Lecture Notes in Electrical Engineering 1148

Afzal Sikander
Marta Zurek-Mortka
Chandan Kumar Chanda
Pranab Kumar Mondal *Editors*

Advances in Energy and Control Systems

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Editors

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Preface

This book features high quality of research papers presented at the 5th International Conference on Energy Systems, Drives and Automations (ESDA2022). The book is organized in three subthemes as energy and drives, electronics and control, and computer and soft computing which includes research work of academicians and industrial experts in the field of electrical and electronics engineering, energy, mechanical, control, automations, IoT, and computers engineering. This proceedings includes full-length papers, research in progress papers, and case studies related to all the areas of above-mentioned topics. The book offers valuable assets for young researchers. In this book, 46 papers are included, and most of the papers are the outcome of study and research works of professors, Ph.D. students with their supervisors as co-authors and of scientists. Most of the editors have contributed chapters for this series and have given their valuable suggestions and comments to improve the quality of this book. The editors are thankful to all the authors and specially research scholars and postgraduate students who have burnt their energy to compile this series of book. We thank all the contributors, authors, experts, and reviewers. We also thank Applied Computer Technology of Kolkata as an organizer of the conference ESDA2022 for collecting, gathering, and pre-processing all documents required for publishing this book.

Afzal Sikander
Marta Zurek-Mortka
Chandan Kumar Chanda
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A New Criss-Cross-Based Asymmetrically Configured T-Type Multi-level Inverter

Kailash Kumar Mahto, Priyanath Das, Durbanjali Das, Sudhanshu Mittal, and Bidyut Mahato

Abstract Significant advancements in power electronics have led to the development of a suitable platform for exploring various multilevel inverter (MLI) topologies. The paper introduces a novel asymmetrical multilevel inverter topology called "A new Criss-Cross based asymmetrically configured T-Type Multi-Level Inverter" that exhibits various beneficial features such as high-quality staircase sinusoidal output voltage, reduced number of power switches, and fewer filter requirements. The proposed topology is designed for 27 levels with a minimized number of inverter components, and its performance is evaluated using both simulation and experimental results. The simulation is conducted using MATLAB/Simulink with a sinusoidal pulse-width modulation (SPWM) technique, and the experimental results are validated using a dSPACE real-time controller. A comparative study is also conducted with other recent proposed topologies, which reveals that the proposed topology requires fewer total MLI components in terms of power switches, isolated DC sources, and main diodes. The simulation and experimental results are analyzed for two different modulation indices, i.e., 0.3 and 1. The output voltage contains 14.89 and 3.36% total harmonic distortion (THD) for modulation indices of 0.3 and 1, respectively.

Keywords SPWM · Power electronics · MLI · Power conversion · Reduced components

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1 Introduction

There are a number of applications and advantages associated with multilevel inverters (MLIs), making their influence high among power electronics converters. To fulfill the gradually increasing power demand, the advent of MLI with other power electronics devices is crucial. MLI play an important role in variable-frequency devices, electrical vehicles, and high voltage DC power transmission [1–4]. Apart from this, it is also useful in renewable energy power conversion systems like those that use solar energy [5] and wind energy. MLI is suitable for high power and medium voltage application [6–8]. In MLI, a high value of voltage is achieved at the output sides in a staircase form by using numerous DC inputs [9]. The output voltage is nearly sinusoidal as a result of this staircase structure which lowers the total harmonic distortion [10–12]. Consequently, the need for filters can be significantly decreased [13]. Apart from that, the d*v*/d*t* [14] ratio gets reduced because of the staircase voltage output. Because the total standing voltage in the case of MLI is low, a low rated semiconductor switch is required, making it cost effective. It is possible to use several switching combinations to get a specific voltage level in many multilevel topologies. A fault-tolerant procedure can be built using these redundant states [15].

The three classes of conventional MLIs that were first introduced in 1981, 1990, and 1996, respectively, are neutral point clamps (NPC) [16], flying capacitors (FC), and cascaded H-bridges (CHB). Although classic MLIs have numerous benefits over two-level inverters, they also have some drawbacks, such as the high switch count needed. In some cases, high number of DC voltage sources and capacitors are needed. Due to the above-mentioned limitations, many new MLI topologies have been proposed with a lower number of components and higher efficiency. Several new MLI topologies have been developed with fewer components and greater efficiency as a result of the aforementioned restrictions. These suggested topologies can be further classified into two groups, symmetrical and asymmetrical, according to the value of the voltage source used in the MLI. The magnitude of each input DC source is the same in symmetrical MLI, whereas it varies in asymmetrical MLI.

Selective harmonic elimination (SHE) [17], space vector pulse-width modulation (SVPWM), carrier-based pulse-width modulation, and nearest level control (NLC) [5] are a few modulation techniques that have been discussed in [5, 18]. The use of H-bridge for generating positive and negative polarities in MLI topologies is discussed by the authors in [12, 19]. In [20] and [21] authors also highlight that some MLI topologies require more DC sources than power switches, [22, 23]. An asymmetrical, 27-level MLI is proposed in this paper. To simulate the proposed MLI, MATLAB/Simulink is used which is also verified by the experimental setup. It has also compared to some recent MLI topologies. This paper has been arranged into four different sections. The modes of operation and the modulation technique of the proposed circuit are covered in Sect. 3. The comparative study is performed in Sect. 4. In Sect. 5, the simulation parameters and required outputs are covered. Section 6 subsequently presents a conclusion.

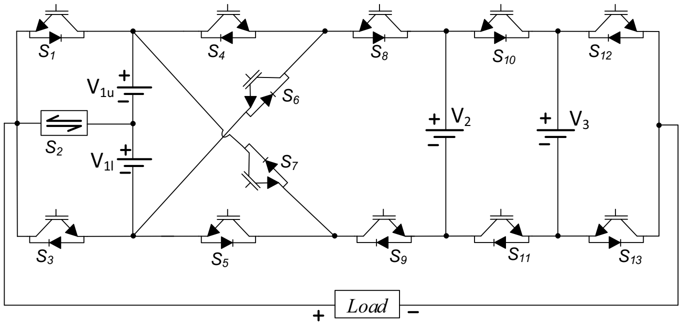


Fig. 1 Proposed criss-cross multi-inverter topology

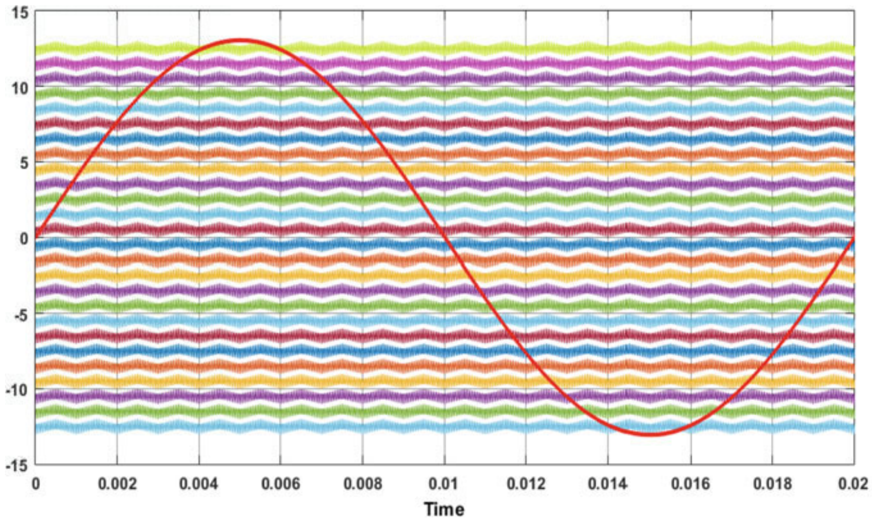
2 Proposed Circuit Topology

The proposed topology depicted in Fig. 1 includes a total of thirteen switches, with S_2 as only bidirectional switch and the other twelve switches as unidirectional. The unidirectional switch has a two-quadrant operation, whereas the bidirectional switch has a four-quadrant operation. Here four isolated DC sources, V_{1u}, V_{1l}, V_2, and V_3, are used, which are working in an asymmetrical mode as the magnitude values of these voltage sources are different. The proposed MLI can produce an output voltage with 27-level when the values of isolated DC sources are used as $V_{1u} = 5\ V_{dc}$, $V_{1l} = 5\ V_{dc}$, $V_2 = V_{dc}$, and $V_3 = 3\ V_{dc}$.

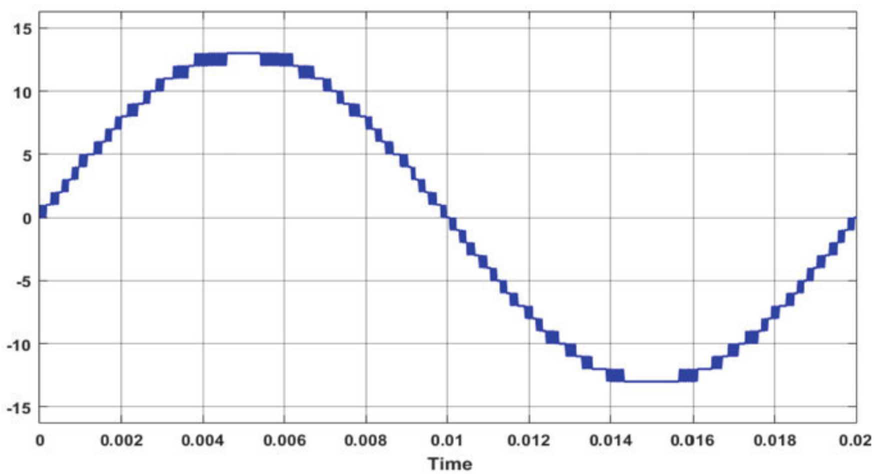
3 Modes of Operation

As multilevel inverters use many switches and generate staircase-type output through the controlled technique of various switches, as mentioned above in the introduction, different modulation techniques have been proposed by the researchers. Out of which the sinusoidal pulse width modulation (SPWM) technique is implemented in this literature. Here, 26 triangular carrier waveforms are considered to generate the PWM for the 27-level inverter as shown in Fig. 2a. The carrier signals and the reference signal are continuously compared using 26 comparators to generate the digital output. The output signals of the twenty-six comparators were combined together to generate the inverter switching signal, as depicted Fig. 2b. The corresponding real-time simulation result of the generated switching signal for a single-phase, 27-level MLI is depicted in Fig. 2b. The gate pulses for the concerned switching devices of the proposed inverter can be obtained by further decoding the switching signals.

Figure 3 illustrates each mode of voltage generation for the 27-level MLI. The blue line represents the positive half-cycle of the voltage generation path, while the red line represents the negative half-cycle. The switching states for each switch of the proposed 27-level MLI have been explained.



(a)



(b)

Fig. 2 PWM generation: **a** comparison of carrier signals with reference signal and **b** corresponding switching signal for the 27-level inverter

- The switches S_1, S_6, S_8, S_{10}, and S_{13} are made ON to achieve $+ 13\ V_{dc}$ (maximum voltage level), as discussed in Fig. 3a, whereas S_1, S_4, S_6, S_9, and S_{13} are made ON to achieve $- 13\ V_{dc}$ (minimum voltage level).
- The switches S_1, S_5, S_9, S_{10}, and S_{13} are made ON to achieve $+ 12\ V_{dc}$, whereas S_3, S_4, S_8, S_{11}, and S_{12} are made ON to achieve $- 12\ V_{dc}$, as depicted in Fig. 3b.

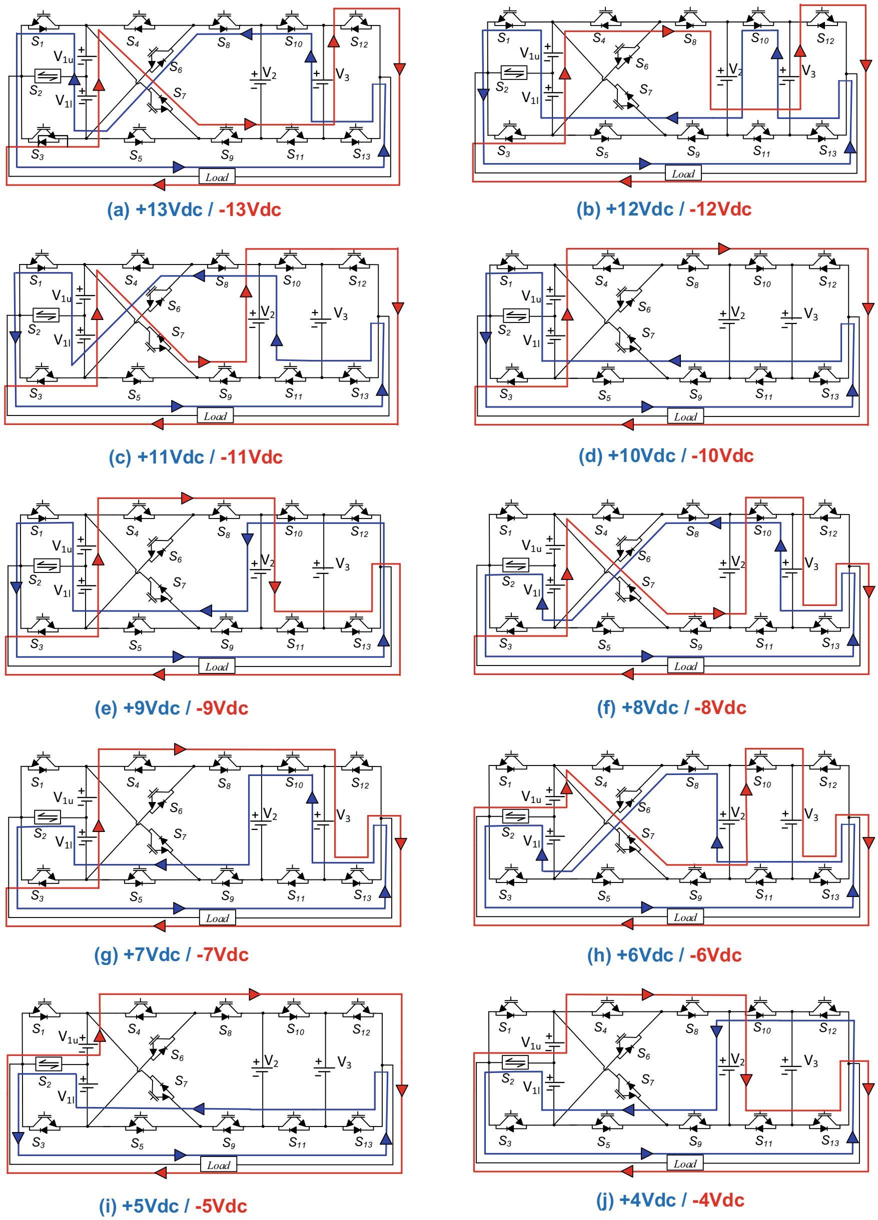


Fig. 3 Modes of operation for the 27-level inverter

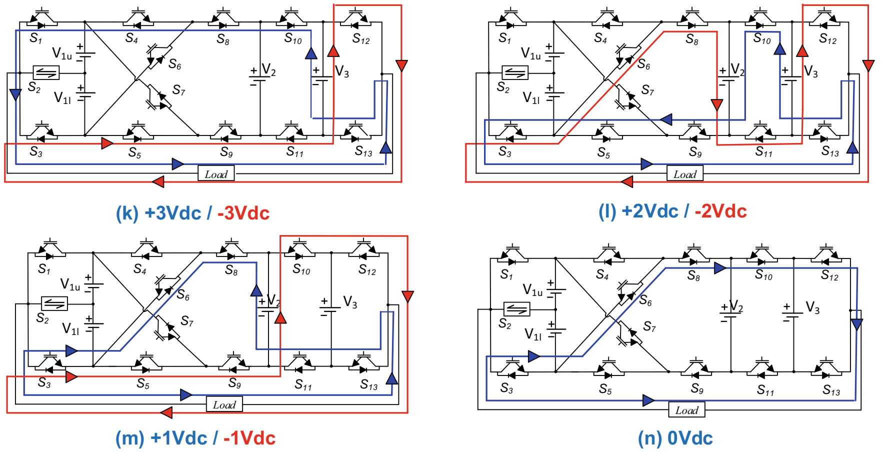


Fig. 3 (continued)

- The switches S_1, S_6, S_8, S_{11} and S_{13} are made ON to achieve $+ 11\ V_{dc}$ whereas S_3, S_7, S_9, S_{10} and S_{12} are made ON to achieve $- 11\ V_{dc}$, as depicted in Fig. 3c.
- The switches S_1, S_5, S_9, S_{11}, and S_{13} are made ON to achieve $+ 10\ V_{dc}$ whereas S_3, S_4, S_8, S_{10}, and S_{12} are turned ON to achieve $- 10\ V_{dc}$, as depicted in Fig. 3d.
- The switches S_1, S_5, S_9, S_{10}, and S_{12} are made ON to achieve $+ 9\ V_{dc}$, whereas S_3, S_4, S_8, S_{11}, and S_{13} are made ON to achieve $- 9\ V_{dc}$, as depicted in Fig. 3e.
- The switches S_2, S_6, S_8, S_{10}, and S_{13} are made ON to achieve $+ 8\ V_{dc}$, whereas S_3, S_7, S_9, S_{10}, and S_{13} are made ON to achieve $- 8\ V_{dc}$, as depicted in Fig. 3f.
- The switches S_2, S_5, S_9, S_{10}, and S_{13} are made ON to achieve $+ 7\ V_{dc}$, whereas S_3, S_4, S_8, S_{10}, and S_{13} are turned ON to achieve $- 7\ V_{dc}$, as depicted in Fig. 3g.
- The switches S_2, S_6, S_8, S_{11}, and S_{13} are made ON to achieve $+ 6\ V_{dc}$, whereas S_2, S_7, S_9, S_{10}, and S_{12} are turned ON to achieve $- 6\ V_{dc}$, as depicted in Fig. 3h.
- The switches S_2, S_5, S_9, S_{11}, and S_{13} are made ON to achieve $+ 5\ V_{dc}$, whereas S_2, S_4, S_8, S_{10}, and S_{12} are made ON to achieve $- 5\ V_{dc}$, as depicted in Fig. 3h.
- The switches S_2, S_5, S_9, $S_{10,}$ and S_{12} are made ON to achieve $+ 4\ V_{dc}$, whereas S_2, S_4, S_8, S_{11}, and S_{13} are made ON to achieve $- 4\ V_{dc}$, as depicted in Fig. 3j.
- The switches S_1, S_4, S_8, S_{10}, and S_{13} are made ON to achieve $+ 3\ V_{dc}$, whereas S_3, S_5, S_9, S_{11}, and S_{12} are turned ON to achieve $- 3\ V_{dc}$ as, depicted in Fig. 3k.
- The switches S_3, S_5, S_9, S_{10}, and S_{13} are made ON to achieve $+ 2\ V_{dc}$, whereas S_3, S_6, S_8, S_{11}, and S_{12} are turned ON to achieve $- 2\ V_{dc}$, as depicted in Fig. 3l.
- The switches S_3, S_6, S_8, S_{11}, and S_{13} are made ON to achieve $+ V_{dc}$, whereas S_3, S_6, S_8, S_{11}, and S_{12} are turned ON to achieve $- V_{dc}$, as depicted in Fig. 3m.
- The switches S_3, S_5, S_9, S_{10}, and S_{12} are made ON to achieve zero volt, as depicted in Fig. 3n.

4 Comparative Study

Nowadays, various recently developed MLI topologies are introduced in [24–30]. These MLIs have been analyzed for the different performance parameters such as total switches (M), capacitors and isolated DC sources (N), and main diodes (O). Generalized formulas for the different topologies proposed have been shown in Table 1, where V_l represents the number of level of output voltage. For 27-level, the above-mentioned references have been shown in Table 2. The number of gate driver circuits needed is equal to the number of switches used because each switch needs one to produce a gate pulse. The main diodes are the ones associated with the switches. One anti-parallel diode is connected in the case of a unidirectional switch, whereas two or four diodes are associated with a bidirectional switch.

From the comparative study, it can be seen that to generate the 27-level output voltage, the required number of power switches and other components, like isolated DC sources and the main diode, is less than in the comparative papers.

Table 1 Generalized formulas for different components

Cited papers	Total switches (M)	Capacitors/isolated DC sources (N)	Main diodes (O)
[24]	$(V_l + 3)$	$(V_l - 1)/2$	$(V_l + 3)$
[25]	$3(V_l - 1)/2$	$(V_l - 1)/2$	$3(V_l - 1)/2$
[26]	$2(V_l - 1)$	$(V_l - 1)/2$	$2(V_l - 1)$
[27]	$(V_l + 3)$	$(V_l - 1)/2$	$(V_l + 3)$
[28]	$7(V_l - 1)/8$	$(V_l - 1)/2$	$(V_l - 1)/8$
[29]	$(V_l + 1)$	$(V_l - 1)/2$	$(V_l + 1)$
[30]	$(V_l + 5)/2$	$(V_l - 1)/2$	4

Table 2 Comparison chart for 27-level output voltage

Cited papers	Number of voltage levels (V_l)	Total switches (M)	Capacitors/isolated DC sources (N)	Main diodes (O)
[24]	27	30	13	30
[25]	27	39	13	39
[26]	27	52	13	52
[27]	27	30	13	30
[28]	27	23	13	4
[29]	27	28	13	28
[30]	27	16	13	4
Proposed MLI	27	13	4	16

5 Simulation and Experimental Results

The simulation and the experimental results of the proposed 27-level inverter have been discussed in this section. The simulation has been performed using MATLAB/Simulink, and it has been validated by the experimental setup. The prototype model of the proposed MLI is developed in using dSPACE-1103 controller. The prototype model's components consist of the power switch (IGBT-CT60AM), isolated DC voltage sources, gate driver circuits (TLP250), DSO-X 2024A, and RL load as shown in Fig. 4. For the proposed 27-level inverter, the magnitude of voltage sources is used as $V_{1u} = 5\ V_{dc}$, $V_{11} = 5\ V_{dc}$, $V_2 = V_{dc}$, and $V_3 = 3\ V_{dc}$.

The simulation analysis and the experimental verification are performed at different modulation index. The simulation results at modulation index 0.3 for the proposed 27-level MLI are depicted in Fig. 5. The simulation is performed for RL load with R = 82.5 Ω and L = 75 MH. For the input DC voltage, $V_{dc} = 23$, $3\ V_{dc} = 69$, and $5\ V_{dc} = 115$, the simulation output voltage, $V_{o/p\ max}$, is 92 V as depicted in Fig. 5a, and the value of the load current, $I_{o/p\ max}$, is 0.86 A as shown in Fig. 5b. The value of THD for the given configuration is 14.89% as depicted in Fig. 5c.

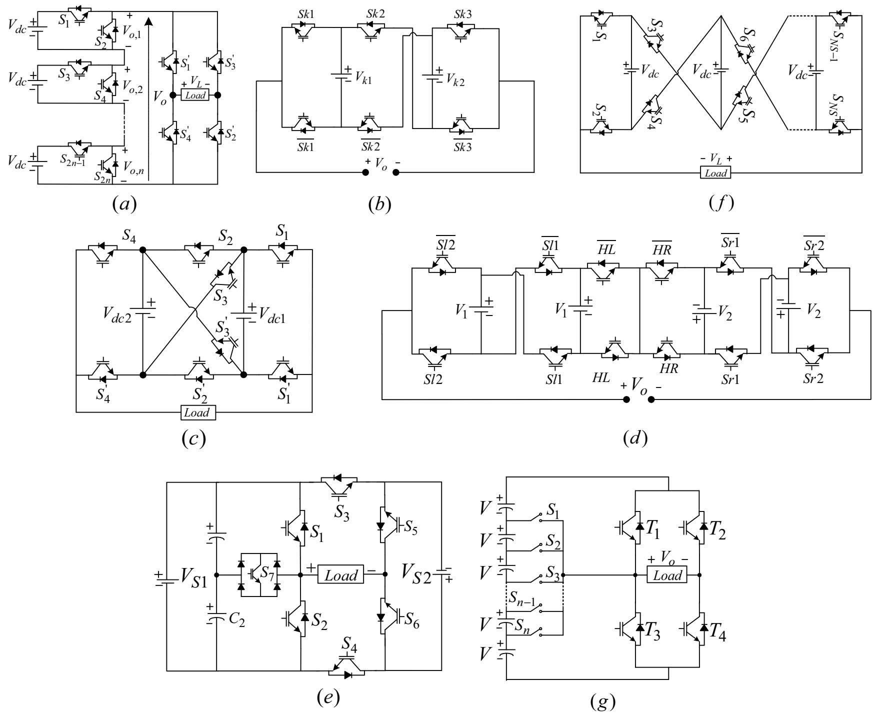
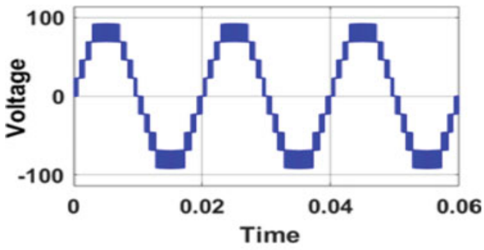
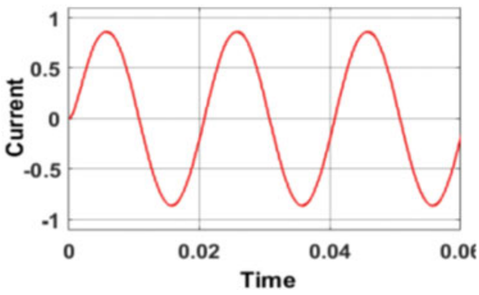


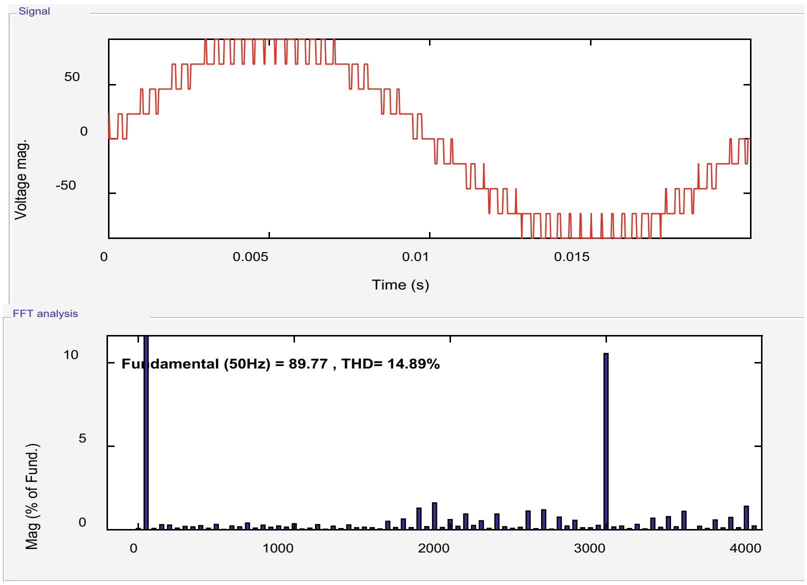
Fig. 4 Circuit of compared reduced switch topologies. **a** Proposed in [24], **b** proposed in [25], **c** proposed in [26], **d** proposed in [27], **e** proposed in [28], **f** proposed in [29], **g** proposed in [30]



(a)



(b)



(c)

Fig. 5 Simulation results for the **a** output voltage, **b** load current, **c** THD of the output voltage, **d** experimental result for the output voltage and the load current at MI = 0.3

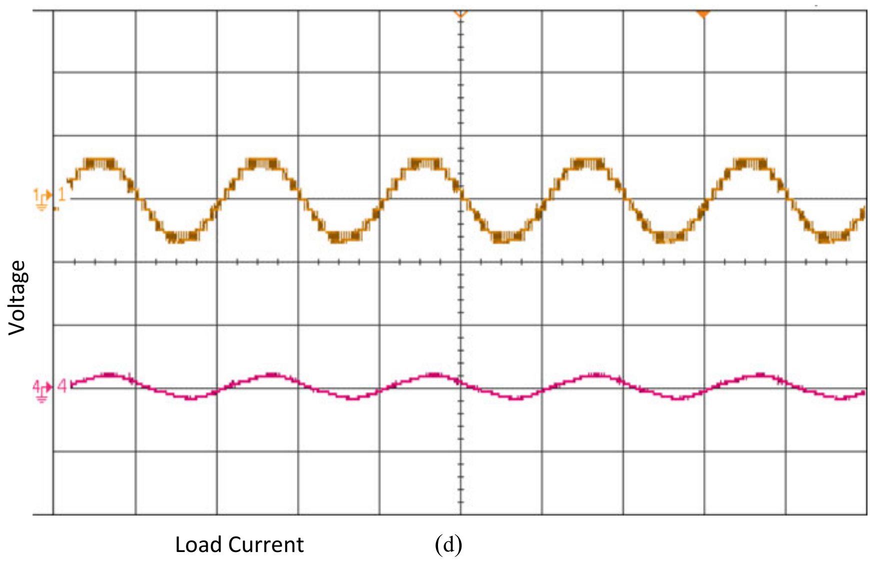


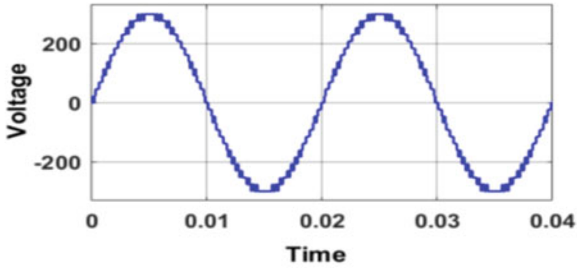
Fig. 5 (continued)

The simulation result for the output voltage and the load current is validated by the experimental result depicted in Fig. 5d.

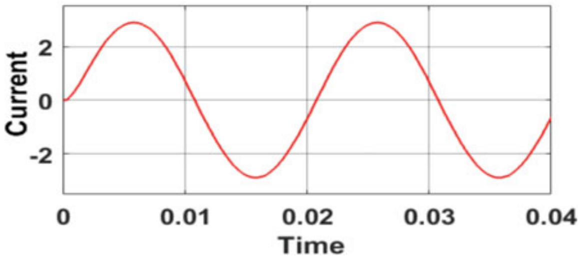
With the same set of loads and the input voltage, the performance of the proposed 27-level MLI is evaluated with MI = 1, whose simulation and experimental result are depicted in Fig. 6. For modulation index 1, the simulation result for the output voltage, $V_{o/p\ max}$ is 296 V as depicted in Fig. 6a, and the load current, $I_{o/p\ max}$ is 2.9 A as shown in Fig. 6b The value of THD of the output voltage is 3.36%, as depicted in Fig. 6c. The experimental result for the output voltage and load current with modulation index 1 for the 27-level inverter is depicted in Fig. 6d.

6 Conclusion

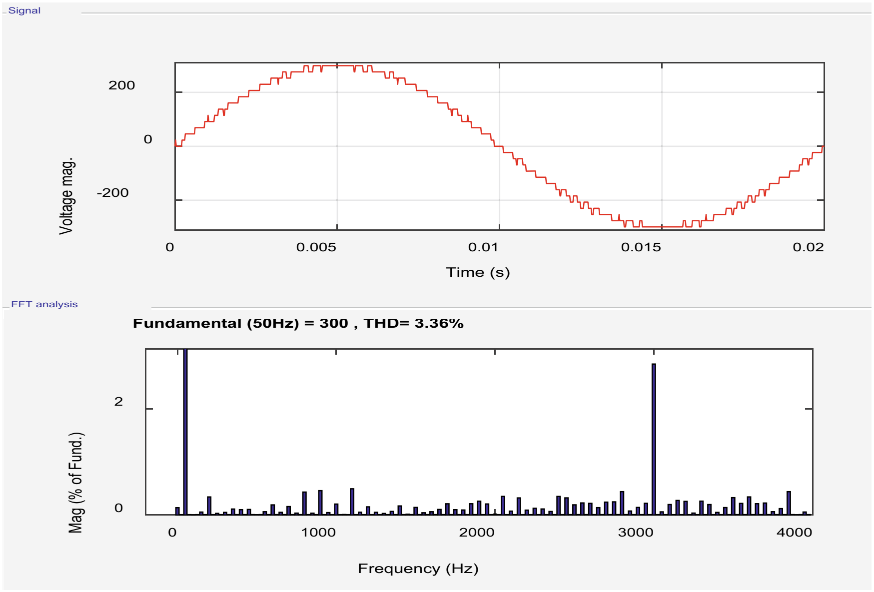
The literature presents a new criss-cross-based asymmetrically configured T-Type multi-level inverter that achieves 27 levels. MATLAB/Simulink is used to simulate the proposed topology, and an experimental setup is used to verify the results. Further the proposed topology is evaluated by comparing it with other recent MLI topologies with have 27-level of output voltage. The comparison is based on the overall count of essential components, such as power switches, main diodes, and isolated capacitors or DC sources that are required for the circuit. The analysis indicates that the proposed topology is more cost-effective since it requires a smaller number of power switches compared to the other compared topologies. In the final section of the literature, simulation and experimental results are presented and discussed for two different



(a)

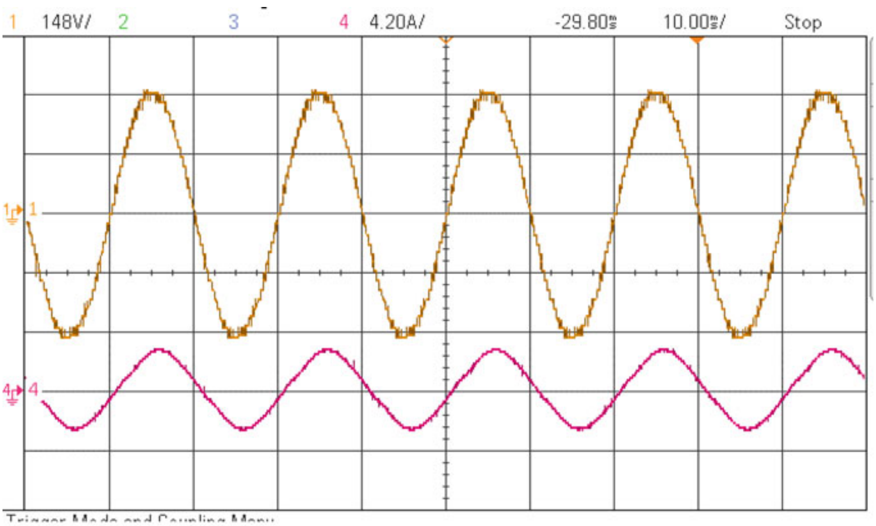


(b)



(c)

Fig. 6 Simulation results for the **a** output voltage, **b** load current, **c** THD of the output voltage and **d** experimental result for the output voltage and the load current at MI = 1



(d)

Fig. 6 (continued)

modulation indices, 0.3 and 1. The THD values for MI = 0.3 and MI = 1 are found to be 14.89% and 3.36%, respectively.

References

1. C.C. Herskind, Grid controlled rectifiers and inverters. Trans. Am. Inst. Electr. Eng.Electr. Eng. **53**(6), 926–935 (1934)
2. A. Chakraborty, Advancements in power electronics and drives in interface with growing renewable energy resources. Renew. Sustain. Energy Rev. **15**(4), 1816–1827 (2011)
3. B. Mahato, K.C. Jana, P.R. Thakura, Constant V/f control and frequency control of isolated winding induction motor using nine-level three-phase inverter, Iranian. J. Sci. Technol. Trans. Elec. Eng. **6**(1), 1–13 (2019)
4. A. Shahin et al., High voltage ratio DC-DC converter for fuel-cell applications. IEEE Trans. Ind. Electron. **57**(12), 3944–3955 (2010)
5. K.K. Mahto, P.K. Pal, P. Das, S. Mittal, B. Mahato, A new design of multilevel inverter based on T-type symmetrical and asymmetrical DC sources. Iran. J. Sci. Technol. Trans. Electr. Eng. 1–19
6. A. Salem, M.A. Abido, F. Blaabjerg, Common-mode voltage mitigation of dual T-type inverter drives using fast MPC approach. IEEE Trans. Industr. Electron.Industr. Electron. **69**, 7663–7674 (2022)
7. M.J. Sathik, V. Krishnasamy, Compact switched capacitor multilevel inverter (CSCMLI) with self-voltage balancing and boosting ability. IEEE Trans. Power Electron. **34**, 4009–4013 (2019)
8. M.J. Ik, N. Sandeep, D. Almakhles, F. Blaabjerg, Cross connected compact switched-capacitor multilevel inverter (C3-SCMLI) topology with reduced switch count. IEEE Trans. Circuits Syst. II Exp. Briefs **67**, 3287–3291 (2020)

9. S. Paul, K.C. Jana, S. Majumdar, P.K. Pal, B. Mahato, Performance analysis of a multimodule staircase (MM-STC)-type multilevel inverter with reduced component count and improved efficiency. IEEE J. Emerg. Selected Topics Power Electron. **10**(6), 6619–6633 (2021)
10. B. Mahato, M. Ranjan, P.K. Pal, S.K. Gupta, K.K. Mahto, Design, development and verification of a new multilevel inverter for reduced power switches. Arch. Electr. Eng.Electr. Eng. **71**(4), 1051–1063 (2022)
11. K.K. Jha, B. Mahato, P. Prakash, K.C. Jana, Hardware implementation of single phase power factor correction system using micro-controller. Int. J. Power Electron. Drive Syst. **7**(3), 787–790 (2016)
12. B. Mahato, S. Majumdar, K.C. Jana, A new and generalized MLI with overall lesser power electronic devices. J. Circ. Syst. Comput. **29**(4), 2050058 (2020)
13. B. Mahato, S. Mittal, P. Kumar Nayak, in *2018 International Conference on Recent Trends in Electrical, Control and Communication (RTECC).* Novel Topology of Multi-level Inverter for higher Voltage Steps (IEEE, 2018), pp. 158–163
14. Y. Zhang, H. Li, Z. Guo, F.Z. Peng, A low-voltage low-loss active reflected wave canceller for a medium-voltage SiC motor drive based on a generalized multilevel inverter topology. IEEE J. Emerg Selected Topics Power Electron. **10**(6), 6845–6853 (2021)
15. S. Peddapati, S.V.K. Naresh, A new fault-tolerant MLI—investigating its skipped level performance. IEEE Trans. Industr. Electron.Industr. Electron. **69**(2), 1432–1442 (2021)
16. S. Bernet, Recent developments of high-power converters for industry and traction applications. IEEE Trans. Power Electron. **15**(6), 1102–1117 (2000)
17. M.S. Dahidah, G. Konstantinou, V.G. Agelidis, A review of multilevel selective harmonic elimination PWM: formulations, solving algorithms, implementation and applications. IEEE Trans. Power Electron. **30**(8), 4091–4106 (2014)
18. B. Mahato, R. Raushan, K.C. Jana, Modulation and control of multilevel inverter for an open-end winding induction motor with constant voltage levels and harmonics. IET Power Electron. **10**(1), 71–79 (2017)
19. G. Ceglia, V. Guzmán, C. Sanchez, F. Ibanez, J. Walter, M.I. Giménez, A new simplified multilevel inverter topology for DC-AC conversion. IEEE Trans. Power Electron. **21**(5), 1311–1319 (2006)
20. R.S. Alishah, S.H. Hosseini, E. Babaei, M. Sabahi, A new general multilevel converter topology based on cascaded connection of submultilevel units with reduced switching components, DC sources, and blocked voltage by switches. IEEE Trans. Industr. Electron.Industr. Electron. **63**(11), 7157–7164 (2016)
21. R.S. Alishah, S.H. Hosseini, E. Babaei, M. Sabahi, Optimal design of new cascaded switch-ladder multilevel inverter structure. IEEE Trans. Industr. Electron.Industr. Electron. **64**(3), 2072–2080 (2017)
22. E. Samadaei, S.A. Gholamian, A. Sheikholeslami, J. Adabi, An envelope type (E-Type) module: asymmetric multilevel inverters with reduced components. IEEE Trans. Industr. Electron.Industr. Electron. **63**(11), 7148–7156 (2016)
23. K.K. Gupta, S. Jain, A novel multilevel inverter based on switched DC sources. IEEE Trans. Industr. Electron.Industr. Electron. **61**(7), 3269–3278 (2013)
24. E. Babaei, S.H. Hosseini, New cascaded multilevel inverter topology with minimum number of switches. Energy Convers. Manage. **50**(11), 2761–2767 (2009)
25. A. Ajami, M.R. Oskuee, M.T. Khosroshahi, A. Mokhberdoran, Cascade-multi-cell multilevel converter with reduced number of switches. IET Power Electronics **7**(12), 2914–2924 (2014)
26. K.K. Gupta, S. Jain, Topology for multilevel inverters to attain maximum number of levels from given DC sources. IET Power Electron. **5**(4), 435–446 (2012)
27. A. Ajami, M.R.J. Oskuee, A. Mokhberdoran, A. Van den Bossche, Developed cascaded multilevel inverter topology to minimise the number of circuit devices and voltage stresses of switches. IET Power Electron. **7**(2), 459–466 (2013)
28. S.P. Gautam, L. Kumar, S. Gupta, Hybrid topology of symmetrical multilevel inverter using less number of devices. IET Power Electron. **8**(11), 2125–2135 (2015)

29. M.F. Kangarlu, E. Babaei, Cross-switched multilevel inverter: an innovative topology. IET Power Electron. **6**(4), 642–651 (2013)
30. R.S. Alishah, D. Nazarpour, S.H. Hosseini, M. Sabahi, Reduction of power electronic elements in multilevel converters using a new cascade structure. IEEE Trans. Industr. Electron.Industr. Electron. **62**(1), 256–269 (2015)

Estimation of State of Charge for Lithium-Ion EV Battery Packs Using Passive Cell Balancing

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Abstract In order to advance the field of sustainable mobility, electric vehicles (EVs) need a battery, which is a key component. Lithium chemistry is presently regarded as the primary energy storage method for electric vehicles. Due to their high energy per mass compared to other electrical energy storage methods, lithium-ion batteries are currently employed in the majority of portable consumer gadgets, including cell phones and laptops. Li-ion battery pack is a combination of number of cells connected according to the purpose of application. Since the manufacturing chemistry of each cell is exactly not similar so, their state of charge and depth of discharge capacity differs from each other to some extent. So, a proper battery management system is necessary to protect the life of Li-ion battery and their proper diagnosis during their usable life span to give them. Prior to discussing the most fascinating modelling approaches for predicting battery performance, this study begins by outlining the stringent standards and requirements that apply to integrating battery management circuits and systems. Following that, a generic and flexible framework for implementing BMS is provided, together with the passive method for cell balancing and SOC estimation under MATLAB environment.

Keywords Battery management system (BMS) · Lithium chemistry · State of charge (SOC) · State of health (SOH) · Depth of discharge (DOD) · State of function (SOF) · C-rate · Passive cell balancing

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1 Introduction

The largest source of climatic pollution, rise in global warming, unwanted change in environment, day to day rise in price of fossil fuels, crisis of crude and petroleum products, and cause of many diseases (i.e. asthma, bronchitis, cancer, lung damage, and Heart attacks) are good enough reasons to move towards sustainable mobility and zero-emission sources of energy when in use [1]. To solve this crisis, electric vehicles (EVs) is the key to eliminate the problems originated by using diesel and petroleum powered vehicles because these vehicles emit harmful gases (i.e. carbon monoxide—CO, hydrocarbons—HC, particulate matter—PM, and nitrogen oxides—NO_x). One of the most important parts of EVs is battery which is solely responsible for determining the driving range capacity of electric vehicles. The selection of the battery technology and its efficient application are therefore of utmost significance [2, 3]. From today's perspective, lithium chemistry is more preferable as compared to other batteries technology (i.e. lead acid battery) due to its following properties:

- **High energy density**: 250–693 Wh/L (0.90–2.43 MJ/L)
- **Specific energy**: 100–265 Wh/kg (0.36–0.875 MJ/kg)
- **Charge/discharge efficiency**: 80–90%
- **Cycle durability**: 1800–2000 cycles (LFP) & 2200–2400 (NMC)
- **Specific power**: ~ 250 to ~ 340 W/kg.

A significant change in large-format battery systems has been brought about by the development of lithium-ion batteries. According to the application, a lot of cells are often connected in series to create a battery line with the necessary voltage amplitude (nearer to 400 V) [3]. Overcharging and deep drain can harm the battery, reduce its lifespan, and possibly create dangerous circumstances because chemistry of lithium ions is extremely fragile to these conditions. Therefore, a proper adoption of battery management system (BMS) is required to keep each cell of the lithium-ion battery within its permissible range of safe operation. BMS may include the following functions as [4]:

- To prevent overcharging of each cell
- To prevent rise in temperature of each cell beyond their threshold limit
- To prevent over discharging of each cell
- To prevent exceeding of charging current beyond limit
- To prevent exceeding of discharging current under limit
- To monitor the battery pack
- To protect the battery
- Cell balancing.

A BMS performs the primary task of guaranteeing battery safety in addition to evaluating the battery condition it also looks after the operating temperature, operating voltage, operating current, and charge quantity to keep the battery under safety. A BMS plays a critical role in extending battery life, or state of health, by assessing the condition of the cells and addressing the amount of charge underbalanced defects which can be arise in cells connected in series. This reduces the battery's utility consumption capacity since the lowest charged unit controls when the discharge process ends even though the battery's other cells still have energy. Because Li-ion batteries are subject to severe voltage restrictions, charge unbalancing cannot be resolved on its own and instead gets worse over time. In fact, the charging process must be paused when a cell hits the upper voltage limit, resulting in some batteries not being fully recharged. Diverse self-discharge rates among the cells can cause charge unbalancing even if they all have the same capacity. A temperature gradient along the battery string can also reveal this discrepancy. Therefore, a charge equalisation mechanism should be used by a BMS to periodically re-establish the balanced state [5].

In order to design and maintain a battery for an electric vehicle (EVs), this paper will outline the key problems. The passive cell balancing approach of a Li-ion battery for an e-mobility application is examined in this research using a MATLAB simulation to estimate energy loss and cost. The design of a cutting-edge BMS that will be included into an electric vehicle is then influenced by them. The first virtually completely integrated active charge equaliser is part of the BMS that has been put into place.

2 Various Modelling Methods

The first strategy involves observing an electrochemical system from the outside (black-box approach). The voltage–current characteristics are used to obtain the parameters of the mathematical functions that define an electrochemical system. Models with quick computation are the result. These models frequently avoid changing a direct parameter without duplicating all the measurements required for configuring the modelling when a system changes, such as when separator thicknesses vary.

The electrical lumped-model is a second strategy. Calculations can produce quick results thanks to this type of modelling. However, there are a number of disadvantages when the need for extensive operation region coverage in an automotive application arises. In order to adapt the model's features into those of the cells, it is necessary to use relatively sophisticated look-up tables to address the parameter variance related to temperature, state of charge, current density, and longevity.