International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 2, Mar-Apr 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Performance analysis of Power Electronic Circuit for Multilevel Inverter

Manisha Muvel[1], C. K. Tiwari[2], Dr. Jay Tiwari[3], Dr. Dev Kumar Rai[4]

[1,2]Department of Electronics & Communication,
[1,2,3,4]Patel College of Science and Technology, Indore, Madhya Pradesh, India

ABSTRACT
This research focuses on the design, analysis, and performance evaluation of a five-level inverter, a crucial component in modern power electronic systems. Multilevel inverters have gained widespread attention due to their ability to generate higher voltage levels with improved output waveform quality compared to conventional two-level inverters. These inverters play a vital role in applications such as renewable energy integration, high-voltage DC (HVDC) transmission, and industrial motor drives. This study provides a comprehensive examination of the working principles, design considerations, control methodologies, and advantages of multilevel inverters. The research also investigates different modulation techniques and their impact on efficiency, power quality, and harmonic reduction. Experimental results and simulations are analyzed to validate the performance of the proposed inverter topology. The findings of this study contribute to the development of more efficient and reliable power electronic systems, addressing the growing demands of modern power grids and industrial applications.

KEYWORDS: *Power grid, High voltage DC (HVDC), Multilevel inverter, Integrated power systems, PEBB hardware*

How to cite this paper: Manisha Muvel | C. K. Tiwari | Dr. Jay Tiwari | Dr. Dev Kumar Rai "Performance analysis of Power Electronic Circuit for Multilevel Inverter" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-2, April 2025, pp.455-463, URL: www.ijtsrd.com/papers/ijtsrd78357.pdf

IJTSRD78357

1. INTRODUCTION

The use of semiconductor power switches for the conversion and control of electric power is known as power electronics. High voltage DC (HVDC) power transmission was one of the first uses of power electronics in electric power grids, starting in the 1950s. Power electronics finds applications both at the load and grid levels [1-2]. The grid-level applications are FACTS and HVDC. Power electronics find significantly more uses at the load level. Two significant uses are switching power supply and electric DC and AC drives. Digital grids of the future will mostly consist of power electronics-based DGRs [3-4]. Stated differently, power electronics will supply essential technology for the digital grids of the future. Power electronics equipment will find extensive grid-level uses in the upcoming digital. Since the energy industry is changing and other new technologies are being applied, power electronics will find many useful uses [5-6].

Power electronics has extensive applications at both the grid level and the load level. At the grid level, Flexible AC Transmission Systems (FACTS) and High Voltage DC (HVDC) transmission enhance efficiency and stability [7-10]. At the load level, applications include switching power supplies, electric DC and AC drives, and advanced distributed generation resources (DGRs) [3-4]. Future digital grids will rely heavily on power electronics-based infrastructures, integrating renewable energy sources, intelligent control systems, and advanced semiconductor technologies. With the emergence of Quantum-dot Cellular Automata (QCA) and quantum-dot computing, next-generation power electronics could experience a paradigm shift in design, performance, and efficiency [13-15]. QCA-based circuits offer ultra-fast switching speeds with low power dissipation, making them suitable for energy-efficient power control systems [16-21]. Wireless communication technologies, combined with quantum-dot computing, can further improve real-time monitoring, fault detection, and adaptive control of multilevel inverters in smart grids and industrial automation [5-6].

2. Power electronics building block concept

Power electronics play an increasingly important part in almost every application where electricity is used since it is a type of energy that can be transformed into various voltage levels, frequencies, pulses, direct current (dc), and other energy forms [15]. This opens up new applications, improves energy efficiency, and allows for the development of new energy generation sources like solar, fuel cells, wind, and novel types of storage. Applications in the maritime domain are not an exception [19]. Power electronics provide medium voltage alternating current (ac) or dc integrated power systems (IPS), variable speed propulsion engines, and optimal utilization of power and energy sources for ships [3]. An increasing number of offshore gas and oil facilities are using HVDC underwater cables to get power from the coast. It has long been understood that resourcefulness and effectiveness in using Three general categories can be used to classify power electronics systems: series-connected voltage controllers, shunt-connected current controllers, and combinations of these [9]. Either a voltage reference signal or a current reference signal should be the output signal for the application level control at the interface. Based on such reference signals, a division between control subsystems that oversee application functions and those that generate the behavior of a regulated current or voltage source can be made [22]. For instance, Fig. 1 depicts the condensed control layer architecture for the shunt setup.

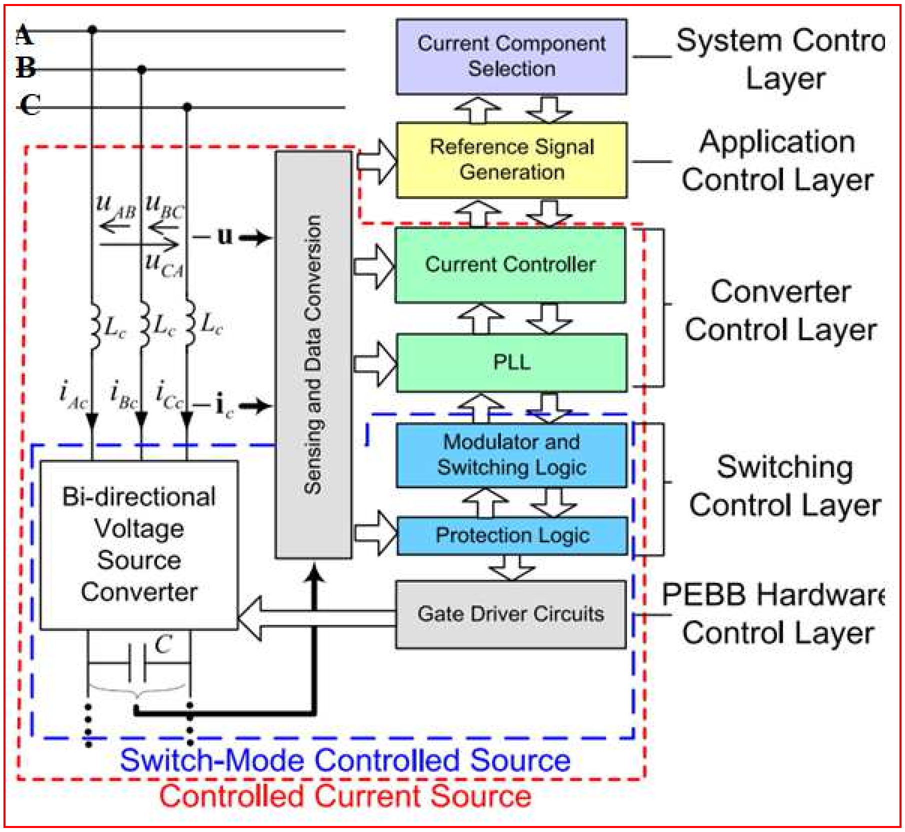

Fig. 1: Converter block diagram with functional portioning

The functionalities that allow some system components to operate as switch-mode controlled voltage sources or controlled current sources are enclosed by dashed lines in Figure 1. Here, the term "controlled current source" refers to the resistance [23]. The coupling impedance's terminals on the PEBB hardware side define the switch-mode voltage source. These divide the three middle levels and help with the system's functional segmentation. Furthermore, the lowest and uppermost layers are made up of functions that are directly related to the converter hardware and those that are supervisory to the application. The shunt design is displayed here because it is the most typical, but the same partitioning holds true for the other converter groups [5, 8, 12, 24]. It is crucial to remember that splitting off hardware modules won't affect the hardware control layer's fundamental duties and will remain invisible to higher control layers.

A. System Control layer

This layer includes all operations that are involved in determining the system mission and, consequently, the responsibilities of the power electronics system or its mode of operation. Any human-machine interfaces would also be included in this layer. All power electronics system operations required to carry out the system mission are carried out by the lower control layers, as seen from the perspective of the system controller.

B. Application Control Layer
In order to fulfill the objective specified by the system control, the application control layer directs how the power electronics system operates. The power electronics system can be seen as either of the two potential equivalent devices—a controlled voltage source or a controlled current source—from the application controller's point of view thanks to its lower control layers [3].

C. Converter Control Layer
The feedback control system is the main feature of the converter control layer, and its input and output requirements are supported by the other components. Many of the features shared by all converters, including measurements, feedback control computations, current and voltage filtering, synchronous timing (PLL), and measurements, are implemented by the converter control layer [6]. Since the application control layer, converter control layer, and switching control layer can all employ the PLL, it is depicted independently in Fig. 1. The temporal distribution in this instance is what determines its placement in the converter control layer.

D. Switching Control Layer
The power electronics can operate as a switch-mode controlled source and perform tasks like modulation control and pulse generation thanks to the switching control layer and all lower levels. These are standard features that don't depend on the finished product. The definition of a switch mode controlled source in this context is one where its terminals are connected directly to the PEBB hardware's power terminals [8].

3. Literature review
In applications like power converters for micro-grids and data centers, inverters for solar and energy, motor drives, hybrid electric vehicles, power management ICs, and similar switch-mode power and energy conversion systems, there is an increasing need to improve efficiencies at the circuit and system level due to advancements in power electronics. Power semiconductor devices, which are the foundation of all power electronics systems, have a major role in determining switching speeds, power quality, power density, system cost, efficiency, and other comparable performance parameters that are essential to power electronics-based systems and circuits. In these systems, silicon-based switching components including MOSFETs, IGBTs, diodes, thyristors, SCRs, CoolMOS, etc. have dominated the market. Nonetheless, recently developed wide band-gap semiconductors like gallium nitride (GaN) and silicon carbide (SiC) With GaN device commercialization, their market will expand and reach a broad variety of power applications in electronics [1]–[3]. Compact models are desperately needed so that designers can accurately predict transient states in power electronics systems and simulate circuits thanks to the increasing ubiquity of GaN devices. A concise physics-based model for the current generation of GaN power devices is presented in this study.

4. Performance of GAN Hemt Device
In order to formulate an accurate compact model and produce accurate terminal behavior, one must have a thorough grasp of the device's physical behavior. Commercial TCAD simulators can be used to characterize the device under different bias situations and to provide a proper knowledge of the device behavior. This study uses ATLAS-Silvaco, a well-liked TCAD simulator for semiconductor process design that is generally accessible in academic institutions. It is utilized to demonstrate the qualitative device behavior for the high-voltage GaN gate injection transistor (GIT). Fig. 2(a) depicts the approximate device structure of a high-voltage enhancement-mode GIT. Fig. 2(b) displays the matching energy-band diagram for it. The AlGaN/ hetero structure generated Two-dimensional electron gas (2DEG) at the junction with extremely high carrier mobility in the restricted quantum well is produced by the GaN material system in huge concentrations. The behavior of hetero junctions, like group III-V nitrides, has been extremely effectively utilized for RF devices; nevertheless, because of the high carrier concentration at the hetero junction, these devices are by default depletion-mode devices. As shown in the diagram, a p-type cap layer with majority-holes is utilized below the gate. These holes mix with the electrons from the AlGaN layer below the gate to deplete the channel of carriers needed for the current from the drain-source to condense while lifting the gate.

5. Analytical Model Description
In order to create a compact model for GaN devices that may be utilized in circuit simulations incorporating topologies containing GaN GITs, this research proposes a physics-based method. The model approximates the device's dc behavior under the effect of externally supplied biases at its terminals by utilizing the classical drift-diffusion model for carrier transport. The following part provides a step-by-step description of the equations used in the formulation of the compact model. The table 1 represents the Parameters used in simulation.

Table 1: Parameters used in simulation

Elements	Parameters	Values
DG1 and DG2	Nominal output voltage (rms)	220V
	Nominal frequency	50Hz
	DC link voltage	700V
	Rated active power	1.5kW
	Rated reactive power	200var
	Filter inductor	0.1Ω, 2mH
	Filter capacitor	0.2Ω, 10μF
	Feeder1	0.1Ω, 2mH
	Feeder2	0.2Ω, 3mH
Conventional load	Real power	2kW
	Reactive Power	150var
Power electronics Load	Filter inductor	5mH
	DC link voltage	700V
	Real Power	1.5kW
Controller	Switching frequency	10kHz

6. Steady State Results

In the Fig. 2 displays the steady-state phase voltage (1), the pole voltage Va'o of the FC inverter (2), the pole voltage Vaa' of the CHB inverter (3), the phase current (4), and the operation (linear modulation range) for 10Hz, 18Hz, 30Hz, 40Hz, 45Hz, and 48Hz for a-phase. For 10Hz, 18Hz, 30Hz, and 40Hz operation, PWM scheme 1 is employed. 48 samples per cycle (spc) are obtained for 10Hz and 18Hz operations, while 24 samples per cycle (spc) are used for 30Hz and 40Hz operations. PWM scheme 2 is put into practice for operation at 45 Hz and 48 Hz (12 spc). It should be noted that the FC inverter only has four switching transitions in a single fundamental cycle because it switches in quasi-square mode. Low switching losses in the FC inverter are the outcome of this.

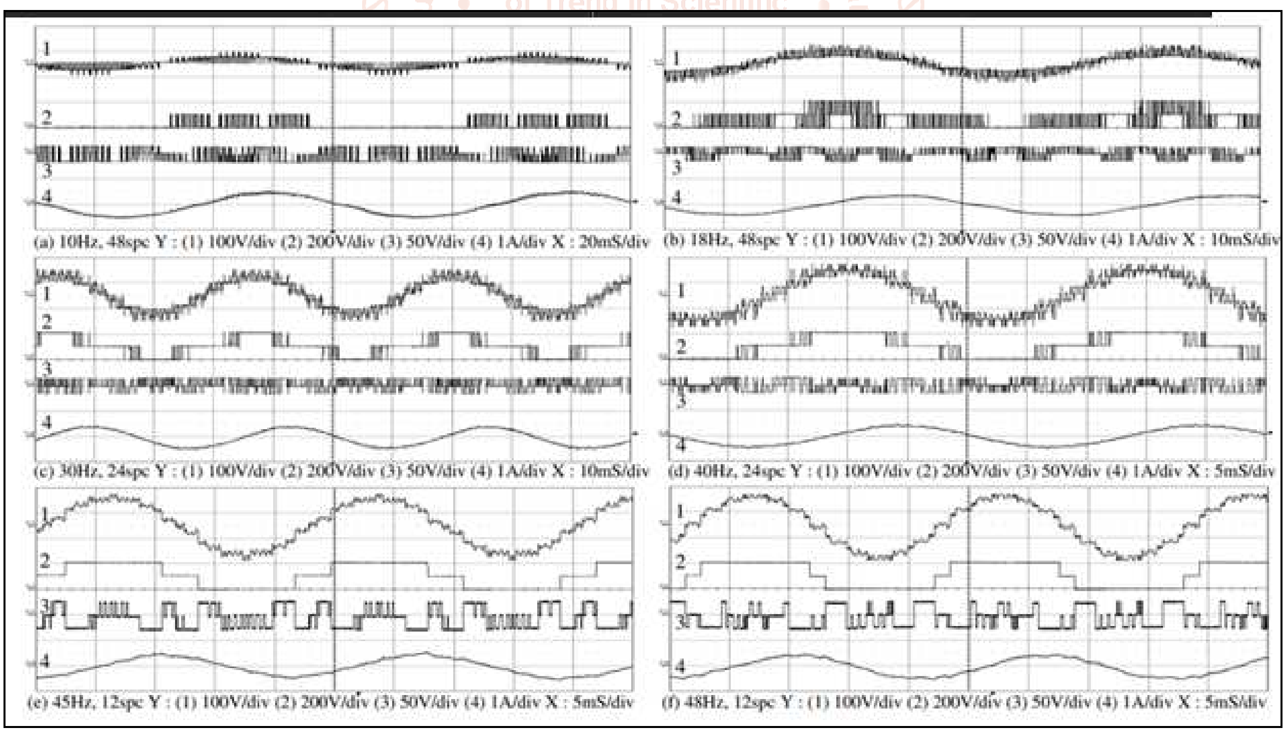

Fig.2 Study-state results: (1) Phase voltage, (2) FC inverter pole voltage, (3) CHB inverter pole voltage, (4) Phase current.

The 50Hz operation is depicted in Fig. 3(a), and the FFT analysis of the 50Hz output waveforms is provided in Fig. 3(b). Note that the FFT displays the presence of 5th and 7th order harmonics, and that the FC inverter produces square wave output. The 5th and 7th order harmonics are eliminated from the FC inverter output by switching the CHB inverter. The final phase voltage output FFT, which displays the absence of 5th and 7th order harmonics, makes this clear.

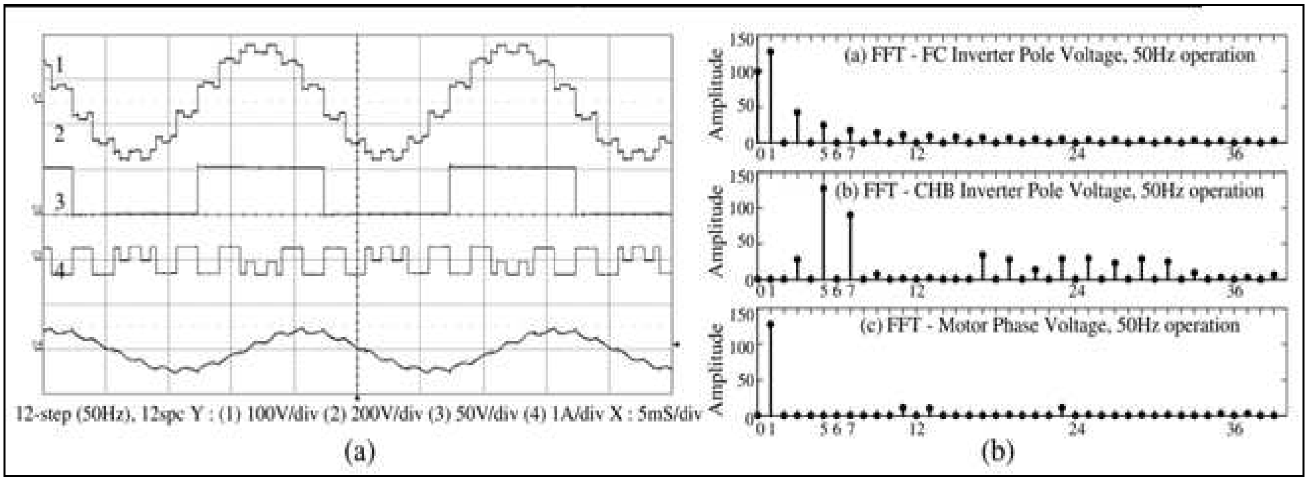

Fig. 3 Steady-state results for extreme over-modulation operation 50Hz.

A. Result analysis

The inverter startup is depicted in Fig. 8(a), where the DC-link voltage is progressively ramped up to Vdc = 200V. Take note of how the capacitor voltages reach their steady state levels. As a result, the PWM method used causes the capacitor voltage to grow up naturally, negating the need for pre-charging circuitry. The acceleration from 10Hz to 48Hz is shown in Fig. 8(b). Constant state values are maintained for capacitor voltages.

7. Conclusion

This study presented a comprehensive analysis and design of a five-level multilevel inverter, highlighting its advantages, operational principles, and significance in modern power electronics applications. Multilevel inverters have demonstrated their capability to enhance output waveform quality, reduce harmonic distortion, and improve efficiency compared to conventional inverters. The research explored various control schemes, capacitor effects, and switching strategies to optimize inverter performance. Through steady-state and transient analysis, the proposed multilevel inverter exhibited stable operation across different frequencies, confirming its suitability for applications in power grids, renewable energy systems, and electric drives. The harmonic elimination results emphasized the effectiveness of cascaded H-bridge and flying capacitor inverters in achieving improved power quality. As power electronics continue to evolve, the integration of wide bandgap semiconductors such as GaN and SiC will further enhance inverter efficiency and switching speeds. Future research could focus on advanced modulation techniques and hybrid topologies to further improve performance and adaptability in smart grid and industrial applications.

References

[1] B. Wu, *High-Power Converters and AC Drives*, Wiley-IEEE Press, 2006.

[2] S. Patel, "Migrating to the Cloud: A Step-By-Step Guide for Enterprise," *Iconic Research and Engineering Journals*, vol. 7, no. 2, 2023.

[3] M. Patidar et al., "A Deep Learning Approach to Improving Patient Safety in Healthcare Using Real-Time Face Mask Detection," *IEEE International Conference on Advances in Computing Research on Science Engineering and Technology (ACROSET)*, Indore, India, 2024, pp. 1-6, doi: 10.1109/ACROSET62108.2024.10743262.

[4] J. Holtz, "Pulsewidth modulation–A survey," *IEEE Transactions on Industrial Electronics*, vol. 39, no. 5, pp. 410-420, Oct. 1992.

[5] S. Patel, "Optimizing Wiring Harness Minimization through Integration of Internet of Vehicles (IOV) and Internet of Things (IoT) with ESP-32 Module: A Schematic Circuit Approach," *International Journal for Research Trends and Innovation*, vol. 8, no. 9, pp. 95-103, 2023.

[6] P. Suraj, "Cloud Computing: Revolutionizing IT Infrastructure with On-Demand Services and Addressing Security Challenges," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 20, 2024.

[7] M. Malinowski, K. Gopakumar, J. Rodriguez, and M. A. Pérez, "A survey on cascaded multilevel inverters," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2197-2206, Jul. 2010.

[8] R. Yadav, P. Moghe, M. Patidar et al., "Performance Analysis of Side Lobe Reduction for Smart Antenna Systems Using Genetic Algorithms (GA)," *14th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Delhi,

India, 2023, pp. 1-5, doi: 10.1109/ICCCNT56998.2023.10306796.

[9] M. Patidar et al., "An Ultra-Area-Efficient Full Adder Circuits Design Based on Nanoscale QCA Technology," *Design Engineering (Toronto)*, vol. 2021(9), pp. 3713-3728, 2021.

[10] L. M. Tolbert, F. Z. Peng, and T. G. Habetler, “Multilevel converters for large electric drives,” *IEEE Transactions on Industry Applications*, vol. 35, no. 1, pp. 36-44, Jan./Feb. 1999.

[11] K. Gupta, M. Patidar et al., "A Review on NFC for Secure Transaction, Its Fundamental Challenges, and Future Directions," *IEEE International Conference on Advances in Computing Research on Science Engineering and Technology (ACROSET)*, Indore, India, 2024, pp. 1-7, doi: 10.1109/ACROSET62108.2024.10743462.

[12] A. Nabae, I. Takahashi, and H. Akagi, “A new neutral-point-clamped PWM inverter,” *IEEE Transactions on Industry Applications*, vol. IA-17, no. 5, pp. 518-523, Sep. 1981.

[13] P. Suraj, "An Overview of Cloud Computing Impact on Smart City Development and Management," *International Journal of Trend in Scientific Research and Development*, vol. 8, no. 6, 2024.

[14] S. Patel, "Enhancing Image Quality in Wireless Transmission through Compression and De-noising Filters," *International Journal of Trend in Scientific Research and Development*, vol. 18, 2021.

[15] J. Rodriguez, J. S. Lai, and F. Z. Peng, “Multilevel inverters: A survey of topologies, controls, and applications,” *IEEE Transactions on Industrial Electronics*, vol. 49, no. 4, pp. 724-738, Aug. 2002.

[16] F. Z. Peng, “A generalized multilevel inverter topology with self-voltage balancing,” *IEEE Transactions on Industry Applications*, vol. 37, no. 2, pp. 611-618, Mar./Apr. 2001.

[17] S. Patel, "Performance Analysis of Acoustic Echo Cancellation using Adaptive Filter Algorithms with Rician Fading Channel," *IJTSRD*, vol. 6, no. 2, pp. 1541-1547, 2022.

[18] P. Suraj, "Optimizing Energy Efficiency in Wireless Sensor Networks: A Review of Cluster Head Selection Techniques," *International Journal of Trend in Scientific Research and Development*, vol. 6, no. 2, 2022.

[19] S. Nagar, M. Patidar et al., "Review and Explore the Transformative Impact of Artificial Intelligence (AI) in Smart Healthcare Systems," *IEEE International Conference on Advances in Computing Research on Science Engineering and Technology (ACROSET)*, Indore, India, 2024, pp. 1-5, doi: 10.1109/ACROSET62108.2024.10743527.

[20] P. K. Bhanodia, S. Rajput, S. Patel, K. Gupta, K. K. Sethi, et al., "Efficient Design of Half-Adders and EXOR Gates for Energy-Efficient Quantum Computing with Delay Analysis Using Quantum-Dot Cellular Automata Technology," *International Conference on Artificial Intelligence of Things for Smart Applications*, 2024.

[21] M. F. Escalante, J. C. Vannier, and A. Arzandé, “Flying capacitor multilevel inverters and DTC motor drive applications,” *IEEE Transactions on Industrial Electronics*, vol. 49, no. 4, pp. 809-815, Aug. 2002.

[22] D. K. Sharma, M. Patidar et al., "Exploring the Impact of Node Velocity on Communication Overhead and Energy Consumption in WSNs Using Fuzzy Clustering," *IEEE International Conference on Advances in Computing Research on Science Engineering and Technology (ACROSET)*, Indore, India, 2024, pp. 1-5, doi: 10.1109/ACROSET62108.2024.10743792.

[23] P. Suraj, "Edge Computing vs. Traditional Cloud: Performance & Security Considerations," *Spanish Journal of Innovation and Integrity*, vol. 12, pp. 312-320, 2022.

[24] N. Gupta, "An Ultra-Efficient Design and Optimized Energy Dissipation of Reversible Computing Circuits in QCA Technology Using Zone Partitioning Method," *Springer Nature, International Journal of Information Technology*, vol. 14, pp. 1483–1493, 2022, doi: 10.1007/s41870-021-00775-y.

[25] M. Patidar, N. Gupta, "An Energy-Efficient High-Speed Quantum-Dot Based Full Adder Design and Parity Gate for Nano Application," *Elsevier ScienceDirect, Materials Today: Proceedings*, vol. 62(7), pp. 4880-4890, 2022, doi: 10.1016/j.matpr.2022.03.532.

[26] S. Patel, "Demystifying Serverless Computing: A Guide to Cost-Effective Cloud Infrastructure," *International Journal of Novel Research and Development*, vol. 9, no. 8, pp. e364-e381, 2024.

[27] S. Patel, "Challenges and Technological Advances in High-Density Data Center Infrastructure and Environmental Matching for Cloud Computing," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 25, 2021.

[28] S. Patel, "Cloud Security Best Practices: Protecting Your Data in a Multi-cloud Environment," *International Journal of Novel Research and Development*, vol. 9, no. 11, pp. d166-d236, 2024.

[29] M. Patidar et al., "Efficient Designs of High-Speed Combinational Circuits and Optimal Solutions Using 45-Degree Cell Orientation in QCA Nanotechnology," *Elsevier ScienceDirect, Materials Today: Proceedings*, vol. 66(8), pp. 3465-3473, 2022, doi:10.1016/j.matpr.2022.06.174.