica, Portugal, 2015, pp. 173-178, doi: 10.1109/CPE.2015.7231068.

[9] W. Shen, T. T. Vo, and A. Kapoor, "Charging algorithms of lithium-ion batteries: An overview," in *2012 7th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, Jul. 2012, doi: 10.1109/iciea.2012.6360973.

[10] Y. Gao, X. Zhang, Q. Cheng, B. Guo, and J. Yang, "Classification and Review of the Charging Strategies for Commercial Lithium-Ion Batteries," *IEEE Access*, vol. 7, pp. 43511–43524, 2019, doi: 10.1109/access.2019.2906117.

[11] Y. He, Y. Tang, H. Xie, D. Ke, F. Wang and R. Kennel, "Power Quality Improvement for Grid-connected High-Speed Switched Reluctance Drive System," *2021 IEEE 12th Energy Conversion Congress & Exposition - Asia (ECCE-Asia), 2021*, pp. 2406-2409, doi: 10.1109/ECCE-Asia49820.2021.9479157.

[12] M. Thakre, J. Mane, and V. Hadke, "Performance Analysis of SRM Based on Asymmetrical Bridge Converter for Plug-in Hybrid Electric Vehicle," in *2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)*, Dec. 2020, doi: 10.1109/icpects49113.2020.9337059.

[13] C. Saber, D. Labrousse, B. Revol and A. Gascher, "Challenges Facing PFC of a Single-Phase On-Board Charger for Electric Vehicles Based on a Current Source Active Rectifier Input Stage," *in IEEE Transactions on Power Electronics*, vol. 31, no. 9, pp. 6192-6202, Sept. 2016, doi: 10.1109/TPEL.2015.2500958.

[14] R. G. Shriwastava, M. P. Thakare, K. V. Bhadane, M. S. Harne, and N. B. Wagh, "Performance enhancement of DCMLI fed DTC-PMSM drive in electric vehicle," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1867–1881, Aug. 2022, doi: 10.11591/eei.v11i4.3714.

[15] M. P. Thakre, J. A. Gangurde, R. Shriwastava, D. P. Kadam, S. S. Kadlag, and H. S. Sonawane, "Investigative uses of overmodulation techniques in modular multilevel cascaded converter," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3147–3156, Dec. 2022, doi: 10.11591/eei.v11i6.3958.

[16] S. P. Jena and K. C. Rout, "Comparative Analysis of Harmonic Reduction of VSI Fed Induction Motor Using SVPWM and Sinusoidal PWM," *2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI)*, 2018, pp. 1-5, doi: 10.1109/ICOEI.2018.8553727.

[17] R. He, D. Liu, R. Teodorescu, Q. Zhang, W. Hou and Z. Chen, "An Improved Submodule Capacitor Voltage Measuring Algorithm for MMC With Reduced Sensors," *in IEEE Sensors Journal*, vol. 21, no. 18, pp. 20475-20492, 15 Sept.15, 2021, doi: 10.1109/JSEN.2021.3095721.

[18] M. P. Thakre and N. Kumar, "Evaluation and Control Perceptive of VSM-Based Multilevel PV-STATCOM for Distributed Energy System," *MAPAN*, vol. 36, no. 3, pp. 561–578, Jun. 2021, doi: 10.1007/s12647-021-00481-x.

[19] C. Kumar, M. K. Mishra and S. Mekhilef, "A new voltage control strategy to improve performance of DSTATCOM in electric grid*," in CES Transactions on Electrical Machines and Systems,* vol. 4, no. 4, pp. 295-302, Dec. 2020, doi: 10.30941/CESTEMS.2020.00036.

[20] M. P. Thakre and N. P. Matale, "Alleviation of Voltage Sag-Swell by DVR Based on SVPWM Technique," in *2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)*, Dec. 2020, doi: 10.1109/icpects49113.2020.9336972.

[21] J. Yi, M. Zhu, X. Zhong, H. WanG and X. Cai, "An Improved Triple Interline DC Power Flow Controller for Bidirectional Power Control," *2020 IEEE REGION 10 CONFERENCE (TENCON)*, 2020, pp. 1301-1306, doi: 10.1109/TENCON50793.2020.9293704.

[22] S. Saravanan, P. U. Rani, and M. P. Thakre, "Evaluation and Improvement of a Transformerless High-Efficiency DC–DC Converter for Renewable Energy Applications Employing a Fuzzy Logic Controller," *MAPAN*, vol. 37, no. 2, pp. 291–310, Jan. 2022, doi: 10.1007/s12647-021-00530-5.

[23] C. Chen, F. Shang, M. Salameh, and M. Krishnamurthy, "Challenges and Advancements in Fast Charging Solutions for EVs: A Technological Review," in *2018 IEEE Transportation Electrification Conference and Expo*, Jun. 2018, doi: 10.1109/itec.2018.8450139.

[24] E. Ayoub and N. Karami, "Review on the charging techniques of a Li-Ion battery," in *2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE)*, Apr. 2015, doi: 10.1109/taeece.2015.7113599.

[25] N. Matanov, A. Zahov and I. Angelov, "Modeling of the Electric Vehicle Charging Process - Part 1," *2021 13th Electrical Engineering Faculty Conference (BulEF), 2021*, pp. 1-4, doi: 10.1109/BulEF53491.2021.9690836.

[26] K. S. Somnath and M. K. Gupta, "Charging Power Station for Electric Vehicles," *International Journal for Research in Engineering Application and Management (IJREAM)*, pp. 111–114, 2019, doi: 10.18231/2454-9150.2019.0555.

[27] K. S. Somnath and M. K. Gupta, "Implementation on Single Phase Electric Vehicle Battery Chargers," *International Journal of Engineering and Advanced Technology*, vol. 9, no. 1, pp. 5186–5189, Oct. 2019, doi: 10.35940/ijeat.a1866.109119.

BIOGRAPHIES OF AUTHORS

Dr. Sunil Somnath Kadlag received B.E in Electrical Engineering from Dr. Babasaheb. Ambedkar. Marathawada University, Aurangabad (Dr B.A.M.U) in 1997 and M.E in Electrical Engineering (Control System) from Government College of Engineering Pune (Pune University) in 2005 and Ph.D in Electrical Engineering from Suresh Gyan Vihar University Jaipur (Rajasthan) in 2021. His research area is Electric vehicles. He is presently working as an Associate Professor & Head, of the Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, Savitribai Phule Pune University, Pune, Maharashtra, India. He can be contacted at email: sunilkadlag5675@gmail.com.

Dr. Pawan Tapre received the B.E. and M.E. degrees in Electrical Power System Engineering from Sant Gadge Baba Amravati University (SGBAU), Maharashtra, India, in 1995 and 2002 respectively, and a Ph.D. degree in Electrical Engineering from Dr. C.V. Raman University (Dr. CVRU), Bilaspur, Chhattisgarh, India in 2022. Currently, he is an Assistant Professor at the Department of Electrical Engineering, S.N.D. College of Engineering and Research Center, Yeola (Nashik), Maharashtra, India. His research interests include deregulated power systems, FACTS, power systems, and power system protection. He can be contacted at email: pawan.tapre73@gmail.com.

Dr. Rahul Mapari received a bachelor's degree and master's degree in electronics engineering from Savitribai Phule Pune University, India, in 2004 and 2007 respectively, and a Ph.D. degree in electronics and telecommunication engineering from Amravati University, India in 2016. He has total of 17 years of experience in various reputed technical institutes. He is working as a Professor in the Department of Electronics and Telecommunication Engineering of Pimpri Chinchwad College of Engineering and Research, Pune since 2017. His research interests include power converters and power electronics. He can be contacted at email: rahul.mapari@pccoer.in.

Dr. Mohan P. Thakre received the B.Tech. and M. Tech degrees in electrical power engineering from Dr. Babasaheb Ambedkar Technological University (Dr. BATU), Maharashtra, India, in 2009 and 2011 respectively, and the Ph.D. degree in electrical engineering from Visvesvaraya National Institute of Technology, (VNIT), Nagpur, Maharashtra, India in 2017. Currently, he is an Associate Professor at the Department of Electrical Engineering, SVERIs College of Engineering, Pandharpur, M.S., India. His research interests include FACTS and power system protection. He can be contacted at email: mohanthakre@gmail.com.

Dr. Deepak Prakash Kadam received a B.E from the Government College of Engineering, Amaravati, and M.E degrees in electrical power systems from Walchand College of Engineering, Sangli, Maharashtra, India, in 1997 and 2005 respectively, and the Ph.D. degree in electrical engineering from Savitribai Phule Pune University, Pune Maharashtra, India in 2015. Currently, he is an Associate Professor at the Department of Electrical Engineering, Bhujbal Knowledge City, MET Institute of Engineering, Nashik, India. His research interests include renewable energy technology, power quality, and power system. His total teaching experience is around 23 years. He can be contacted at email: dpkadam@gmail.com.

Dr. Dipak J. Dahigaonkar received a Ph.D. in Electronics Engineering from SGB Amravati University. He is having 26 years of teaching and 4 years of industry experience. He has published many research papers in National and International Journals of repute. He has 4 patents, 1 book and 3 copyrights to his credit. He is member of professional organizations like ISTE and IE(I). His areas of interest include electronic circuits, VLSI design, smart sensing devices and computer networks. Currently, he is also serving as Chairperson of Interdisciplinary Board of studies, RCOEM and In-charge of RCOEM Media Center. He can be contacted at email: dahigaonkardj@rknec.edu.