A novel pulse charger with intelligent battery management system for fast charging of electric vehicle

Sunil Somnath Kadlag[1], Mohan P. Thakre[2], Rahul Mapari[3], Rakesh Shriwastava[4], Pawan C. Tapre[5], Deepak P. Kadam[6]

[1]Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, India
[2]Department of Electrical Engineering, K.K. Wagh Institute of Engineering Education and Research, Nashik, India
[3]Department of electronics and telecommunication Engineering, Pimpri Chinchwad College of Engineering and Research, Pune, India
[4]Department of Electrical Engineering, Matoshri College of Engineering and Research Centre, Nashik, India
[5]Department of Electrical Engineering, S.N.D. College of Engineering and Research Center, Yeola, India
[6]Department of Electrical Engineering, MET's Institute of Engineering, BKC, Nashik, India

Article Info

Article history:

Received Sep 26, 2022
Revised Nov 16, 2022
Accepted Jan 3, 2023

Keywords:

Arduino Uno
Artificial neural network
Battery management system
Electric vehicle
PID control action
Pulse charging technique

ABSTRACT

Electric vehicles contribute a major role in building an eco-friendly environment. Li-ion batteries are most widely used in electric vehicles. It is very important to maintain the operation of Li-ion batteries within their "safety operation area (SOA)". Hence implementing a battery management system (BMS) becomes a necessity while using Li-ion batteries. This paper proposes an intelligent BMS for electric vehicles using proportional integral derivative (PID) control action along with artificial neural network (ANN). It prefers the improved pulse charging technique. The design consists of a battery pack containing four 12 V Li-ion batteries, MOSFETs, Arduino Uno, a transformer, a temperature sensor, a liquid-crystal displays (LCD), a cooling fan, and four relay circuit are used. Arduino Uno is used as a master controller for controlling the whole operation. Using this design approximately 38 minutes are required to fully charge the battery. Implementation results validate the system performance and efficiency of the design.

Corresponding Author:

Sunil Somnath Kadlag
Department of Electrical Engineering, Amrutvahini College of Engineering
Sangamner, Maharashtra 422608, India
Email: sunilkadlag5675@gmail.com

1. INTRODUCTION

Industries face numerous challenges in introducing electrified approaches to their ranges, and engine configurations, as well as inverters' acquiescence by customers of electric vehicles (EVs) and electric vehicle batteries that are not hybridized with ICEs. The investigators discuss different electrical drives, such as switched reluctance motor (SRM) [1]-[4], brushless DC motor (BLDC), permanent magnet synchronous motors (PMSM), and induction motor drives, in addition to their constraints, and presented configurations for EV applications in [5], [6]. High-efficiency DC-DC converter for renewable energy applications employing a fuzzy logic controller has been presented in [7]. Contrasts the experimental applications of over-modulation schemes in modular multilevel cascaded converters for harmonic elimination for 3-phase two-level voltage source inverters are discussed [8], [9]. For voltage balancing, [10] presented a modular multilevel converter with a simplified nearest-level control (NLC) strategy. Characterizes the implementation and monitoring conceptions of a value stream mapping (VSM-based) multilevel PV-STATCOM for harmonic elimination in a distributed energy system [11]. The uses of include flexible AC transmission systems (FACTS) controllers and custom devices as well as EV applications demonstrate a wide range of power quality improvement methodologies [12]-[14].

EVs contribute to the efficient use of energy and zero-emission of gases that causes global warming. major components of an EV are the electric motor along with the motor controller, battery, battery management system (BMS), wiring system, plug-in charger, regenerative braking system, and lastly the frame and vehicle body [15], [16]. The plug-in charger should be capable of operating separately for the vehicle. The battery of an EV comprises battery cells on a large scale. For efficient charging and monitoring of these battery cells a well-designed BMS is a necessity especially while using Li-ion batteries [17], [18]. The design of BMS is the most crucial part of the EV system as protecting the battery from overcharging/over-discharging is the main target as it may further lead to major damage to the battery along with temperature rise. This can also reduce the battery lifespan [19], [20]. On average 30-100 KWH is the general battery capacity range used in EVs [21]. The main function of BMS is maintaining the safety and reliability of the battery. Constant monitoring and evaluation of battery state. Control and monitor the state of charge (SoC). Cell balancing and control of operating temperature, ensure fast charging. This paper focuses on the hardware implementation of intelligent BMS for the fast charging of EVs. It consists of a pulse charging circuit where a neural network is used to optimize proportional integral derivative (PID) parameters. The whole system is operated using an Arduino Uno controller. Liquid-crystal displays (LCD) are used to display the corresponding results. Validation of the proposed design is tested for charging and discharging modes. Major contributions from this research are ensuring a fast and optimized charging process with approx. 38 mins requirement to fully charge the battery. To continuously control and monitor on charging/discharging process maintaining 100% SoC. To minimize the conversion losses and ensure minimum risk of battery damage and also to an extended battery of life.

This paper is divided into five sections. Section 1 describes the introduction of paper and details literature review with problem identification. Section 2 illustrates the proposed system architecture with a block diagram in which AC-DC and DC-DC converters, the control system using PID control action with the help of the neural network, and MOSFET circuitry controls of pulse-width modulation (PWM-based) charge pulses are explained in detail. In section 3, the experimental setup is described in detail with all hardware used in the proposed system. Section 4 gives information related to hardware implementation results in terms of battery SoC, and the temperature in charging and discharging mode, and also gives information related to SoC variation with time and temperature variation with time. Section 4 also gives comparison results for software implementation of the hardware-designed system. Section 5 finally gives the conclusion of the proposed system design.

2. PROPOSED SYSTEM ARCHITECTURE

Figure 1 illustrates the structure of the battery charging unit for electric vehicles. The electric grid, AC-DC converter, DC-DC converter, master control, control system, and batteries are the main components of the charging unit. The electric grid is the source of energy generation. This can be either conventional sources or renewable energy sources such as solar energy. The incoming energy which is AC nature due to the generation sources needs to be converted into DC as batteries operate on DC voltage, hence the use of AC-DC and DC-DC converters. AC-DC and DC-DC converters along with the designed digital control system together constitute the pulse charger. The pulse charger monitors and controls the frequency of charge pulses sent to the batteries. Master control is the controller used as an interface between the electronic components and the user.

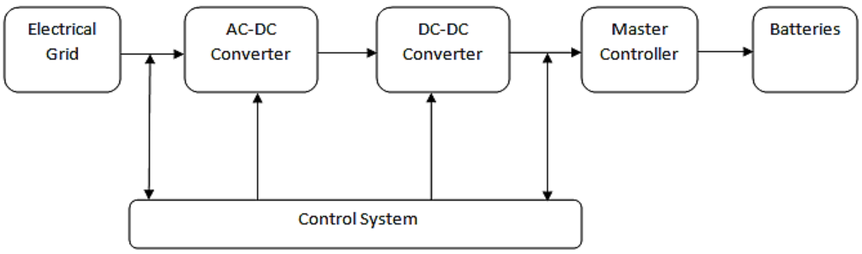

Figure 1. Structure for EV battery charging

It communicates with the user interface as well as the designed BMS installed in the electric vehicle and also acts as the connector which is used for safe and efficient charging. The most preferred type of battery today for electric vehicles is the lithium-ion battery due to its various advantages over lead-acid batteries [22]. The control system monitors and controls all the energy conversions up to master control. Master control along with the control system together monitors the charging activity of batteries making it more efficient and faster with minimum losses. Figure 2 represents the system architecture of the BMS [23].

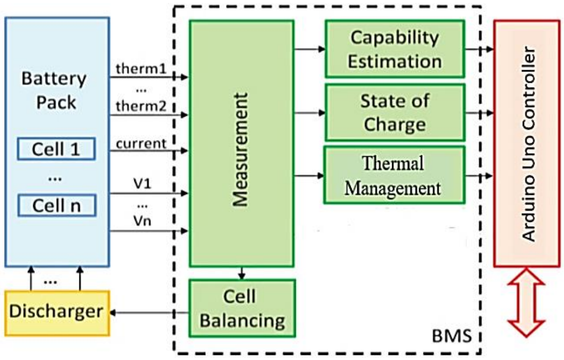

Figure 2. System architecture of BMS

Figure 3 represents the block diagram of the proposed design. To enhance the system performance, mainly two circuits are monitored and controlled those are the charger power circuit and the charger control circuit. As stated above, the pulse charging technique is preferred in this design. MOSFET circuit is used to trigger the pulse charging unit when connected to the batteries either for the charging or discharging process. The proposed BMS along with charger power and control circuits increases the efficiency and performance of the battery as well as its life span. The design also consists of four driver circuits, which are the relay circuits that are used to drive the four batteries utilized for experimentation.

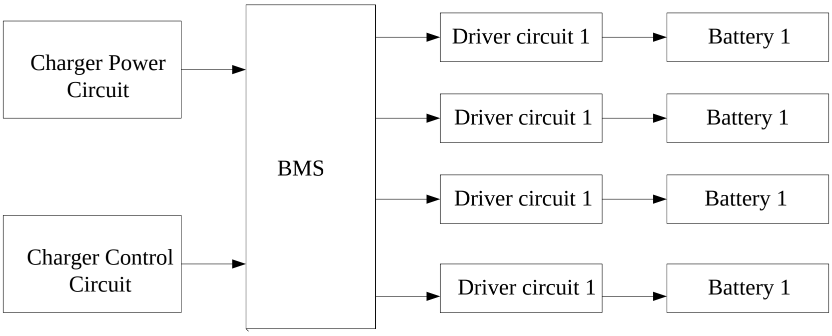

Figure 3. Block diagram of proposed design architecture

To well optimize the charging process and time, PID control action is used. The parameters of PID control action are decided with the help of neural networks and feed forward artificial neural network (ANN) is also implemented. PID triggers the MOSFET. MOSFET circuitry controls the PWM of charge pulses. Controlling the PWM means controlling the charge/discharge cycles of the battery. Distribution of incoming charging pulses to the required batteries of a battery pack is another important aspect to be considered. A BMS is hence implemented (i.e. programmed in Arduino Uno controller) to monitor this aspect.

3. Functions provided by the designed battery management system

The primary function of a battery management system is to protect from excessive heat or cold, voltages that are too high or too low, and shorts that can occur in the system. The BMS offers protection to the cells by shutting down the battery if any of these events occur. Following are the fuctions provided by design BMS:

a. Charging control: inappropriate charging can damage the battery. Hence it is of utmost importance to monitor the charging process to prevent damage as well as optimize the charging process to make it fast and accurate.

b. Discharging control: fluctuations in load can damage the battery [23]-[25]. This makes it essential for BMS to monitor the discharging process and auto-cut the load under the occurrence of uncertain situations if any.
c. Determine SoC: SoC is an important parameter stating the battery condition, making it a key role for BMS to continuously track the SoC.
d. Determining state of health (SoH): SoH gives an idea of battery health, hence monitoring SoH can inform us appropriate time for battery replacement. This will make the system well efficient improving the battery capacity and helping eliminate adverse effects in case of any battery failure.
e. Cell balancing: giving weaker cells priority for charging to equalize charge on all cells will help compensate the weaker cells and keep a perfect balance among them. While using chains of multi-cell batteries, minor differences between cells most commonly due to operating conditions or production tolerances, magnify according to each charge/discharge cycle [25], [26]. Also, weaker cells tend to be overstressed while charging causing battery failure. BMS helps incorporate cell balancing techniques to compensate for the differences.

4. EXPERIMENTAL SETUP

Figure 4 illustrates the experimental setup of the proposed design. The setup consists of four batteries, two four-relay circuits, a controller circuit, a fuse, a MOSFET circuit, a pulse charging unit, a 16×4 LCD, and a cooling fan. As a prototype, a battery pack of four Li-ion batteries each of 12 V rating is considered. The two four-relay circuits are used to drive these four batteries to avoid overvoltage/overcurrent situations. It also consists of a cooling fan which is switched ON/OFF automatically in case the temperature of any of the batteries rises above a certain limit to avoid overheating hazards. The proposed design is based on improvements in pulse charging. Hence the setup also consists of a pulse charger unit to charge the batteries. MOSFET circuit is used as a switching circuit that is triggered by PID control action. A fuse is also used as a protection device. 16×4 LCDs the results of monitored battery parameters such as SoC, Temperature, state of a cooling fan, and battery number which is monitored/charged/discharged. This working of the entire system is controlled and operated using an Arduino Uno controller.

Figure 5 illustrates a detailed view of the used circuitry. We can observe the 16×4 LCD unit, and the four driver circuits i.e., the relay circuits named B1, B2, B3, and B4. B1 represents the driver circuit to drive the first battery, B2 drives the second battery, B3 drives the third battery, and B4 drives the fourth battery. A temperature sensor is used to sense the overall system temperature. In case, of excessive heating or temperature rise, the control system will switch on the cooling fan automatically. Arduino Uno controller monitors and controls the whole system operation, which is interfaced with the whole project using its development board. Table 1 shows the hardware parameter details and its specifications.

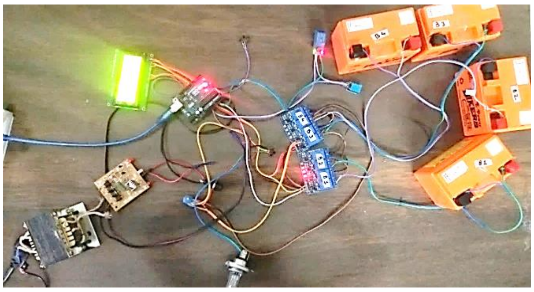

Figure 4. Experimental setup of the proposed design

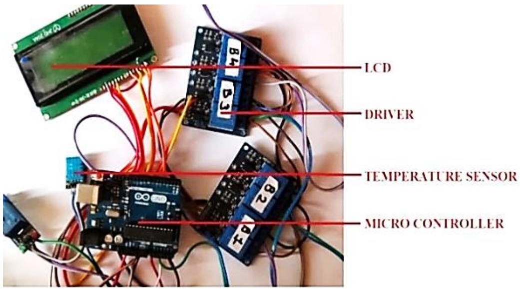

Figure 5. Experimental setup (detailed view of used circuitry)

Table 1. Hardware parameter details

Sr. No	Hardware	Specification
1	Battery Lithium ion	12V, 7 Ah, PVC, 4LB
2	Fuse	10 Amp,
3	Arduino Uno	AVR microcontroller, Atmega328, 14 I/O ports
4	Transformer	Input 0-230 V, Output 0-12 V
5	Temperature sensor (DHT11)	3 to 5 V powerand I/O, 3 pins, Dimensions:15.5 mm×12 mm×5.5 mm
6	LCD	16×4 LCD
7	Cooling Fan	12 V DC, 0.9 Amp
8	Four relay circuit	Sugar can relay

3.1. Case 1: all batteries fully charged

Figure 6 depicts the LCD for parameters. When, all the battery is showing fully charged. SoC is displayed 100%, all batteries are monitored, and the temperature is 27 degrees. As the temperature is near room temp, and the cooling fan is off.

Figure 6. Parameters displayed for case 1

3.2. Case 2: charging mode

Consider the scenario where the SoC of the third battery is lower. Hence this battery requires charging. As the batteries are controlled via relay circuits, to access the third battery we need to turn ON the third relay. Figure 7 shows the LED on the relay circuit is glow red, indicating the ON state of relay 3 (B_3) hence connecting the third battery with the charging unit. Initially, SoC of battery 3 is 75.05% at 27 degrees which is shown in Figure 8. After certain seconds the SoC is increased from 75.05 to 76.75 as shown in Figure 9, to 78.75 as shown in Figure 10 Further increased to 79.75 as shown in Figure 11, and 81.25 as shown in Figure 12 keeping all other parameters constant and it is gradually increasing.

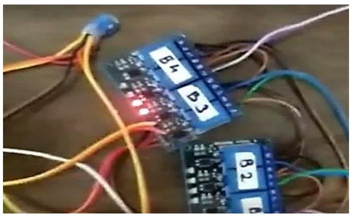

Figure 7. Relay B3 ON

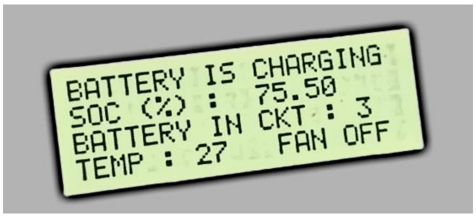

Figure 8. SoC=75.05 for third battery

Figure 9. SoC=76.75

Figure 10. SoC=78.75

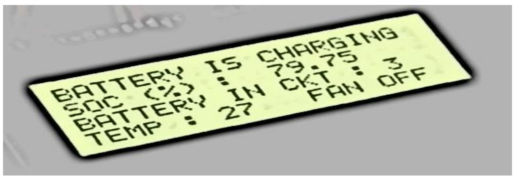

Figure 11. SoC=79.75

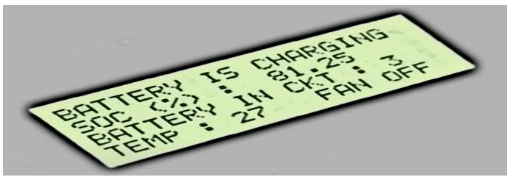

Figure 12. SoC=81.25

3.3. Case 3: discharging mode

Switching towards the discharging mode, batteries will start supplying the current to loads. Figure 13 shows SoC of the batteries is 97.50, which states that all batteries are almost fully charged and ready to drive the load. Figure 14 shows SoC reduced to 95.75 which states that batteries are successfully driving the load.

Figure 13. SoC=97.50 for all batteries connected

Figure 14. SoC reduced to 95.75

Table 2 illustrates the results of various test case scenarios performed on the setup. Approximately 38 mins are required to fully charge the battery. SoC percentage while charging process for all four batteries with time gradually increasing from 0 to 38 mins at a regular interval of 2 mins is shown in the table. The temperature rises to 43° starting from 24°, this is within tolerance limits for the elements.

Table 2. Hardware results

Time in sec.	Battery 1 (SOC %)	Battery 2 (SoC %)	Battery 3 (SoC %)	Battery 4 (SoC %)	Temp.
0	24	34	49	52	24
2	37	34	49	52	24
4	48	34	49	52	25
6	67	34	49	52	26
8	79	34	49	52	26
10	90	36	49	52	27
12	90	48	49	52	27
14	90	63	49	52	27
16	90	84	49	52	28
18	90	90	53	52	29
20	90	90	68	52	30
22	90	90	81	52	32
24	90	90	90	57	33
26	90	90	90	72	34
28	90	90	90	86	35
30	92	91	92	91	37
32	96	93	94	93	39
34	97	95	95	96	41
36	98	97	98	98	42
38	100	100	100	100	43

Figure 15 depicts the graph of SoC percentage plotted against time ranging from 0-38 mins. The SoC of four batteries is highlighted with four different colors. Also, Figure 16 depicts the graphical representation of the rise in temperature during the whole charging process plotted against time.

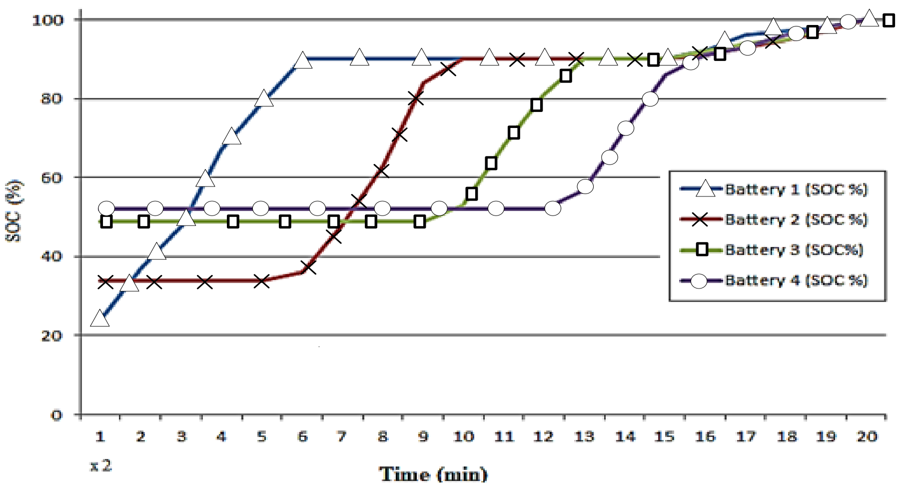

Figure 15. Battery-wise SoC

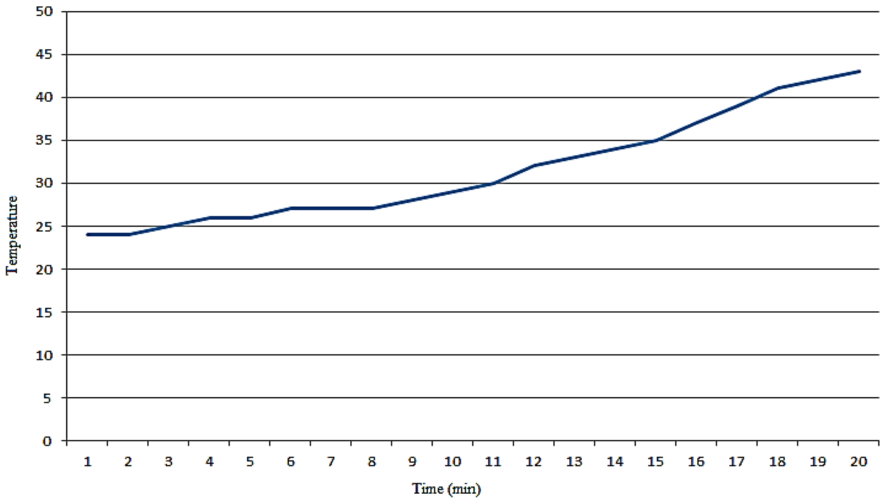

Figure 16. Temperature vs time

Table 3 gives the comparison between the software and hardware implementation of the proposed design. It requires about 38 minutes to fully charging the batteries. The minimum tolerable temperature rises of 19° is observed. Certain fluctuations of the tolerable range are observed for all performance parameters in hardware implementation as compared to the software one due to the practical use of electrical components.

Table 3. Comparison between software and hardware implementation

Sr. No.	Performance parameter	Software implementation	Hardware implementation
1	Voltage	11.95 V	12.30 V
2	Charge efficiency	90%	92%
3	Charge time	35 min	38 min
4	SOH	91%	93%
5	SOC	93%	99%
6	Temperature rise	20°	19°
7	Charge current settlement time	18 ms	20 ms
8	Life span	35% more	38% more

5. CONCLUSION

Electric vehicles are solely dependent on batteries as the power source. Hence BMS plays a vital role in EVs. The major sectors to be included in BMS are parameter monitoring units, protection systems for various inbuilt units, a system that can keep track and maintain the battery ever-ready to deliver maximum power to the load, and also systems that can help extend the battery lifespan. It should also include circuits to maintain the thermal side and charging time optimization. Various types of BMSs designed today tend to focus only on avoiding battery failure by monitoring voltage, current and internal temperature parameters along with charging/discharging ambient temperature. The proposed design ensures fast charging with minimum losses that too within 38 minutes. Implementation results validate the system performance while charging as well as discharging mode. Three test cases i.e., initial full charged, charging mode, and discharging mode is discussed in this paper. The system architecture includes fewer electronic components and circuits, reducing the overall system cost.

REFERENCES

[1] C. Gan, Q. Sun, J. Wu, W. Kong, C. Shi and Y. Hu, "MMC-Based SRM Drives With Decentralized Battery Energy Storage System for Hybrid Electric Vehicles," *in IEEE Transactions on Power Electronics*, vol. 34, no. 3, pp. 2608-2621, March 2019, doi: 10.1109/TPEL.2018.2846622.

[2] M. A. E. Bolaños, M. Díaz, F. Donoso, A. Letelier, and R. Cárdenas, "Control and operation of the MMC-based drive with reduced capacitor voltage fluctuations," *The Journal of Engineering*, vol. 2019, no. 17, pp. 3618–3623, Apr. 2019, doi: 10.1049/joe.2018.8080.

[3] M. P. 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.

[4] V. Shah and S. Payami, "A Novel 4-level Converter with Inherent Voltage Boosting for 4-Phase SRM," *2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 2020, pp. 1-6, doi: 10.1109/PEDES49360.2020.9379535.

[5] A. Poovathody and R. Ramchand, "Twelve Sector Based Direct Power Control of Induction Motor Drives," *2020 International Conference on Power Electronics and Renewable Energy Applications (PEREA)*, 2020, pp. 1-5, doi: 10.1109/PEREA51218.2020.9339794.

[6] A. Shukla, A. Ghosh and A. Joshi, "Flying-Capacitor-Based Chopper Circuit for DC Capacitor Voltage Balancing in Diode-Clamped Multilevel Inverter," *in IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2249-2261, July 2010, doi: 10.1109/TIE.2009.2029527.

[7] 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.

[8] N. Nagao, J. Liu, Y. Miura, T. Ise and N. Morishima, "Resonance suppression control for flying capacitor type bidirectional three-level chopper circuit," *2019 IEEE Third International Conference on DC Microgrids (ICDCM)*, 2019, pp. 1-8, doi: 10.1109/ICDCM45535.2019.9232918.

[9] Z. Liu, K. -J. Li, Z. Guo, J. Wang and J. Qian, "A Comprehensive Study on the Modulation Ratio for Modular Multilevel Converters," *in IEEE Transactions on Industry Applications*, vol. 58, no. 3, pp. 3205-3216, May-June 2022, doi: 10.1109/TIA.2022.3155472.

[10] R. chan, K. -H. Kim, J. -Y. Park and S. -s. Kwak, "Simplified Model Predictive Control with preselection Technique for Reduction of Calculation Burden in 3-Level 4-Leg NPC Inverter," *2020 IEEE Applied Power Electronics Conference and Exposition (APEC), 2020*, pp. 2291-2296, doi: 10.1109/APEC39645.2020.9124186.

[11] 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.

[12] J.-S. Lai and F. Z. Peng, “Multilevel converters-a new breed of power converters,” *IEEE Transactions on Industry Applications*, vol. 32, no. 3, pp. 509–517, 1996, doi: 10.1109/28.502161.

[13] Z. Elkady, N. Abdel-Rahim, A. Mansour and F. Bendary, "Voltage Sag/Swell Detection Based on Decoupled Stationary Reference Frame PLL in DVR," *2021 22nd International Middle East Power Systems Conference (MEPCON)*, 2021, pp. 678-682, doi: 10.1109/MEPCON50283.2021.9686301.

[14] L. Chen et al., "Performance Evaluation Approach of Superconducting Fault Current Limiter in MMC-HVDC Transmission System," *in IEEE Transactions on Applied Superconductivity*, vol. 31, no. 8, pp. 1-7, Nov. 2021, Art no. 5602507, doi: 10.1109/TASC.2021.3091045.

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] M. P. Thakre, Y. V. Mahadik, D. S. Yeole, and P. K. Chowdhary, “Fast Charging Systems for the Rapid Growth of Advanced Electric Vehicles (EVs),” in *2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)*, Dec. 2020, doi: 10.1109/icpects49113.2020.9336979.

[20] Y. Liu, Y. Zhu, and Y. Cui, “Challenges and opportunities towards fast-charging battery materials,” *Nature Energy*, vol. 4, no. 7, pp. 540–550, Jun. 2019, doi: 10.1038/s41560-019-0405-3.

[21] 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.

[22] 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.

[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 (ITEC)*, Jun. 2018, doi: 10.1109/itec.2018.8450139.

[24] S. S. Kadlag, “A Single-Phase Electric Vehicle Battery Charger,” *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 4, pp. 4984–4988, Aug. 2020, doi: 10.30534/ijatcse/2020/114942020.

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

[26] 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 did B.E in Electrical Engineering from Dr. Babasaheb Ambedkar, Marathawada University, Aurangabad (Dr. B.A.M.U) in 1997 and an M.E in Electrical Engineering (control system) from Government College of Engineering Pune (Pune University) in 2005. He had done a 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 and 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. 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 Assistant Professor at the Department of Electrical Engineering, K. K. Wagh Institute of Engineering Education and Research, Nashik, India. His research interests include flexible AC transmission systems (FACTS) and power system protection. He can be contacted at email: mohanthakre@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 a 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. Rakesh Shriwastava obtained a Ph.D. degree in electrical engineering specializing in power electronics and drives from RTM Nagpur University, (India) in 2017. He occupied various positions serving the engineering institutes for about 24 years. He is currently working as a Professor in the Department of Electrical Engineering, Matoshri College of Engineering and Research Center, Nashik. His research interests include the analysis and control of electrical drives, particularly in hybrid and electric vehicle applications. He has several publications in national and international journals. He attended International and National conferences and also worked as a jury member. He is a member of professional bodies such as ISTE and IAENG. He can be contacted at email: rakesh_shriwastava@rediffmail.com.

Dr. Pawan C. 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, flexible ac transmission systems (facts), power systems, and power system protection. He can be contacted at email: pawan.tapre73@gmail.com

Dr. Deepak P. 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.