A Fuzzy controlled grid connectedSolar PV-Fed Multilevel Inverter with Series Compensator for Power Quality Improvement

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ABSTRACT
Problems with electricity quality arise as a result of grid integration of renewable energy sources (RES). Grid users are impacted by power quality issues such as voltage spikes, dips, and harmonic distortion. Using a cheap series compensator, such the Dynamic Voltage Restorer (DVR), is the best way to fix these problems. A solar PV integrated DVR with a novel multilayer inverter is introduced in the article as a solution to the power quality issues plaguing the grid. The main objective of the proposed endeavour is to enhance power quality via the development of a DVR integrated with a 23-level multilevel inverter. In addition, the boost converter is tailored to use an improved INC-MPPT approach, which guarantees the solar PV modules gather the maximum amount of energy. Although multilayer inverters have several benefits, such as decreased total harmonic distortion (THD) and fewer components, they also have a variety of dependability concerns. The suggested design can generate 23 different output voltage levels by using asymmetrical DC sources. The MLI has several advantages, including a smaller inverter, lower costs, and fewer components. Part of this package includes a thorough mathematical analysis of the rotational behaviour of the do reference frame control. Experimental evaluations of the DVR's dynamic performance under a balanced load are conducted. We use MATLAB/Semolina to produce results from the simulations of the proposed system. The system that is demonstrated is created using a fuzzy controller and the MATLAB simulator. The results show that the proposed system's architecture is much better at correcting for voltage sag and significantly improves power quality. The observed THD at the grid side is reduced in line with IEEE standards.

INTRODUCTION

In today's smart economy, digital, electronic, and non-linear gadgets—sometimes called devices controlled by microprocessors—is everywhere. If the power to any of these devices were suddenly cut off, they would all be rendered useless. When power quality is bad, it may cause a lot of problems, such as data errors, automatic resets, memory loss, unit failure, software corruption, circuit board failure, power supply difficulties, and electrical distribution system overheating. With these realities in mind, PQ is more crucial than it has ever been [1]. Worries about the power quality of sensitive loads have been heightened in recent years due to a quadrupling of their utilisation, which includes diagnostic equipment in healthcare institutions, schools, jails, etc. [2]. Important power quality issues include voltage spikes, dips, harmonics, transients, flickers, fluctuations, and interruptions [3]. Important and sensitive loads must be unaffected by power quality issues and voltage disturbances. Several solutions have been introduced to this field; however Custom Power Devices (CPDs) are the most successful. CPDs compensate and alleviate voltage anomalies. The DVR is the ideal CPD since it is small, inexpensive, and quick to respond to voltage disturbances [4, 5]. In grid-connected networks, dynamic voltage restorers (DVR) play an essential role in mitigating voltage disruptions. Dynamic voltage regulation (DVR) based on photovoltaic (PV) technology and a new kind of boost converter control voltage variations in grid networks [6]. Modern electronics rely on a wide range of DC-DC converter topologies, some of which include renewable energy sources [7]. The installation of PV systems allows for the generation of clean, renewable energy, which contributes to the reduction of pollution levels. In the event of a grid loss, it supports key loads, which enhances reliability and simultaneously addresses energy concerns. Integrating PV and DVR not only satisfies energy demands, but also improves power factor, reduces voltage dips and harmonics. In recent years, MLIs have become an essential component in several industrial applications, such as UPFC, medium-voltage drives, DSTATCOM, EVs, active power filters, micro-grid, grid-integrated or freestanding solar systems, and countless more [8]. A half-bridge inverter and an H-Bridge (full-bridge) inverter are two popular inverter topologies used in single-phase DVR [9, 10]. Also, several matrix converters, Impedance-fed inverters, and multilayer inverters are used by three-phase and single-phase DVRs [11]. When an AC-AC converter is not available, DVRs based on this technology may enhance power quality [12]. The AC-AC converters are a major power hog when the voltage lowers, unfortunately. For that reason, they aren't an ideal solution for the long-term mitigation of voltage sags that weak grids need. There is a potential of shoot-through and storage needs for a Z-source converter-based DVR with lower dc-link voltage that was presented for deep voltage sag [13]. Full bridge and four-leg six-switch topologies are two popular choices for three-phase direct voltage regulator inverters. Due to electromagnetic interference caused by an increase in the voltage-to-time ratio and the fact that two-level inverters include valves that block the passage of very high voltages, they are not suitable for use with very high voltage power sources. Multilayer inverters are the best choice. Minimal harmonics, decreased switching losses, improved electromagnetic compatibility, and a smaller output voltage step are just a few of the many benefits of MLIs. Due to the increasing difficulty in balancing the capacitors with increasing voltage, diode-clamped MLI can only operate at three voltage levels. Still, the three-level NPC inverter finds widespread use throughout most industries. Flying Capacitor MLI requires an increasing number of dc capacitors with increasing voltage. But the switching combinations are customisable, and DC capacitor voltage balancing is achievable [14]. Due to its modularity characteristic, the CHB MLI architecture is becoming more popular and reliable. The number of switches required increases with each level, and each bridge requires its own DC source [15]. Hybrid topologies, which are often based on conventional topologies, have been proposed by academics as a cost-effective approach to address power quality challenges and meet high grid code requirements [8]. The 49-level modular asymmetrical inverter was proposed for comparison and study in [16]. In [17], the authors presented a new design for a DVR that relies on a buck-boost ac/ac converter. Along with an inductor, capacitor, and five switches, the architecture is remarkable for not having an injection transformer. This allows for a direct connection to the grid without the need for storage devices. Consequently, this topology is less expensive, lighter, and smaller than the usual ones. A direct connection between a DVR and a cascaded H-Bridge multilevel converter [15] was used to circumvent the MV network. This zero active power adjustment system fixes the voltage by storing it in capacitors.

A DVR equipped with a five-level reduced power component TCHB inverter was one of two voltage compensation solutions used to deal with the voltage sag [18]. The authors of [19] proposed an inexpensive S4L inverter-based DVR with a single DC power supply, fewer switches, and seven levels that significantly aids in lowering the system harmonic problem.

According to the authors of [20], a combination of an interline DVR with a CHB multilevel inverter may decrease voltage sag and increase THD. It is possible to correct for both short- and long-period sag using an adjustable dc-link linked MLI-based DVR [...]. An open-end winding transformer was used in a planned DVR to decrease inverter loss and harmonics [22]. According to [23], a cascaded OEW transformer-based DVR may reduce total harmonic distortion (THD) and enhance voltage level without using extra clamping diodes. It was for applications that needed medium to high power levels that a T-type MLI-based DVR was proposed [24]. A new asymmetrical multilevel inverter with an E-type clamped X-type DVR integrated was proposed with a reliable fractional-order super-twisting sliding mode control. Due to the high number of switches needed by these topologies at a given voltage level, the size, cost, and driver circuit requirements are all increased (see to [25]). In [26], the authors suggested an "odd-nary" cascading asymmetric multi-level inverter that uses fewer switches to provide staircase output at higher levels. A novel hybrid control micro-LCI (HCMLI) linked to a solar power source is proposed as an AC-voltage synthesiser for DVR, with the aim of mitigating voltage disturbances [27]. Following the recommendation in [28], MV DVR uses a selective harmonic feedback control approach to address voltage harmonics while preserving sag compensation. An H∐ voltage controller-based DVR might effectively compensate for voltage decreases in MV applications, as proposed in [29]. In order to overcome all of the limitations, this paper proposes an asymmetrical 23-level MLI. The 23-level MLI is implemented in a PV-fed DVR using a rotating do reference frame controller. After looking at the numbers, it seems that the 23-level MLI is the better and more cost-effective option. The proposed PV-fed MLIDVR has many advantages, such as improved power quality, less voltage dips, and more voltage spikes. Here are some important characteristics of the proposed topology: As a result of reduced voltage stress, most of the eleven switches that comprise the 23-level MLI can operate at medium voltages. The proposed PV-fed MLI-DVR improves power quality, reduces voltage swells and sags, and has a better harmonic profile than conventional VSIDVR; it also conforms to the IEEE standard. Therefore, everything else may move on with the piece.

PROPOSED CONTROLLER

In recent years, fuzzy logic has become more popular in a wide variety of settings. Countless consumer products, including cameras, camcorders, washing machines, and microwave ovens, as well as medical devices and industrial process control, make use of it. The term "fuzzy logic" has two separate meanings. Fuzzy logic is a kind of system of logic that is a subset of multivalve logic. Fuzzy logic (FL) and fuzzy set theory are almost identical in scope; both address classes of objects whose membership is determined by degree rather than absolute boundaries. In this view, fuzzy logic is a special case of fuzzy logic. Fuzzy logic differs from traditional multivalve logical systems, both in theory and practice, even when stripped down to its barest elements.

The core concept of fuzzy logic (FL) and essential to most of its applications is a fuzzy if-then rule, or simply fuzzy rule. In artificial intelligence, rule-based systems are not new, but they struggle with unclear antecedents and consequents. This method comes from fuzzy logic's calculus of fuzzy rules. Fuzzy rule calculus is the foundation of what can be called the Fuzzy Dependency and Command Language (FDCL). Although FDCL is a key component of the toolbox, it is not directly used by it. For the most part, when you apply fuzzy logic, what you get is essentially a human-translated response in FDCL.

More and more, neural networks and evolutionary algorithms are being used in conjunction with fuzzy logic. Fuzzy logic, neuron-computing, and genetic algorithms are some of the fundamental components of what may be called soft computing in a larger sense. Soft computing offers greater leeway than traditional, hard computing due to its incorporation of the real world's inherent ambiguity.

Soft computing is based on the idea that one may achieve tractability, resilience, and low solution cost by making use of the tolerance for imprecision, ambiguity, and partial truth. It is possible that in the future, with the aid of soft computing, systems with a much higher MIQ (Machine IQ) than those made using conventional methods would be more often envisaged and constructed.

Combining neuron-computing with fuzzy logic, neuron-fuzzy systems are now the most popular soft computing paradigm. Fuzzy logic relies on these types of systems to derive rules from observations.

A fascinating aspect of fuzzy logic that makes it an excellent area to study is the trade-off between accuracy and relevance. An obstacle that humanity has been surmounting for an extraordinarily long time. Although fuzzy logic is a relatively new scientific field, the concept underlying it is based on tried-and-true human reasoning skills, making it both new and old in this regard.

RESULTS

We evaluate the proposed multilayer inverter fuzzy ontrolledsolar PV provided DVR with an aim towards improving the voltage profile. Use of the MATLAB/Semolina environment is used to display the results. Table 7 displays the DVR parameters. Connecting the DVR to the system is the 10 KVA, 400V (1:1) injection transformer. An additional 400V may be extracted from a PV array by use of a boost converter. In order to keep the DC link voltage constant, a 500Ah battery with a typical 400V voltage and an 8 kW, 0.85 lagging PF linear load (RL Load) are used. Here you may find the results of the EINC MPPT-based simulations of the PV and boost converters. Photovoltaic systems generate

TABLE 1. Specifications and reviews of DVRs

Source (AC grid)	400V, 50 Hz
DC-link voltage	400V
Filter	L=5 mH, C=80 μF, R=1.5Ω
Switching frequency	5kHz
Transformer ratio	1:1

Brought the voltage up to 400 volts at the DC connector from 112.8 volts using a boost converter. Figure 11 shows the R phase voltage waveform of the 23-level asymmetrical MLI. The voltage sag mode is activated by applying overload at intervals ranging from 0.2 to 0.285 seconds. This test applies 0.5pu of sag in contrast to the load point reference voltage. Both Figure 12 and Figure 14 show the operational state of the suggested DVR, which accurately injects voltage while maintaining the load voltage profile. As seen in Figure 12,

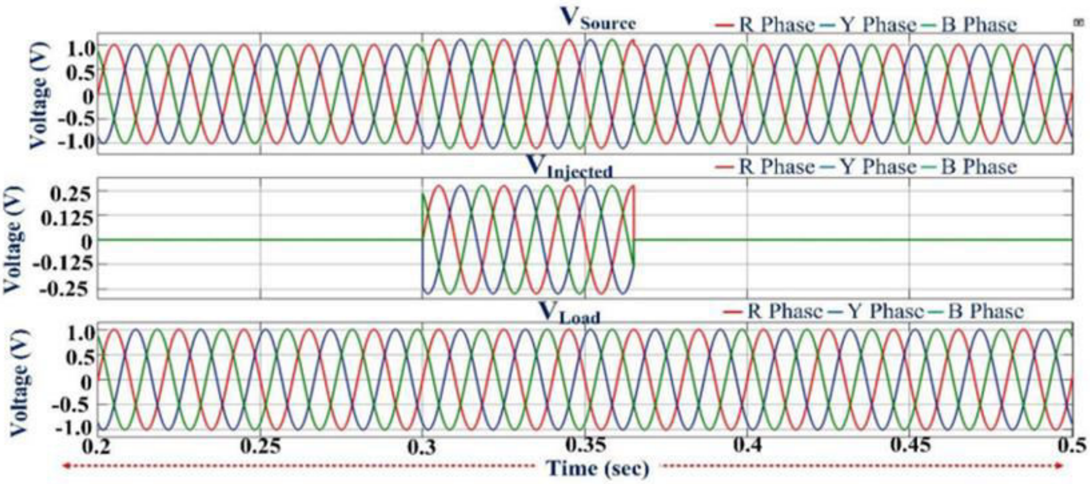

Fig 2 proposed simulation results

Here we can see the three-phase voltage profile of the DVR for the 0.5pu sag situation, as illustrated in Figure 14. Figure 13 displays the voltage THD at the load side while the DVR is in sag mode. Create a double voltage sag mode by comparing the load point reference voltage to an overload at 0.7pu time intervals of 0.2 to 0.285 seconds and 0.5pu time intervals of 0.3 to 0.385 seconds. Keeping the load voltage profile constant, the suggested DVR injects the right voltages, as shown in Figure 15. In this test, a swell mode is created at intervals between 0.3 and 0.365 seconds. Swelling of 1.2 up affects the load point reference voltage. The proposed DVR, shown in Figure 16, keeps track of the load voltage profile and makes adjustments based on the appropriate voltage.

CONCLUSION

Fuzzy PV-fed MLI-DVR is suggested in this work, which uses an asymmetrical 23-level MLI and a rotating do reference frame controller. In the lab, we create and evaluate a model of an innovative multilayer inverter. Reducing the number of circuit components is how the proposed MLI gets a low total harmonic distortion (THD) synthesised output voltage. This proposed MLI offers better value for money and more features than the existing topologies, with a TSVPU of 2.4 and CF/L values of 1.07 and 1.15 for 'α', respectively. We used the MATLAB simulator to evaluate the proposed PV-fed MLI-DVR. The proposed method successfully reduces voltage sag, which helps maintain a constant DC connection voltage. Maximise the power output of your photovoltaic modules with the INC MPPT technique. We compare the proposed MLI-DVR to existing topologies and find that the new system performs well with voltage sag correction. When adjusting the grid voltage, a total harmonic distortion (THD) reduction of 1.28% is achieved to satisfy IEEE standards. Future HVDC and FACTS devices may make use of the proposed technology due to its efficacy.

REFERENCES

[1] M. K. Saini and R. Kapoor, ‘‘Classification of power quality events—A review,’’ Int. J. Electra. Power Energy Syst., vol. 43, no. 1, pp. 11–19, Dec. 2012, doe: 10.1016/j.ijepes.2012.04.045.

[2] D. Li, T. Wang, W. Pan, X. Ding, and J. Gong, ‘‘A comprehensive review of improving power quality using active power filters,’’ Electra. Power Syst. Res., vol. 199, Jun. 2021, Art. No. 107389, doe: 10.1016/j.epsr.2021.107389.

[3] R. Sepehrzad, A. Mahmoodi, S. Y. Ghalebi, A. R. Moridi, and A. R. Seifi, ‘‘Intelligent hierarchical energy and power management to control the voltage and frequency of micro-grids based on power uncertainties and communication latency,’’ Electr. Power Syst. Res., vol. 202, Jan. 2022, Art. no. 107567, doi: 10.1016/j.epsr.2021.107567.

[4] F. K. De Araújo Lima, J. M. Guerrero, F. L. Tofoli, C. G. C. Branco, and J. L. Dantas, ‘‘Fast and accurate voltage sag detection algorithm,’’ Int. J. Electr. Power Energy Syst., vol. 135, Feb. 2022, Art. no. 107516, doi: 10.1016/j.ijepes.2021.107516.
[5] C. Dhanamjayulu and S. Meikandasivam, ‘‘Fuzzy controller based design of 125 level asymmetric cascaded multilevel inverter for power quality improvement,’’ Anal. Integr. Circuits Signal Process., vol. 101, no. 3, pp. 533–542, 2019.
[6] M. Bajaj, ‘‘Design and simulation of hybrid DG system fed single-phase dynamic voltage restorer for smart grid application,’’ Smart Sci., vol. 8, no. 1, pp. 24–38, Apr. 2020, doi: 10.1080/23080477.2020.1748928.
[7] A. B. Kanase-Patil, A. P. Kaldate, S. D. Lokhande, H. Panchal, M. Suresh, and V. Priya, ‘‘A review of artificial intelligence-based optimization techniques for the sizing of integrated renewable energy systems in smart cities,’’ Environ. Technol. Rev., vol. 9, no. 1, pp. 111–136, Jan. 2020, doi: 10.1080/21622515.2020.1836035.
[8] P. Kala and S. Arora, ‘‘A comprehensive study of classical and hybrid multilevel inverter topologies for renewable energy applications,’’ Renew. Sustain. Energy Rev., vol. 76, pp. 905–931, Sep. 2017, doi: 10.1016/j.rser.2017.02.008.
[9] S. M. Silva, S. E. D. Silveira, A. S. Reis, and B. J. C. Filho, ‘‘Analysis of a dynamic voltage compensator with reduced switch-count and absence of energy storage system,’’ IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1255–1262, Sep. 2005, doi: 10.1109/TIA.2005.853382.
[10] M. Fang, A. I. Gardiner, A. MacDougall, and G. A. Mathieson, ‘‘A novel series dynamic voltage restorer for distribution systems,’’ in Proc. Int. Conf. Power Syst. Technol. (POWERCON), vol. 1, Aug. 1998, pp. 38–42, doi: 10.1109/ICPST.1998.728702.
[11] M. R. Banaei and A. R. Dehghanzadeh, ‘‘DVR based cascaded multilevel Z-source inverter,’’ in Proc. IEEE Int. Conf. Power Energy, Nov. 2010, pp. 51–56, doi: 10.1109/PECON.2010.5697556.
[12] S. Jothibasu and M. K. Mishra, ‘‘An improved direct AC–AC converter for voltage sag mitigation,’’ IEEE Trans. Ind. Electron., vol. 62, no. 1, pp. 21–29, Jan. 2015, doi: 10.1109/TIE.2014.2334668.
[13] M. Balamurugan, T. S. Sivakumaran, and M. Aishwariya, ‘‘Voltage sag/swell compensation using Z-source inverter DVR based on FUZZY controller,’’ in Proc. IEEE Int. Conf. Emerg. Trends Comput., Commun. Nanotechnol. (ICECCN), Mar. 2013, pp. 648–653, doi: 10.1109/ICE-CCN.2013.6528580.
[14] E. Salary, M. R. Banaei, and A. Ajami, ‘‘Analysis of hybrid multilevel inverters using a reduced voltage stress switch,’’ Cankaya Univ. J. Sci. Eng., vol. 13, no. 2, pp. 51–56, 2016.
[15] S. Galeshi and H. Iman-Eini, ‘‘Dynamic voltage restorer employing multilevel cascaded H-bridge inverter,’’ IET Power. Electron., vol. 9, no. 11, pp. 2196–2204, Sep. 2016, doi: 10.1049/iet-pel.2015.0335.
[16] E. Salari and A. D. Falehi, ‘‘A novel 49-level asymmetrical modular multilevel inverter: Analysis, comparison and validation,’’ Anal. Integr. Circuits Signal Process., vol. 101, no. 3, pp. 611–622, Dec. 2019.
[17] B.-H. Kwon, G.-Y. Jeong, S.-H. Han, and D.-H. Lee, ‘‘Novel line conditioner with voltage up/down capability,’’ IEEE Trans. Ind. Electron., vol. 49, no. 5, pp. 1110–1119, Oct. 2002, doi: 10.1109/TIE.2002. 803236.
[18] R. J. Satputaley and V. B. Borghate, ‘‘Performance analysis of DVR ‘using new reduced component’ multilevel inverter,’’ Int. Trans. Electr. Energy Syst., vol. 27, no. 4, pp. 1–11, 2017, doi: 10.1002/etep.2288.
[19] J. Ye, H. B. Gooi, X. Zhang, B. Wang, and J. Pou, ‘‘Simplified four-level inverter-based dynamic voltage restorer with single DC power source,’’ IEEE Access, vol. 7, pp. 137461–137471, 2019, doi: 10.1109/ACCESS.2019.2941999.

[20] M. Shahabadini and H. Iman-Eini, ''Improving the performance of a cascaded H-bridge-based interline dynamic voltage restorer,'' IEEE Trans. Power Del., vol. 31, no. 3, pp. 1160–1167, Jun. 2016, doi: 10.1109/TPWRD.2015.2480967.
[21] E. Babaei, M. F. Kangarlu, and M. Sabahi, ''Dynamic voltage restorer based on multilevel inverter with adjustable dc-link voltage,'' IET Power Electron., vol. 7, no. 3, pp. 576–590, Mar. 2014, doi: 10.1049/iet-pel.2013.0179.
[22] G. A. De Almeida Carlos, E. C. Dos Santos, C. B. Jacobina, and J. P. R. A. Mello, ''Dynamic voltage restorer based on three-phase inverters cascaded through an open-end winding transformer,'' IEEE Trans. Power Electron., vol. 31, no. 1, pp. 188–199, Jan. 2016, doi: 10.1109/TPEL.2015.2404798.
[23] G. A. De Almeida Carlos, C. B. Jacobina, J. P. R. A. Mello, and E. C. D. Santos, ''Cascaded open-end winding transformer based DVR,'' IEEE Trans. Ind. Appl., vol. 54, no. 2, pp. 1490–1501, Mar. 2018, doi: 10.1109/TIA.2017.2768531.
[24] K. Rajkumar, P. Parthiban, and N. Lokesh, ''Real-time implementation of transformerless dynamic voltage restorer based on T-type multilevel inverter with reduced switch count,'' Int. Trans. Electr. Energy Syst., vol. 30, no. 4, Apr. 2020, doi: 10.1002/2050-7038.12301.
[25] A. D. Falehi and H. Torkaman, ''Promoted supercapacitor control scheme based on robust fractional-order super-twisting sliding mode control for dynamic voltage restorer to enhance FRT and PQ capabilities of DFIG-based wind turbine,'' J. Energy Storage, vol. 42, Oct. 2021, Art. no. 102983. [26] A. Darvish Falehi, ''Half-cascaded multilevel inverter coupled to photovoltaic power source for AC-voltage synthesizer of dynamic voltage restorer to enhance voltage quality,'' Int. J. Numer. Model., Electron. Netw., Devices Fields, vol. 34, no. 5, p. e2883, Aug. 2021.
[27] A. D. Falehi and M. Rafiee, ''Enhancement of DFIG-wind turbine's LVRT capability using novel DVR based Odd-nary cascaded asymmetric multilevel inverter,'' Eng. Sci. Technol., Int. J., vol. 20, no. 3, pp. 805–824, 2017.
[28] M. J. Newman, D. G. Holmes, J. G. Nielsen, and F. Blaabjerg, ''A dynamic voltage restorer (DVR) with selective harmonic compensation at medium voltage level,'' in Proc. 38th IAS Annu. Meeting Conf. Rec. Ind. Appl. Conf., vol. 2, 2003, pp. 1228–1235.
[29] Y. W. Li, D. M. Vilathgamuwa, F. Blaabjerg, and P. C. Loh, ''A robust control scheme for medium-voltage-level DVR implementation,'' IEEE Trans. Ind. Electron., vol. 54, no. 4, pp. 2249–2261, Aug. 2007.
[30] M. T. Khosroshahi, ''Crisscross cascade multilevel inverter with reduction in number of components,'' IET Power Electron., vol. 7, no. 12, pp. 2914–2924, Dec. 2014.
[31] P. Devalraju and C. Dhanamjayulu, ''A novel 19-level asymmetrical multilevel inverter for dynamic voltage restorer applications,'' in Proc. Innov. Power Adv. Comput. Technol. (i-PACT), 2021, pp. 1–7.
[32] K. Thakre, K. B. Mohanty, A. Chatterjee, and V. S. Kommukuri, ''A modified circuit for symmetric and asymmetric multilevel inverter with reduced components count,'' Int. Trans. Electr. Energy Syst., vol. 29, no. 6, Jun. 2019, Art. no. e12011.
[33] M. A. Hosseinzadeh, M. Sarbanzadeh, E. Sarbanzadeh, M. Rivera, and P. Wheeler, ''New asymmetric cascaded multi-level converter with reduced components,'' in Proc. IEEE Int. Conf. Electr. Syst. Aircr., Railway, Ship Propuls. Road Vehicles Int. Transp. Electrific. Conf. (ESARS-ITEC), Nov. 2018, pp. 1–6.
[34] M. T. Khosroshahi, A. Ajami, A. O. Mokhberdoran, and M. J. Oskuee, ''Multilevel hybrid cascade-stack inverter with substantial reduction in switches number and power losses,'' Turkish J. Electr. Eng. Comput. Sci., vol. 23, no. 4, pp. 987–1000, 2015.

[35] A. Thiruvengadam and K. Udhayakumar, ‘‘An enhanced H-bridge multilevel inverter with reduced THD, conduction, and switching losses using sinusoidal tracking algorithm,’’ Energies, vol. 12, no. 1, p. 81, Dec. 2018.
[36] S. T. Meraj, N. Z. Yahaya, K. Hasan, and A. Masaoud, ‘‘A hybrid T-type (HT-type) multilevel inverter with reduced components,’’ Ain Shams Eng. J., vol. 12, no. 2, pp. 1959–1971, Jun. 2021.
[37] K. K. Gupta and S. Jain, ‘‘Topology for multilevel inverters to attain maximum number of levels from given DC sources,’’ IET Power Electron., vol. 5, no. 4, pp. 435–446, Apr. 2012.
[38] S. N. Rao, D. V. A. Kumar, and C. S. Babu, ‘‘Grid connected distributed generation system with high voltage gain cascaded DC-DC converter fed asymmetric multilevel inverter topology,’’ Int. J. Electr. Comput. Eng., vol. 8, no. 6, p. 4047, Dec. 2018, doi: 10.11591/ijece.v8i6.pp4047-4059.
[39] A. Belkaid, I. Colak, and O. Isik, ‘‘Photovoltaic maximum power point tracking under fast varying of solar radiation,’’ Appl. Energy, vol. 179, pp. 523–530, Oct. 2016, doi: 10.1016/j.apenergy.2016.07.034.
[40] J. G. Nielsen, F. Blaabjerg, and N. Mohan, ‘‘Control strategies for dynamic voltage restorer compensating voltage sags with phase jump,’’ in Proc. APEC. 16th Annu. IEEE Appl. Power Electron. Conf. Expo., 2001, pp. 1267–1273, doi: 10.1109/APEC.2001.912528.
[41] P. Boonchiam and N. Mithulananthan, ‘‘Diode-clamped multilevel voltage source converter based on medium voltage DVR,’’ Int. J. Elect. Power Energy Syst. Eng., vol. 1, no. 2, pp. 590–595, Jan. 2008.
[42] B. Wang, G. Venkataramanan, and M. Illindala, ‘‘Operation and control of a dynamic voltage restorer using transformer coupled H-bridge converters,’’ IEEE Trans. Power Electron., vol. 21, no. 4, pp. 1053–1061, Jul. 2006, doi: 10.1109/TPEL.2006.876836.
[43] K. Chandrasekaran and V. Ramachandaramurthy, ‘‘An improved dynamic voltage restorer for power quality improvement,’’ Int. J. Elect. Power Energy Syst., vol. 82, pp. 354–362, Nov. 2016, doi: 10.1016/j.ijepes.2016.02.036.
[44] M. I. Marei, A. B. Eltantawy, and A. A. El-Sattar, ‘‘An energy optimized control scheme for a transformerless DVR,’’ Electr. Power Syst. Res., vol. 83, no. 1, pp. 110–118, Feb. 2012, doi: 10.1016/j.epsr.2011.09.015.
[45] A. J. Visser, J. H. R. Enslin, and H. D. T. Mouton, ‘‘Transformerless series sag compensation with a cascaded multilevel inverter,’’ IEEE Trans. Ind. Electron., vol. 49, no. 4, pp. 824–831, Aug. 2002, doi: 10.1109/TIE.2002.801067.
[46] A. M. Massoud, S. Ahmed, P. N. Enjeti, and B. W. Williams, ‘‘Evaluation of a multilevel cascaded-type dynamic voltage restorer employing discontinuous space vector modulation,’’ IEEE Trans. Ind. Electron., vol. 57, no. 7, pp. 2398–2410, Jul. 2010, doi: 10.1109/TIE.2010.2041732.