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ANALYTICAL STUDY ON MODELLING OF Z-SOURCE CONVERTER WITH RESPECT TO ADVANCED TOPOLOGIES BASED ON WIND POWER CONVERSION SYSTEM

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A B S T R A C T

A novel control drive for a switching reluctance generator (SRG) driven by a wind energy system is introduced in this work. For the first time, a model predictive control (MPC) technique is used to regulate the SRG in order to deliver the required voltage applied to the phase winding being fed by a z-source converter. Another MPC technique is utilized to run the converter immediately in order to as rapidly as possible follow the reference voltage of the segment before. In order to account for the SRG's nonlinear characteristics, the flux linkage and electromagnetic torque have been produced from the machine's finite element analysis and applied to the model. The generator's output power is enhanced in three different ways by this novel drive. Minimizing the phase current's rise-up time, keeping it in flat-top mode at all speeds, and making the most of the phase inductance's producing zone, or negative slope area. After the complete system is modelled in MATLAB-SIMULINK, the effectiveness of the recommended strategy is evaluated using the simulation results. There are several different topologies for permanent magnet generators, including radial flux, axial flux, and transverse flux PMGs. Due of the permanent axial flux generator's intricate design, large wind turbines cannot use it. Due to the simple design of the radial flux PMG, the manufacturing of many poles may be easily accommodated in the size of wind turbines. In order to overcome this problem, the research project recommends a unique topology quasi-Z-source Matrix converter-based DC/DC that uses a zigzag transformer. It is simulated and contrasted with other existing DC-based Z-source converters. DC will be certified from the start of the power supply unit in DC power supply systems.

K E Y W O R D S

Z-Source Inverter, DC Power Supply Systems, Power Conditioning, DC-DC Converter, and Wind Systems

Introduction

The fast depletion of conventional energy sources is a result of increased consumption rates. More energy sources are therefore required as a result. Wind power is the most alluring of all unconventional resources because of its adaptability. A lot of research is now being done on merging wind energy. The mechanical compression, negative energy input, etc. are all included in the fixed wind speed conversion system [1]. Direct Driven Wind Energy Conversion Systems (DDECS) with permanent magnet generators are used in the most recent wind turbine generator installations; nevertheless, the three-phase power conversion method used by these systems results in considerable conversion losses. This study's primary objective is to decrease this conversion loss by minimizing the number of stages required for energy conversion. Since conventional energy sources like oil, gas, and coal have run out during the past 30 years, renewable energy sources are receiving greater attention these days. The most significant renewable energy systems are thought to be those that use wind and solar energy [2]. A significant source of renewable energy sources in emerging nations is the wind energy conversion program, in particular. According to the Indian Wind Energy Association Report, India has 1,02,788 MW of wind energy. The installed capacity, however, is just 23,499 MW. As a result, the installed volume and the current power are vastly different. Additionally, modern wind turbine generators are unable to provide power in light winds. Traditional generators can produce power at speeds between 600 and 2000 rpm, whereas conventional wind turbines are made to work at speeds between 20 and 200 rpm. Therefore, the only device that can link the turbine and the generator is the gearbox. The fixed wind speed conversion system includes the mechanical compression, negative energy input, etc. [1]. The most recent wind turbine generator installations use Direct Driven Wind Energy Conversion Systems (DDECS) with permanent magnet generators; Consequently, the machine will be bigger in size. These generators also have relatively poor power factor and efficiency. They also need sophisticated braking techniques and significant beginning torque [3].

The price of permanent magnet materials is currently being reduced, which makes them more desirable as permanent magnet generators DDWECS. Because a permanent magnet generator (PMG) may be built without a DC source to excite the field because it always performs more efficiently than traditional generators. Because PMG is compact and has a high flux density (up to 1.4 tesla), it can be built with several poles in a small area. Due to its smaller weight, PMG has a lower starting and operating torque need and can generate power at low wind speeds. PMG velocity may be readily calculated by multiplying the frequency of PMG produced by the quantity of poles. As a result, installing the sensors for Maximum Power Point Tracking (MPPT) is simple [4]. However, to function at very high points, most generator types need a position sensor and complex vector control algorithms. Wind speed causes a continual change in the voltage and frequency of direct drive turbine generators. To manage the voltage, optical power circuit circuits are necessary. Many electrical power-based topologies are already in use in DDWECS. By Ismail et al., the control Z-source matrix converter has been introduced (2019The ZSMC is controlled via model predictive control. MPC models are used to forecast future values of topology parameters like as capacitor voltage, inductor current, and load current. We were able to keep an eye on the controlled variables' reference values thanks to this technique. Because of the uneven distribution of shoot-through placement, switching stress and losses are increased [5]. Power conversion has a new form of converter called a Z-source converter (ZSC), which was launched in 2002 and has special capabilities that can get around VSI and CSI's drawbacks. Implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion using a Z-Source Inverter or impedance source (or impedance-fed) power converter and its control technique. The Z-source inverter (ZSIAC)'s voltage may potentially be regulated to any value between zero and infinity. The power circuit was given the term Z-source converter to set it apart from other traditional VSI and CSI.

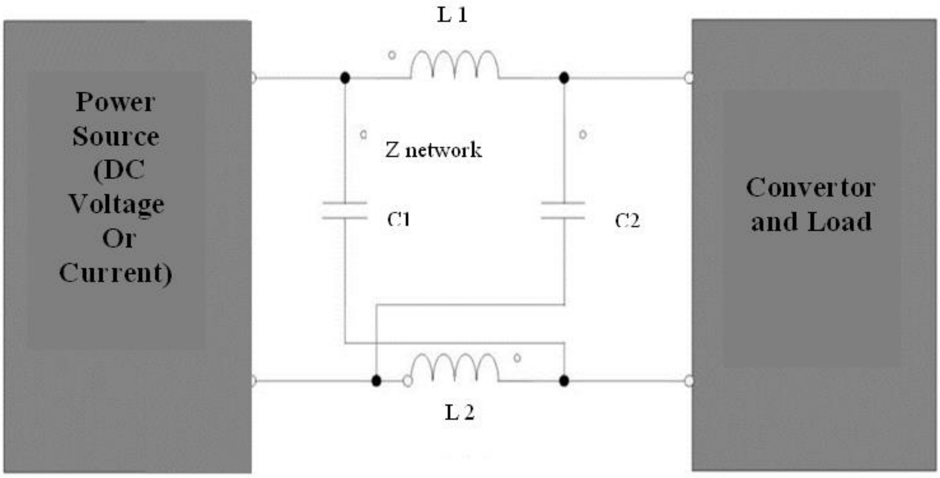

Figure 1 depicts a Z-source converter typical setup [6].

Figure 2 displays a condensed equivalent circuit for a voltage source-based ZSC. In the simplified circuit, the VSI inverter bridge is seen as an equivalent current source or drains connected in parallel with an active switch S2.

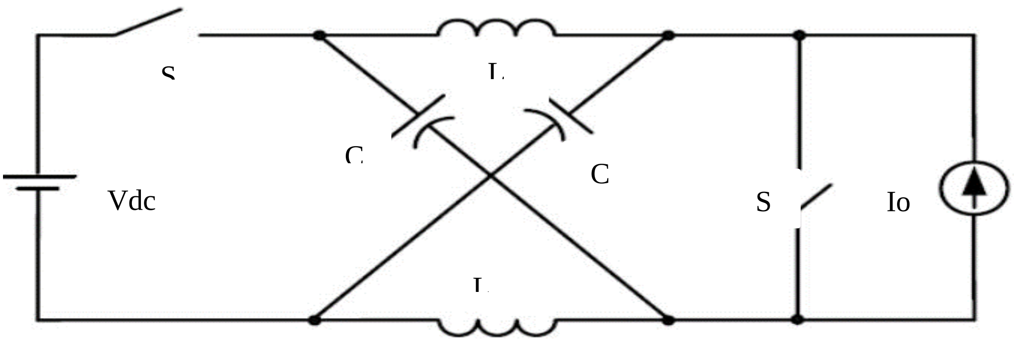

Figure 2 shows the equivalent circuit for a Z-Source Converter based on a voltage source.

The shoot-through condition, unlike a typical VSI, is not detrimental and has been used in ZSI. The study shows that the shoot-through state, as opposed to the non-shoot-through state, controls the system's buck-boost factor. By combining the boost factor with the typical modulation index M of VSI, one can derive the DCAC buck-boost factor.

1. Problem Statement

In a Z-source inverter, two parameters must be modified to get the required output AC voltage. The modulation index is the first, and it is present in conventional voltage source inverters as well. The second variable, known as the boosting factor, is the shoot-through time [18]. The boosting factor can theoretically take values between one and infinity, while the modulation index can take values between zero and one. Therefore, when they are multiplied, the output voltages are all at the required values. When building single-phase Z-source inverters and their control schemes, these two characteristics are taken into account. The modelling, simulation, and control methodologies for achieving dc-to-ac power conversion using a single-phase Z-source inverter are presented [19]. The Sinusoidal carrier-based PWM and Simple Boost Control methods are two different pulse width modulation (PWM) control strategies that are described. In a MATLAB-Simulink environment, the design of Z-source inverter modulation and simulation are performed. Based on simulations performed in MATLAB/Simulink, these strategies are discussed in depth and contrasted. With modulation index and switching frequency, the Z-source element's harmonic profile, output voltage, current, and ripple all change. Additionally, it emphasizes how shoot-through status impacts standard and Z-source inverters. Similarly, there are two distinct applications. The first is based on a photovoltaic (PV) system's performance and simulation analysis using the Z-Source inverter [20].

2. Simulation and experiment results

Utilizing a Z-source inverter and MPRVS-based P&O MPPT, the proposed hybrid PV-Wind microgrid is put to the test. The suggested hybrid microgrid is built on a real-time platform called dSPACE, and Figure 3 shows how its practical structure has been constructed. The MPRVS-based P&O-based MPPT, which uses the current and voltage sensors LV-25P and LA-25P to measure the PV panel parameters VPV and IPV, respectively, controls the SEPIC converter. Utilizing a power quality analyzer (FLUKE 43B), the power factor coefficient and THD are assessed while taking into account the key converter components, including the IGBT (IRG4PH50U), diode (Freewheel RHRG30120), driver circuit (HCPL 3120), and others. The wind turbine generator used in the system is a permanent magnet synchronous generator (PMSG), and the DC motor is mechanically connected to it By adjusting the wind turbine's characteristics, the switched mode power converter causes the wind turbine to have fluctuating wind speed, which generates the necessary mechanical torque.

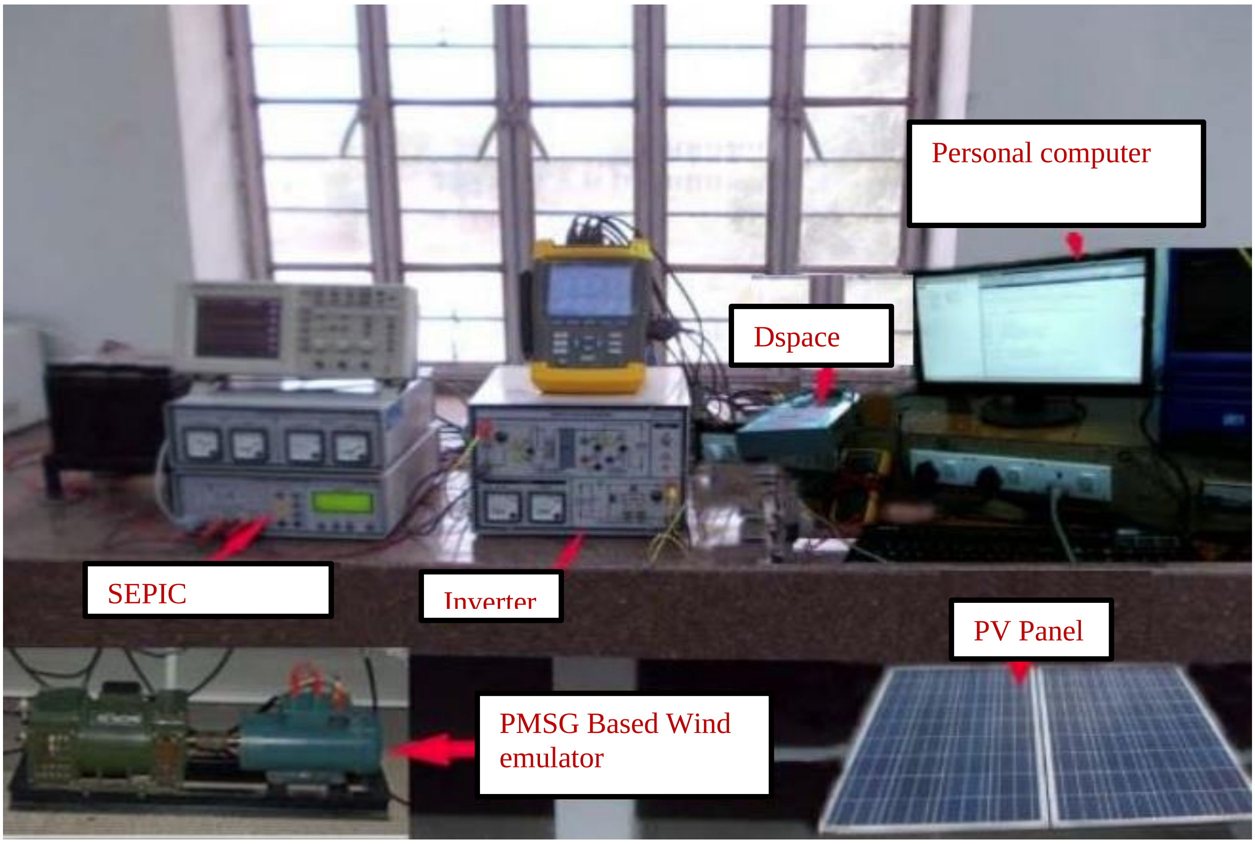

Figure 3 Created an experimental setup for the proposed hybrid microgrid system using the dSPACE platform real-time digital simulator.

The following converter parameters—L1 = L2 = 2mH, C1 = C2 = 20F, and capacitors C3 and C4—are chosen at random for a particular input voltage of 70V. The capacitors C3 and C4 may have different values, such as 1.5 F, 15 F, or 150 F. DC / DC is referred to above. With a frequency switch of 20 Khz, three separate switching systems, and a modulation indicator with a value of 1, topology and simulation are carried out. Tables 1 through 8 show the power assigned to capacitors C3 and C4 for a double voltage reset circuit as well as the DC output voltage achieved from these DC/DC converters. To exhibit the potential for experimental testing of the suggested solution as shown in Fig. 10, the prototype of the investigated topology has been built and tested (a). In place of the grid, the previously discussed topology feeds a local resistive load. The prototype features an induction motor, a variable frequency converter, a dual-star PMSG, a single set of six pulse diode rectifiers, a single-phase double-input Z-source inverter, and a PCI-1716 data collection board (DAQ). The dual-star PMSG prototype was driven by an induction motor that was provided by a variable voltage, variable frequency (VVVF) driver. Table 1 displays the tested dual-star PMSG parameters in accordance with the laboratory prototype.

Table 1 shows the output DC voltage for a two-level Z source inverter-based DC/DC converter for different values of capacitors C3 and C4 for various switching schemes.

Capacitor Values (C3 and C4 in μF)	Output DC Voltage (in volts)		
	Simple Boost PWM	Carrier-based PWM	SVPWM
1.5	105.7	137.7	107.4
17	108.9	178.7	109.5
180	89.7	98.41	96.74

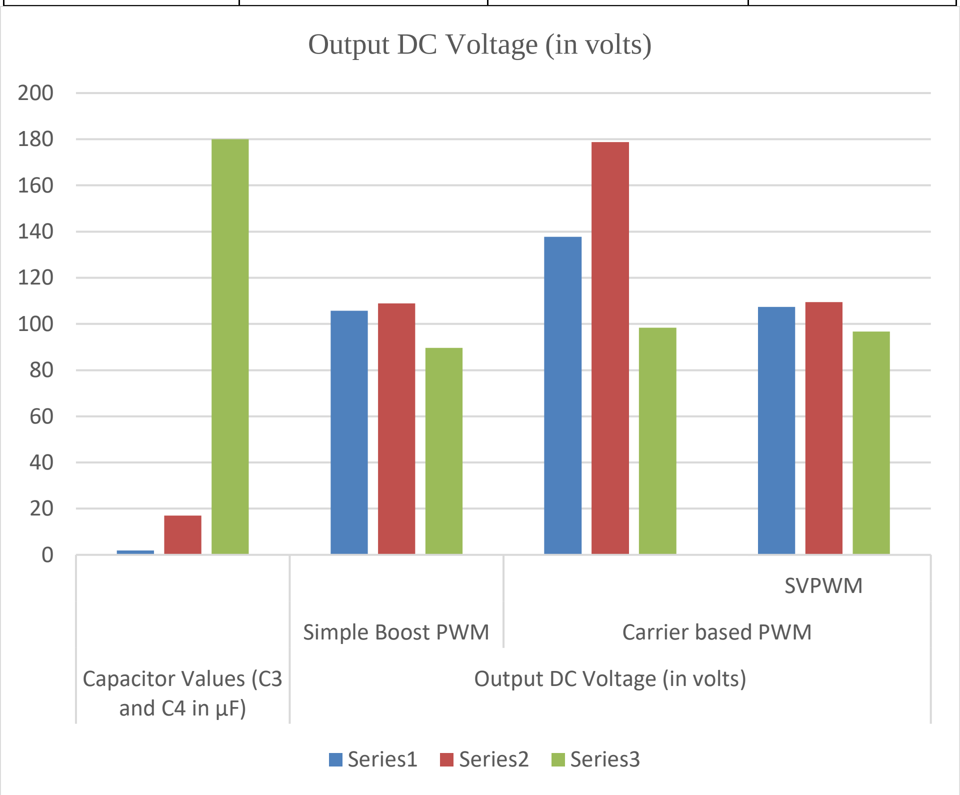

Figure 4 Obtained output Dc voltages for a one-level AC source and a two-level Z source.

Table 2: Two-Level Z Source Inverter-Based DC/DC Converter Capacitors C3 and C4 Voltage Stress Shared by Capacitors

Capacitor Values (C3 and C4 in µF)	Voltage Shared by Capacitors C3 and C4 (involts)		
	Simple Boost PWM	Carrier-based PWM	SVPWM
1.5	(58.05 V, 47.58V)	(47.88 V,67.48V)	(58.22 V, 57.25 V)
15	(64.257V, 52.98 V)	(48.87 V, 65.90 V)	(67.27 V, 45.26 V)
150	(47.11 V,41.19 V)	(61.68 V, 48.97 V)	(47.48V, 43.28 V)

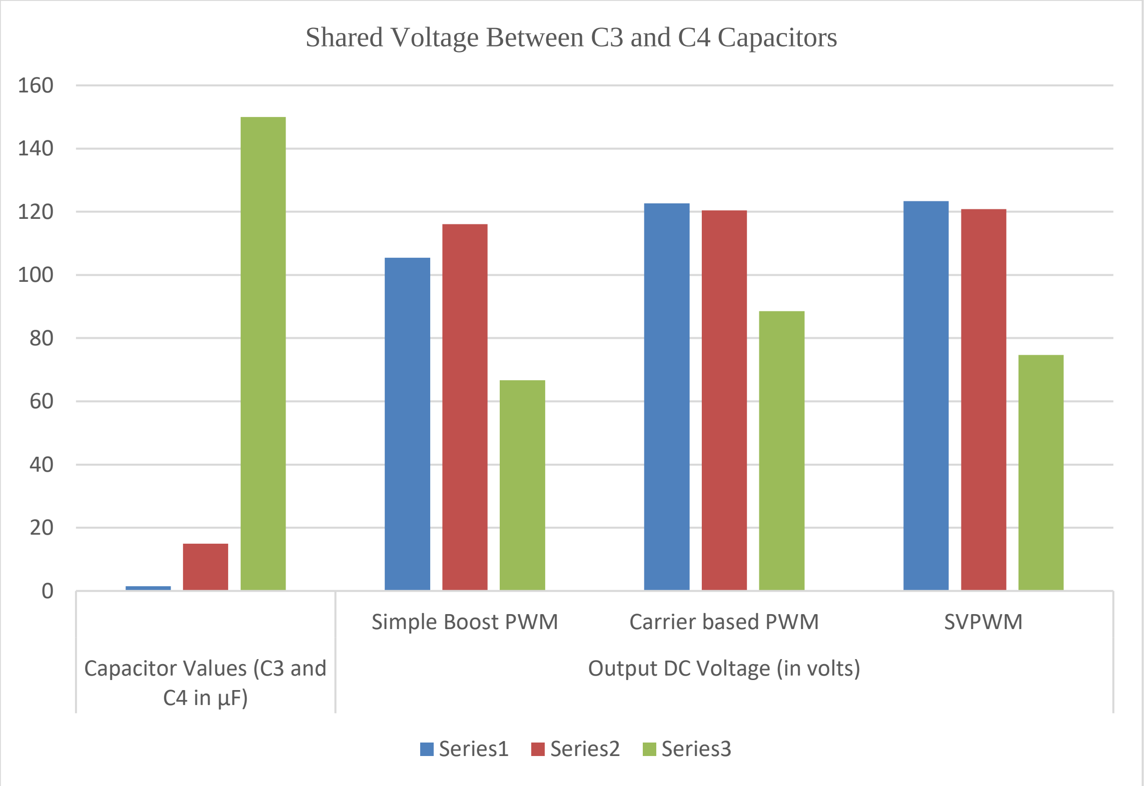

Figure 5 DC/DC Converter Based on a Two-Level Z Source Inverter

Table 3 demonstrates the output DC voltage for a single-phase quasi-Z source network-based DC/DC converter with various values for the capacitors C3 and C4.

Capacitor Values (C3 and C4 in μF)	Voltage Shared by Capacitors C3 and C4 (in volts)		
	Simple Boost PWM	Carrier-based PWM	SVPWM
1.5	(52.74 V, 52.81 V)	(67.9 V, 54.76V)	(58.99 V, 64.45V)
15	(54.33 V,61.81 V)	(58.51 V, 61.87 V)	(57.74 V,63.02V)
150	(32.09 V, 34.56 V)	(41.55 V, 45.96 V)	(36.71V, 37.96 V)

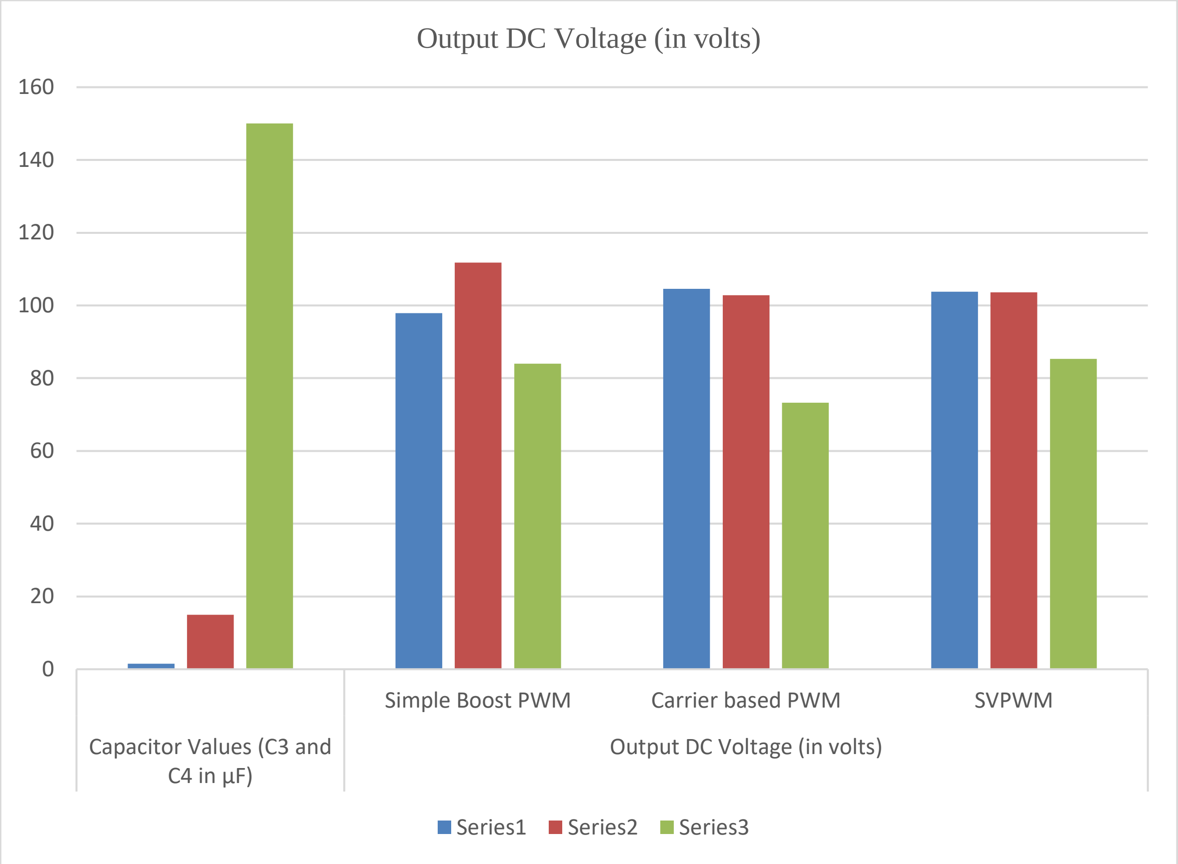

Figure 6 Output DC voltage for a single-phase quasi-Z source network-based DC/DC converter with various values for the capacitors C3 and C4.

Table 4: a three-phase DC/DC converter using a quasi-Z source network, an isolation transformer, and capacitors C3 and C4 that share voltage stress.

Capacitor Values (C3 and C4 in µF)	Voltage Shared by Capacitors C3 and C4 (in volts)		
	Simple Boost PWM	Carrier-based PWM	SVPWM
1.5	(53.1 V, 44.81 V)	(42.85 V, 61.74 V)	(56.13 V, 47.53V)
15	(62.23 V, 49.56 V)	(43.45 V, 59.37 V)	(59.05 V, 44.54 V)
150	(42.59 V, 41.42 V)	(38.84 V, 34.47 V)	(42.43V,42.92V)

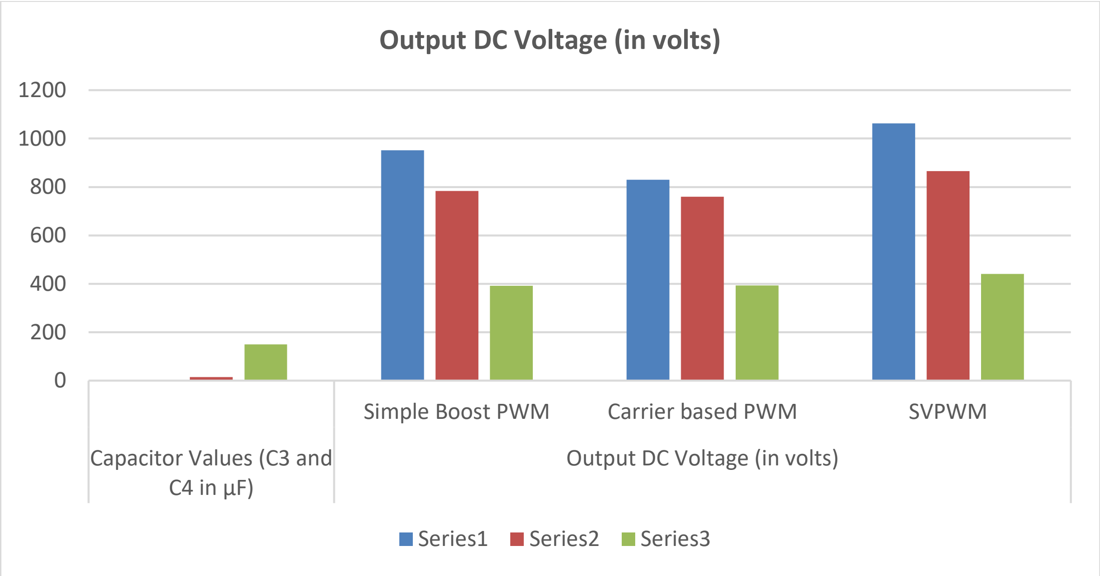

Figure 7 A three-phase DC/DC converter using a quasi-Z source network, an isolation transformer, and capacitors C3 and C4 that share voltage stress.

The capacitor value used for the voltage doubler rectifier circuit has an impact on the output voltage dc of DC/DC converters, as indicated in the tables above. It can be observed that the power-sharing between capacitors C3 and C4 is almost equal if the capacitor value chosen is 150 F. When compared to prior DC/DC-based Z-based converters, the proposed three-phase DC/DC source network with a zigzag transformer and VDR delivers a significant output power output. The two winding sets from the tested dual-star PMSG's no-load phase voltage waveforms at a rotor speed of 60 RPM . The figure demonstrates that two winding sets' phase voltages have the same amplitude and a 30 electrical degree phase change. The Z-input network's DC voltages are about 45 V when the load is connected to the inverter. The output voltage of the Z network is shown; vi values range from 0 to 56. When compared to the DC voltage input, the voltage's magnitude increases by B = 1.25. The experimental inverter's output voltage, Vo, is shown. When measured, three levels fall between 0 and 56.
The capacitor voltage of the Z-network (VC). It is nearly 34 V. The THD of the output voltage (Vo) was found to be around 65% using a power analyzer. A few examples are the speed of the wind, the speed of the rotor, the active power injected into the grid, the q axis of the current injected into the

grid, the capacitor voltage of the Z-network (Vc), and the output voltage of the Z-network. The simulation results validated the performance of the proposed dual-star PMSG model and the control system capabilities of power electronic converters. Additionally, the experimental outcomes confirmed the effectiveness of the suggested inverter and dual-star PMSG in boosting voltage and producing the necessary output voltage waveform.

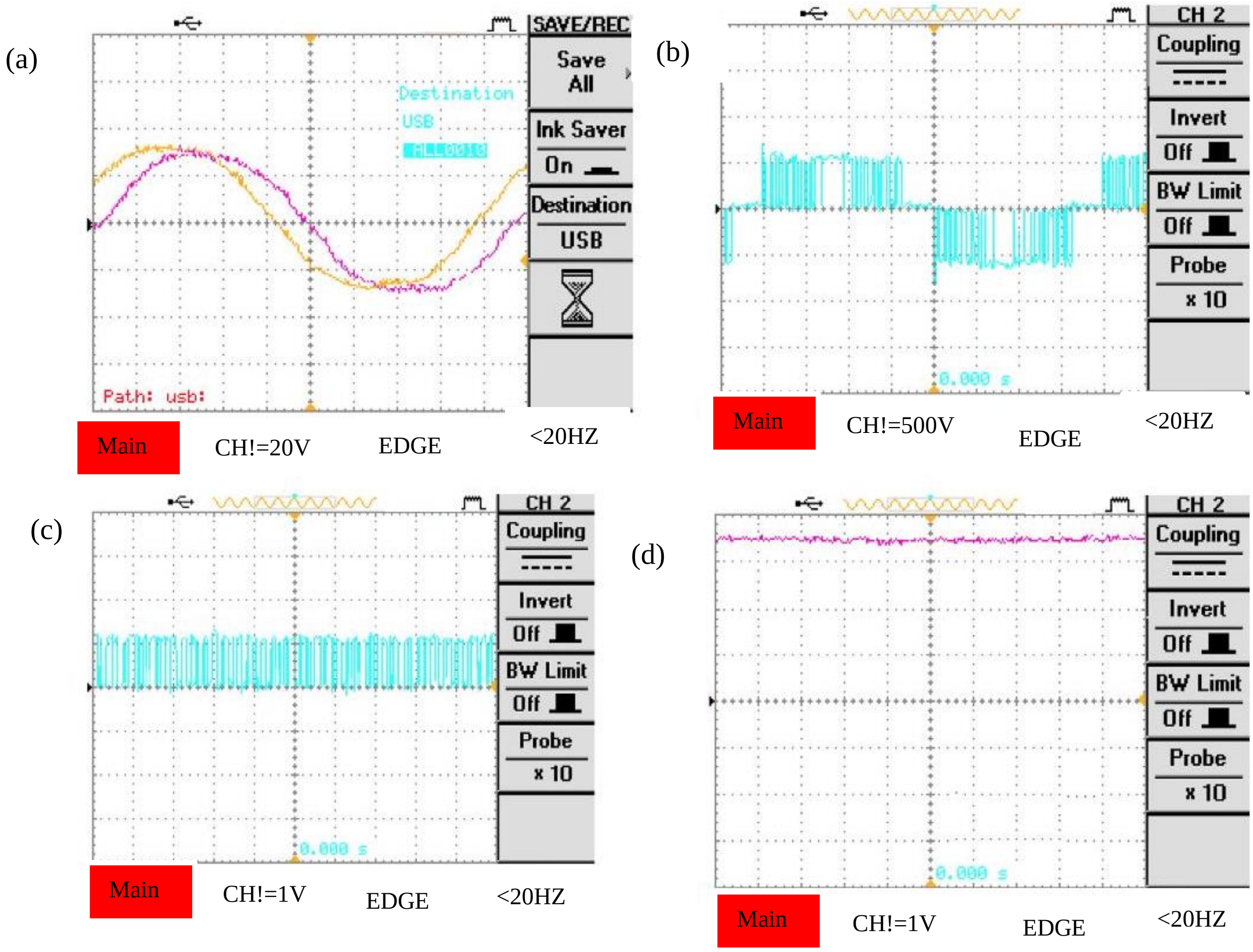

Figure 8 Experimental findings for the suggested system, a representation of the experimental prototype, b the dual-star PMSG output voltage, c the Z network output voltage, and d the inverter output voltage.

CONCLUSION

The topological research of the ZSI source inverter topology described in this paper is conducted using complete simulations. These simulations have several advantages over other ZSI subjects, including improved development capabilities and excellent waveform quality. It is also being tested to use a different Z source with an inverter-based converter architecture. According to the simulation test compared to other conventional Z-based ZO-based topologies, a three-phase quasi-Z-based network converter based on DC / DC flexible zigzag has a stronger converter. Any power setting unit may use the Z source view, and it has been demonstrated that the modelling and simulation of a Z-network with a single-phase full bridge inverter is provided in the MATLAB-Simulink environment, from which several Z-source conversion modes can be generated to validate the design parameters. Simple Boost Control and Sinusoidal carrier-based PWM are recommended as two PWM control methods. Based on simulations performed in MATLAB/Simulink, these strategies are discussed in depth and contrasted. With modulation index and switching frequency, the Z-source element's harmonic profile, output voltage, current, and ripple all change. Additionally, it emphasizes how shoot-through status impacts both standard and Z-source inverters. The successful presentation of two separate applications is similar. The first application is based on the performance and simulation study of a photovoltaic (PV) system based on the source inverter.

References

1. Hansen AD, Michalke G. Multi-pole permanent magnet synchronous generator wind turbines' grid support capability in uninterrupted operation during grid faults. IET Renew Power Gener 2009;3:333–48.
2. Geng Hua, Dewei Xu. Stability analysis and improvements for variable-speed multi pole permanent magnet synchronous generator-based wind energy conversion system. IEEE Trans Sustain Energy 2011;2:459–67.
3. Ko Kyoung-Jin, Jang Seok-Myeong, Park Ji-Hoon, Cho Han-Wook, You Dae- Joon. Electromagnetic performance analysis of wind power generator with outer permanent magnet rotor based on turbine characteristics variation over nominal wind speed. IEEE Trans Magn 2011;47:3292–5.
4. Qiao Wei, Qu Liyan, Harley RG. Control of IPM synchronous generator for maximum wind power generation considering magnetic saturation 2009;45:1095–105.
5. Dehghan SM, Mohamadian M, Varjani AY. A new variable-speed wind energy conversion system using permanent-magnet synchronous generator and Z- source inverter. IEEE Trans Energy Convers 2009;24:714–24.
6. Andriollo Mauro, Bettanini Giulio, Martinelli Giovanni, Morini Augusto, Tortella Andrea. Analysis of double star permanent magnetic synchronous generator by a general decoupled d-q model. IEEE Trans Indus Appl 2009;45 (4):1416–24.
7. Kallio Samuli, Karttunen Jussi, Peltoniemi Pasi, Silventoinen Pertti, Pyrhönen Olli. Determination of the inductance parameters for the decoupled d–q model of double-star permanent-magnet synchronous machines. IET Electr Power Appl 2014;8(2):39–49.
8. Kato Shinji, Inui Yoshitaka, Michihira Masakazu, Tsuyoshi Akira. A low-cost wind generator system with a permanent magnet synchronous generator and diode rectifiers. In: IEEE international symposium on industrial electronics (ISIE); 2011. p. 1063–8.
9. Choube, P. R., & Aharwal, V. K. (2022). Evaluation of Z-Source Inverter Topologies for Power Conditioning Unit for DC Power Supply Systems. Journal of Integrated Science and Technology, 10(3), 209-214.
10. Kumari, S., & Mandal, R. K. (2022). Study of shoot-through control pulse generation for a Z-source converter with wind turbine energy system. Engineering Research Express, 4(3), 035035.
11. Choube, P. R., & Aharwal, V. K. (2022). Development of suitable closed loop system for effective wind power control using different ZSC topologies and different switching techniques. Journal of Integrated Science and Technology, 10(2), 156-167.
12. Kato Shinji, Michihira Masakazu. A comparative study on power generation characteristics of permanent magnet synchronous generators. In: International power electronic conference; 2010. p. 1499–505.

13. Ng CH, Parker MA, Ran L, Tavner PJ, Bumby JR, Spooner E. A multilevel modular converter for a large light weight wind turbine generator. IEEE Trans Power Electron 2008;2(3):1062–74.
14. Chen Z, Guerrero JM, Blaabjerg F. A review of the state of the art of power electronics for wind turbines. IEEE Trans Power Electron 2009;24:1859–75.
15. Carrasco JM, Franquelo LG, Bialasiewicz JT, Galvan E, Guisado RCP, Prats AM, et al. Power electronic systems for the grid integration of renewable energy sources: A survey. IEEE Trans Industr Electron 2006;53:1002–16.
16. Polinder H, Van de Pijl FFA, de Vilder G-J, Tavner PJ. Comparison of direct drive and geared generator concepts for wind turbines. IEEE Trans Energy Convers 2006;21:725–33.
17. Chinchilla M, Arnaltes S, Burgos JC. Control of permanent-magnet generators applied to variable-speed wind-energy systems connected to the grid. IEEE Trans Energy Convers 2006;21:130–5.
18. Peng FZ. Z-source inverter. In: Proc. IEEE/IAS annu. meeting; 2002. p. 775–81.
19. Erginer V, Sarul MH. A novel reduced leakage current modulation technique for Z-source inverter used in photovoltaic systems. IET Power Electron 2014;7:496–502.
20. Li Ding, Loh Poh Chiang, Zhu Miao, Gao Feng, Blaabjerg F. Cascaded multicell trans-Z-source inverters. IEEE Trans Power Electron 2013;28:826–36.
21. Tang Yu, Xie Shaojun, Ding Jiudong. Pulse width modulation of Z-source inverters with minimum inductor current ripple. IEEE Trans Industr Electron 2014;61:98–106.
22. Banaei Mohamad Reza, Dehghanzadeh Ali Reza, Fazel Ali, Oskouei Aida Baghbany. Switching algorithm for single Z-source boost multilevel inverter with ability of voltage control. IET Power Electron 2013;6:1350–9.
23. Manjunatha, B. M., Rao, S. N., Kumar, A. S., Devi, V. L., Mohan, P. R., & Bramhanandam, K. (2022). An Enhanced Z-Source Switched MLI Capacitor for Integrated Micro-Grid with Advanced Switching Pattern Scheme. Engineering, Technology & Applied Science Research, 12(4), 8936-8941.
24. Akshath, N. S. S., Naresh, A., Barman, M., Nandan, D., & Abhilash, T. (2022). Analysis and simulation of even-level quasi-Z-source inverter. International Journal of Electrical & Computer Engineering (2088-8708), 12(4).
25. Zenk, O., & Ertuğral, B. Electric Vehicle Application of Fuzzy Logic Controlled Z Connected DC Converter Topology.
26. Rafiq, M. A., Ulasyar, A., Uddin, W., Zad, H. S., Khattak, A., & Zeb, K. (2022). Design and Control of a Quasi-Z Source Multilevel Inverter Using a New Reaching Law-Based Sliding Mode Control. Energies, 15(21), 8002.
27. Korlepara, N. P., Elanchezhian, E. B., & Subramani, P. (2022). Analysis of Dual Stator Winding Induction Generator-Based Wind Energy Conversion System Using Artificial Neural Network Maximum Power Point Tracking. International Journal of Renewable Energy Research (IJRER), 12(1), 372-382.
28. Alzahrani, A., Ramu, S. K., Devarajan, G., Vairavasundaram, I., & Vairavasundaram, S. (2022). A review on hydrogen-based hybrid microgrid system: Topologies for hydrogen energy storage, integration, and energy management with solar and wind energy. Energies, 15(21), 7979.
29. Ramanathan, G., Bharatiraja, C., Srikar, R. S., & Tej, D. S. (2022). Implementation of modified Z-source inverter integrated for electric vehicle fast charging. Materials Today: Proceedings, 65, 265-270.

30. Mande, D., Trovão, J. P. F., Ta, M. C., & Do, T. V. (2022). Dual-Source Bidirectional Quasi-Z-Source Inverter Development for Off-Road Electric Vehicles. World Electric Vehicle Journal, 13(9), 174.
31. Rauf, T., Furqan, M., Zulifqar, S., & Rafiq, S. (2022). Implementation and Performance Analysis of Z Source Inverter with Space Vector PWM Technique with Low THD Factor and High Gain. Journal of Electrical and Electronic Engineering, 10(3), 95-103.
32. Pangtey, T., & Naik, M. V. (2022, July). Control and Analysis of SEPIC Topology based Boost DC-DC Converter with High Gain for Fuel Cell Fed Electric Vehicle Driving System. In 2022 IEEE Students Conference on Engineering and Systems (SCES) (pp. 01-06). IEEE.
33. Ravindran, R., Sathiasamuel, C. R., Ramasamy, P., & Balasubramanian, K. (2021). MSVM-based hybrid energy-fed quasi-Z-source cascaded H-bridge inverter for grid-connected system. International Transactions on Electrical Energy Systems, 31(12), e13139.
34. Beena, V., & Jayaraju, M. Analysis of Grid-Connected Single-Phase Quasi Z Source Inverter for Distributed Generation Systems.
35. Immanuel, T. B., Rathnavel, M. P., Suresh, A., & Manikandan, K. Inter Combining Quazi Z Source Network With Matrix Converter For Wind Powered Distribution System.
36. Subhani, N., Kannan, R., Mahmud, M. A., Roy, T. K., & Romlie, M. F. (2019). Analysis of steady-state characteristics for a newly designed high voltage gain switched inductor Z-source inverter. Electronics, 8(9), 940.