Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 15, Issue 2, February 2024: 40-49
DOI: 10.53555/tojqi.v15i2.10250

Research Article

Solar Based Hybrid Multilevel Converter With Floating DC-Links

Koneti Sri Vidhya[1]*, Dr P Nagaraju Mandadi[2], T. Anil Kumar[3]

Abstract—

Advancements in converter technology have been driven by the need for enhanced power quality in contemporary power systems. This extensive study introduces a novel method that involves using lower voltage cells with floating DC-links. The objective of this technique is to mitigate voltage distortion in an NPC (Neutral Point Clamped) converter used for active rectifier applications. An approach is devised to compensate for harmonics in the output voltage of the NPC system and to manage the voltages of the floating DC-link by drawing a comparison between floating H-bridges and series active filters. This approach streamlines the existing control system and expands its range of operation, leading to improved overall performance. The study explores the examination of power quality and total harmonic distortion (THD) values for various switching pulses in more detail. The current system combines a solar photovoltaic array, boost converter, and multilayer inverter. The efficacy of the suggested modulation approach is substantiated by the experimental findings of a low-power prototype, which exhibit a significant improvement in the quality of the output waveform. This comprehensive investigation provides significant findings on optimizing power quality in solar-based hybrid multilevel converters, therefore advancing the efficiency and dependability of power systems.

Keywords— power quality, multilevel converter, cascaded H-bridge converter, floating DC-links, Neutral Point Clamped converter, series active filters, harmonic compensation, control strategy, total harmonic distortion.

I. INTRODUCTION

The emergence and development of the Hybrid Multilevel Converter (HMC) with Floating DC-links for Current Waveform Improvement is a significant milestone in the history of power electronics [1]. This innovative technology arose as a solution to the inherent difficulties and restrictions encountered by conventional converters in satisfying the increasing requirements of contemporary power systems. In order to understand the importance of the HMC, it is necessary to explore the historical background of multilevel converters and the development of floating DC-links [2]. The origins of multilevel converters may be traced back to the second half of the 20th century, with significant contributions from pioneers in the field of power electronics [3]. The pursuit of enhanced power quality, efficiency, and decreased harmonic distortion drove the investigation of innovative converter configurations [4]. Initially, multilevel converters used power semiconductor devices linked in series to provide greater voltage levels. Nevertheless, these topologies were plagued by disadvantages such as heightened intricacy, strain on components, and restricted expandability. The NPC topology [5] was a significant milestone in the development of multilevel converters. The NPC converter, which was created in the latter half of the 20th century, effectively tackled several obstacles that were presented by previous designs. The substantial breakthrough was distinguished by its capability to reach diverse voltage levels while reducing component stress and enhancing dependability. The widespread use of multilevel

---

[1]* PG Scholar Department of EEE Anurag University, Hyderabad, Telangana. srividyakoneti@gmail.com,
[2] Assistant professor Department of EEE Anurag University, Hyderabad, Telangana. Nagarajueee@anurag.edu.in,
[3] Professor and Head, Department of EEE Anurag University, Hyderabad, Telangana. thalluruanil@gmail.com

converters in high-power applications, such as renewable energy systems and high-voltage direct current (HVDC) transmission, was made possible by this development [6].

In response to the increasing need for power electronic solutions that are both more efficient and smaller in size, researchers and engineers endeavored to improve the performance of multilayer converters. The idea of using floating DC-links has emerged as a possible approach for enhancement [7]. The use of the floating DC-link design provided an additional level of flexibility in voltage regulation, allowing for more precise modulation and enhanced quality of the current waveform [8]. The Hybrid Multilevel Converter signifies a fundamental change in the field of power electronics. This system effortlessly combines the benefits of traditional two-level converters and multilevel converters with floating DC-links. This hybridization facilitates a versatile and effective method of converting power, making it highly suitable for a wide range of applications, including motor drives and renewable energy systems [9].

The Hybrid Multilevel Converter stands out due to its capability to function with floating DC-links. The use of floating DC-links allows for superior control over the output voltage, facilitating accurate modulation and enhancing the quality of current waveforms. This not only enhances power quality but also tackles the difficulties linked to the integration of renewable energy sources into the grid, where ensuring a reliable and superior power supply is of utmost importance.

II. LITERATURE SURVEY

Manoj, P., A. Kirubakaran, and V. T. Somasekhar [10] proposed that a quasi-switched capacitor (QSC)-based grid-connected photovoltaic (PV) inverter would have the lowest leakage current. The QSC inverter design, control algorithms, and simulations were needed to evaluate its leakage current reduction performance. Due to a lack of experimental validation and practical applicability issues, Khanzadeh, Babak, Torbjorn Thiringer, and Yuriy V. Serdyuk [11] used revised switching patterns to reduce loss at partial loads of multi-level Diode-Clamped (DAB) converters. Modifying switching patterns to maximize losses at partial loads and simulating the strategy's efficacy was the method. Experimental validation and real-world load variations were constraints. Vardhan, et. al [12] studied grid-connected wind energy conversion system Doubly Fed Induction Generator (DFIG) control and performance study. This investigation assessed DFIG performance. Simulations, mathematical modeling, and control procedures were employed to evaluate the DFIG under various operating conditions. Other disadvantages were the need to account for real-world wind changes and insufficient experimental validation.

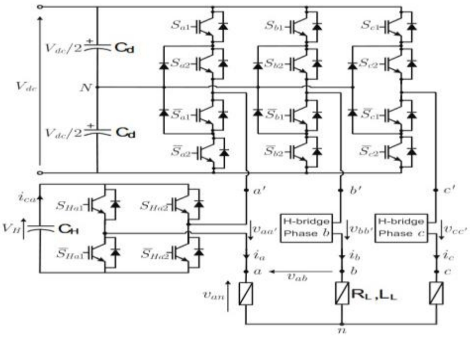
Liu, Hao, and others [13] proposed a Reduced Switch Hybrid Multilevel Converter (RSHMC) with coordinated control to minimize current distortion and balance capacitor voltage. We constructed the RSHMC structure, developed the coordinated control algorithm, and ran simulations to test it. Further experimental validation and practical application challenges were limited. A hybrid solar-energized back-to-back high voltage direct current modular converter for scattered networks was presented by Thadkapally, Karunakar, and others [14]. Distributed networks used this converter. The method included converter architectural design, control algorithm development, and simulations to evaluate converter performance in scattered networks. The limited experimental validation and requirement to account real-world network oscillations were limitations. Haghighian, Saiedeh Khadem, and others [15] proposed a Seventeen-Level Step-up Switched-Capacitor based Multilevel Inverter for PV applications to reduce capacitor charging current stress. Several control techniques, simulations, and inverter structure design were employed to assess its PV performance. Further experimental validation and practical application challenges were limited.

Krishnamoorthy, Umapathi, and others investigated the performance of an MPC-based Harmonic-Reduced Modified PUC Multi-Level Inverter [16]. We created the new inverter structure, applied the MPC algorithm, and ran simulations to assess harmonic reduction. The limited experimental validation and requirement to account real-world load changes were limitations. Kumari, Akanksha, and others [17] proposed a single-source five-level switching capacitor-based multilayer inverter with fewer devices. The procedure includes designing the inverter structure, implementing control algorithms, and simulating its performance with included components. Further experimental validation and practical application challenges were limited. Ezhilarasan, G., and colleagues examined multilevel inverter topologies, evolution, and recent advances [18]. Literature study, classifying multilevel inverter topologies, and field development and trends analysis were the methods. The requirement for empirical study and reliance on published information were limitations.

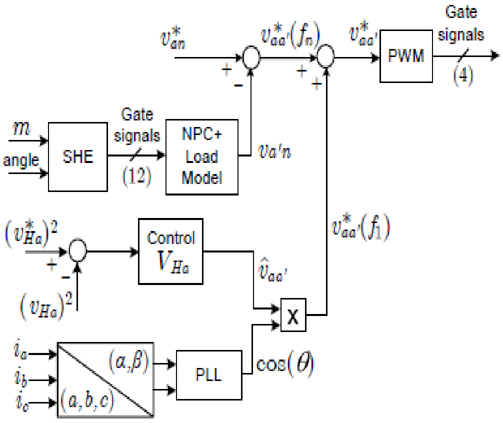
Yang, Junfeng, and colleagues [19] proposed an online adaptive Sinusoidal-Hybrid Elimination (SHE) approach for multilevel converters. We used an embedded control system to achieve this strategy. The approach included developing the adaptive SHE algorithm, applying it to multilayer converters, and simulating its performance. The requirement for experimental validation and consideration of real-world operating conditions were constraints. Thakur, et. al [20] focused on automated flaw monitoring and detection for multilayer inverter solar PV systems. The approach included fault detection algorithms, simulations, and a PV system fault detection efficiency assessment. Due to a lack of experimental validation and practical applicability issues.

III. PROPOSED SYSTEM MODEL

Figure 1 depicts the complex structure of a solar-powered hybrid multilevel converter with a floating DC link and a specialized HB controller. This graphic illustrates the fundamental elements and their linkages, providing a thorough understanding of the cutting-edge technology developed to improve the incorporation of solar energy into the electricity grid. The Selective Harmonic Elimination (SHE) block is in the core of the system and plays a crucial role in shaping the PWM signals. The SHE blocks serve a crucial role in creating a sinusoidal voltage reference by removing harmonics from the NPC pulsed voltage pattern. This determined distortion estimate provides the foundation for a rapid and efficient feed-forward correction method. Significantly, the reference voltage produced by the SHE blocks is devoid of a crucial voltage element, so guaranteeing that it does not affect the voltage of the floating average DC-link capacitor.



Hybrid multi-level converter with floating DC Links



Proposed Control Scheme.

The HB controller orchestrates the complex power dynamics inside the converter by using a dual-reference technique to provide accurate control. The initial reference, labeled as vaa-∗(fn), corresponds to the reciprocal of the residual harmonics resulting from the SHE pulses sequence. This reference not only simplifies the process of estimating distortion, but also allows for quick and efficient adjustment. It is important to emphasize that this voltage reference does not include a basic voltage element, thereby maintaining the stability of the floating average DC-link capacitor voltage.

In addition, the second component of the voltage reference (vaa-∗(f1)) has a dual function. Its main function is to facilitate the charging of the start-up capacitor and counteract voltage fluctuations that occur during transient operations. This component is produced by a signal that is synchronized with the load current, guaranteeing that it introduces minimal quantities of active power into the cell. The goal is to effectively regulate the HB DC-link voltage, ensuring its stability at the specified reference value (vH∗). The dual-reference technique is an advanced method for managing voltage regulation, effectively balancing compensation, and stability. The converter operates by generating the fundamental load current during its active phase in the NPC converter. A PLL method is used to align the voltage reference (vaa-∗(f1)) with the current. The PLL algorithm guarantees a complete absence of phase shift between the voltage reference and the load current, hence optimizing the transfer of active power to the capacitors for all power factors. The synchronization mechanism is crucial for ensuring optimal efficiency and responsiveness in the power distribution system.

The voltage reference magnitude (vaa-∗(f1)) is determined by the DC-link voltage controller, as shown in the figure. The controller plays a crucial role in managing the intricate equilibrium between the floating DC link and the NPC converter. It not only aids in the synchronization process but also plays a crucial part in compensating, guaranteeing that the voltage deviation caused by transient operations is efficiently resolved. The converter's operation is characterized by a stable and reliable DC-link voltage that closely matches the reference value (vH∗), resulting in an overall well-regulated effect. The complexities of the HB controller's work become clearer when examining the compensating measures included into the system. The SHE blocks, in conjunction with the PLL algorithm and the DC-link voltage controller, produces compensating signals. These signals have a crucial function in reducing distortions, regulating voltage levels, and guaranteeing the smooth transmission of power inside the converter. The converter delivers a high level of flexibility and response to different operating settings by using compensating signals.

Furthermore, the inclusion of a floating DC connection is a crucial characteristic that amplifies the converter's adaptability. The floating DC connection acts as an intermediary between the solar panels, energy storage devices, and the grid, enabling smooth energy transmission and distribution. The absence of permanent DC cables enables a power conversion technique that is more versatile and adaptable. Integrating energy storage technologies, such as batteries, into the converter design enhances its possibilities even further. Surplus solar energy may be effectively stored during times of high production and released when demand is high or solar input is limited, hence enhancing the resilience and dependability of the energy system.

Figure 2 provides a detailed illustration of the solar-based Hybrid Multilevel Converter with Floating DC-Links and an HB Controller, highlighting the complex interaction between different components in this innovative system. This diagram visually represents the fundamental aspects of the technology, clarifying the movement of energy and the methods of control that define its revolutionary design. The central component of the diagram is the crucial piece - the solar panels. The solar panels function as the main energy source, transforming sunlight into electrical power via the photovoltaic process. The solar panels, located at the beginning of the system, represent the renewable and sustainable basis on which this hybrid converter is constructed. The arrow emanating from the solar panels represents the one-way movement of solar energy, serving as the starting force that drives the complete process of energy conversion.

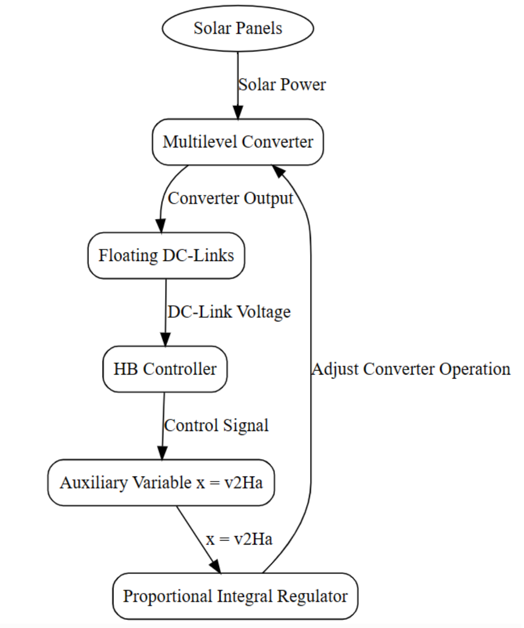


Fig. 1. Solar-based Hybrid Multilevel Converter with Floating DC-Links and an HB Controller.

The next element in the schematic is the Multilevel Converter, a pivotal component that has a significant impact on the properties of the electrical output by undergoing a transforming process. The multilayer converter, depicted as a separate unit, receives the solar power input and transforms it into a converted output that is essential for further transmission and distribution. The arrow connecting the solar panels to the multilevel converter demonstrates the direct impact of solar power on the converter, highlighting its role as a mediator between the solar source and the rest of the system. An important aspect emphasized in the figure is the existence of Floating DC-Links, shown as a distinct component linked to the multilevel converter. The floating DC-links represent a shift away from traditional fixed DC-links, adding a dynamic component to the system. The complex wiring seen in Figure 2 represents the fundamental concept of the floating DC-links, which serve as bridges to enable the seamless transmission of energy throughout the system. An arrow symbolizes the connection between the multilevel converter and the floating DC-links, highlighting the crucial function of these connections in directing the generated energy for further processing. The solar-based hybrid converter system is made more intricate by the addition of an HB Controller, a crucial component that oversees and regulates the functioning of the whole system. The HB Controller is strategically positioned in the diagram and serves as a central hub that governs the dynamics of the solar-based hybrid converter. A directional arrow represents the transmission of information and control signals from the floating DC-links to the HB Controller.

The control method in this system is made more interesting by the inclusion of an Auxiliary Variable, represented as 'x = v2Ha.' Figure 2 illustrates the use of this additional variable to tackle the inherent nonlinearity in the control equation. The implementation of 'x' functions as a crucial regulatory mechanism, enabling more efficient manipulation and management of the system. The block diagram effectively represents this complexity by graphically linking the HB Controller to the Auxiliary Variable, illustrating the interdependent connection between control techniques and auxiliary variables. The incorporation of a Proportional Integral Regulator provides further understanding of the control approach. The regulator is a crucial component that fine-tunes and adjusts the system's performance. It is located downstream from the Auxiliary Variable. The regulator, shown as an independent component, is linked to the multilevel converter, signifying its function in adjusting the converter's operation according to the feedback obtained from the auxiliary variable. The closed-loop control method improves the accuracy and flexibility of the solar-based hybrid converter.

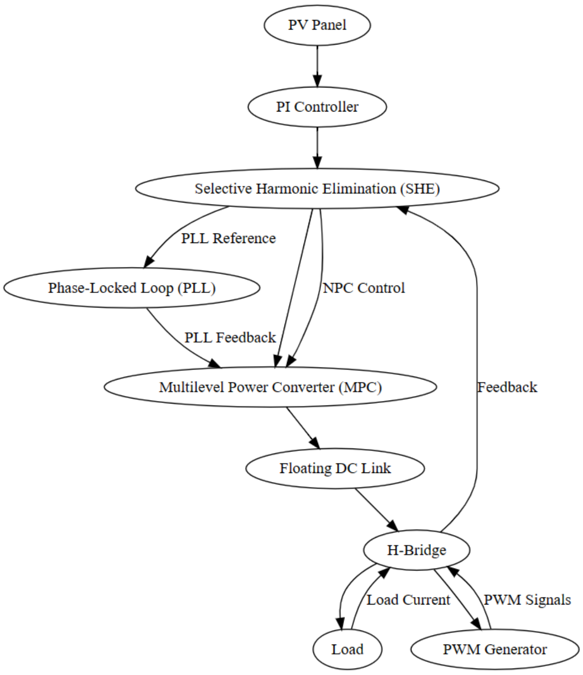


Fig. 2. HB DC-Link Voltage Control Under Regenerative Operation.

Figure 2 depicts a detailed diagram of a solar-powered hybrid multilevel converter that includes floating DC-links and an external current control loop. This complex graphic visually illustrates the interrelated components necessary for the system to work at its best. The central element of the diagram is the PV Panel, representing the main source of energy derived from solar power. The PV Panel is carefully positioned to serve as the primary location for harvesting solar energy and converting it into electrical power. Continuing through the schematic, we come across the PI Controller, which represents a Proportional-Integral controller that is responsible for controlling and precisely adjusting the system parameters. The PI Controller is crucial for guaranteeing the entire system's dynamic and efficient response to changes in input circumstances. The link between it and the PV Panel indicates its control over the process of converting solar energy, where it changes settings to optimize power extraction.

The SHE block is a crucial component in the schematic, specifically designed to tackle the difficulties related to low frequency switching patterns. The SHE blocks, located behind the PI Controller, use sophisticated modulation methods to reduce low-order harmonics. This is especially critical in situations when there are irregular intervals between zero-crossings, such as the SHE modulation stated in the adjacent paragraph. The interaction between the SHE block and the MPC emphasizes its function in eliminating harmonics, hence enhancing the cleanliness and stability of the electrical output. Next to the SHE blocks, we come across the PLL, a crucial element for ensuring synchronization throughout the system. The Phase-Locked Loop (PLL) functions as a point of comparison for the Model Predictive Controller (MPC), guaranteeing that the converter adjusts its output to match the frequency of the electrical grid. Ensuring synchronization is essential for the integration of the grid, enabling the system to effortlessly link with the current electrical infrastructure. The link between SHE and PLL demonstrates the influence of SHE on the reference signal for the PLL, highlighting the complex interdependence of both control components.

The graphic prominently features the MPC, highlighting its crucial function in power conversion. The MPC, which is connected to both the SHE blocks and the Floating DC Link, functions as the central technology that combines numerous voltage levels. This advanced converter design enables efficient high-voltage conversion while minimizing harmonic distortion. The compensatory impact of SHE on switching harmonics is well seen in the relationship between SHE and MPC, emphasizing SHE's function in streamlining the design of the outer load current control loop. The Floating DC Link, located downstream of the MPC, provides a novel feature to the system. Unlike conventional converters that have fixed DC linkages, the floating characteristic of this component introduces a level of adaptability, enabling efficient energy transmission and distribution. The Floating DC Link serves as a connector, linking different components such energy storage systems and the H-Bridge, therefore enhancing the adaptability and resilience of the energy ecosystem.

The H-Bridge is an essential element in the system, representing a collection of semiconductor switches that regulate the movement of electric current. The connection to both the Floating DC Link and the Load indicates its function in controlling and directing the converted energy to the desired destination. The Load, shown in the figure, is the last receiver of the electrical power, representing the tangible implementation of the complete system. The PWM Generator, located next to the H-Bridge, generates the Pulse Width Modulation signals that regulate the switching of the semiconductor devices in the H-Bridge. This component is essential for determining the shape of the output waveform and guaranteeing the effective functioning of the whole system. The bidirectional arrow connecting the H-Bridge and the PWM Generator highlights the feedback loop, symbolizing the mutual effect between both components for accurate control and regulation.

IV. RESULTS AND DISCUSSION

Figure 3 provides a detailed representation of the whole Simulink model for the proposed system. This macroscopic depiction encompasses the whole system, offering a comprehensive overview of the interrelated subsystems and components. It functions as a graphical representation that helps to comprehend the hierarchical arrangement and movement of data inside the simulated setting. The interaction among various modules, signals, and control components is shown in a clear and organized way, providing a comprehensive view of how the proposed system operates as a unified entity. This picture is an essential point of reference for engineers, researchers, and stakeholders who want to understand the architecture and dynamics of the system without getting into the details of each individual component.

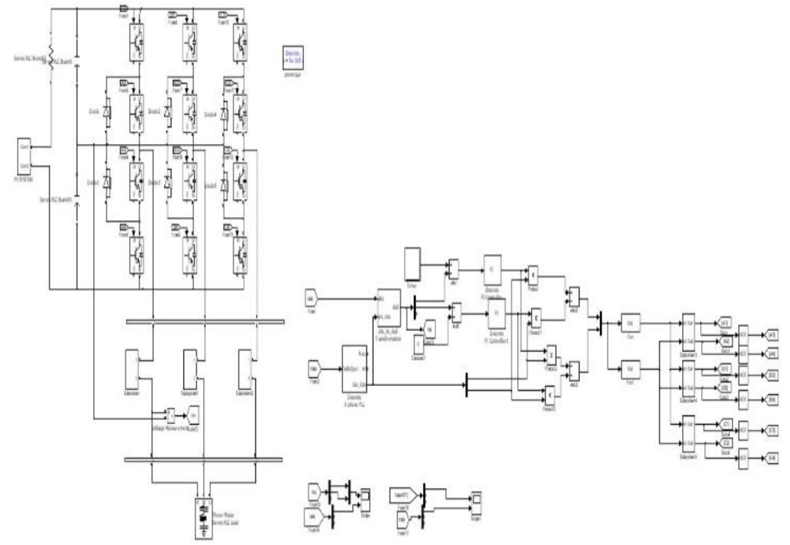


Fig. 3. Overall Simulink Model of Proposed System.

Figure 4 reveals the closed-loop current response in the proposed model, providing important insights into the dynamic behaviour of the system. Figure (a) presents a close-up depiction of the Measured Currents in the d/q synchronous frame, ranging from 4 to 9. The little increase in measured currents indicates the use of a controlled experiment or the ability to adapt to different situations, providing a detailed grasp of the closed-loop control mechanisms in the suggested model. Subfigure (b) depicts the Phase Current, illustrating a sine wave with amplitudes ranging from +4 to +9. The uniform time of 0.35 in both subfigures corresponds to the temporary character of the system's reaction. This picture is essential for assessing the closed-loop behaviour of the proposed model. It illustrates the progression of the measured currents and the response of the phase current to varying situations.

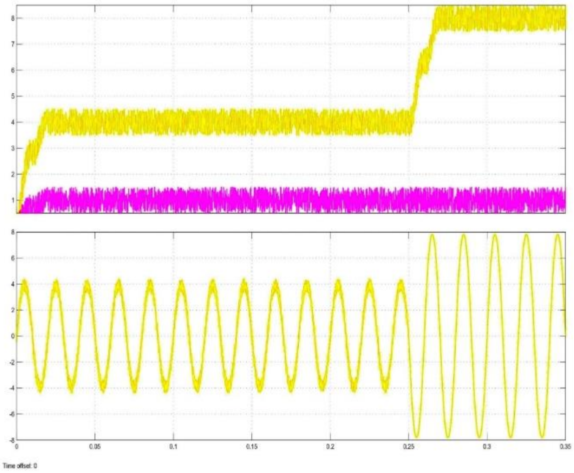


Fig. 4. Proposed Model Closed loop current response. (a) Measured currents in synchronous frame d/q. (b) Phase current.

Figure 5 examines the voltage dynamics of the proposed model when a current step is applied, providing insight into how the system responds to different situations. Subfigure (a) depicts the NPC Voltage Response, illustrating a square wave with amplitudes of +85V and -85V. The waveform demonstrates the suggested model's capacity to adjust voltages in accordance with variations in the current, suggesting an improved control mechanism in comparison to the present model. Subfigure (b) illustrates the Total Load Phase Voltage as a sinusoidal waveform with amplitudes ranging from +42 to 105. The time period of 0.35 is compatible with the system's dynamic response, allowing us to understand how the voltage of the total load phase changes throughout a current step in the suggested model. This figure functions as a crucial diagnostic instrument, enabling a thorough assessment of the suggested model's ability to modulate voltage and its overall response to changing current circumstances.

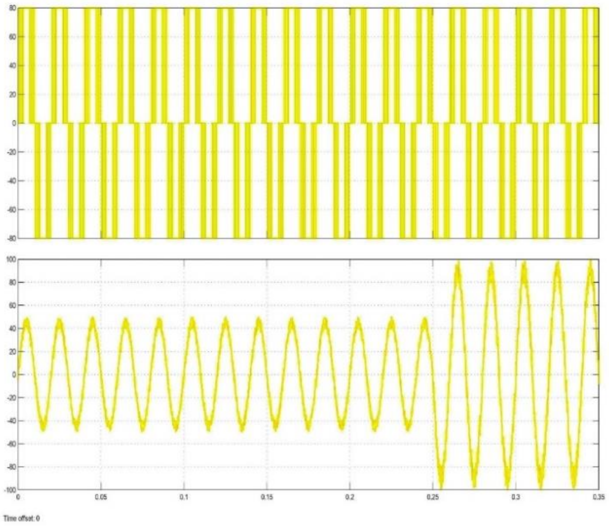


Fig. 5. Proposed Model Voltage during Current step. (a) NPC voltage response. (b) Total load phase voltage.

Figure 6 illustrates the THD response of the existing system, which stands at 8.08%. Total harmonic distortion is a measure of the deviation of the waveform from its ideal sinusoidal shape due to the presence of harmonics. In the context of power systems, high THD values indicate poor power quality, which can lead to issues such as voltage distortion and increased losses in electrical equipment.

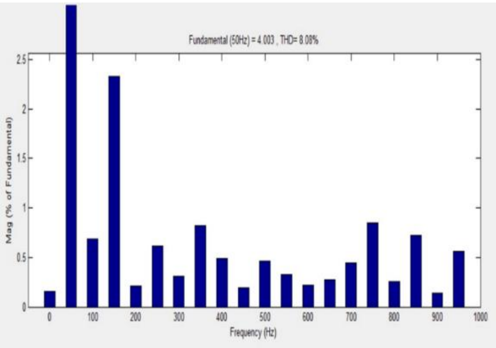


Fig. 6. Existing THD Responce.

In contrast, Figure 7 displays the THD response of the proposed system, which demonstrates a significant improvement with a THD value of 6.25%. This reduction in THD indicates an enhancement in the power quality of the system achieved through the implementation of the novel method involving lower voltage cells with floating DC-links. By mitigating voltage distortion in the NPC converter and compensating for harmonics in the output voltage, the proposed approach effectively reduces the level of harmonic content in the waveform. The lower THD value shown in Figure 7 reflects the improved performance and efficiency of the system in terms of power quality.

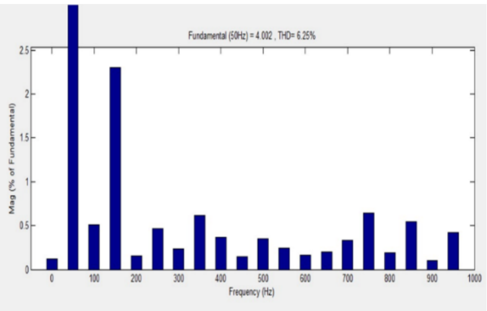


Fig. 7. Proposed THD Responce.

V. CONCLUSION

The paper illustrates a comprehensive plan of a solar-powered hybrid multilevel converter with floating DC-links and an external current control loop. The graphic presents a methodical depiction of essential elements and their interconnectedness inside the system. The graphic showcases the PV Panel as the primary solar energy source, with the PI Controller responsible for optimizing power extraction by adjusting settings. The SHE block, strategically positioned, effectively tackles issues associated with low-frequency switching patterns by completely removing harmonics. The PLL guarantees synchronization with the grid, which is crucial for achieving smooth integration. The MPC is the key technology used for voltage synthesis and is impacted by the sinusoidal PWM, highlighting its significance in streamlining control loop design. The Floating DC Link enhances versatility by establishing a connection between energy storage devices and the H-Bridge, enabling customization. The H-Bridge controls the flow of current to the Load, which is a realistic implementation of the system. The PWM Generator regulates the operation of semiconductor devices inside the H-Bridge, manipulating the characteristics of the output waveform.

REFERENCES

Nyamathulla, Shaik, and Dhanamjayulu Chittathuru. "A Review of Multilevel Inverter Topologies for Grid-Connected Sustainable Solar Photovoltaic Systems." Sustainability 15.18 (2023): 13376.

Sambhavi, Y. Vijaya, and Vijayapriya Ramachandran. "A technical review of modern traction inverter systems used in electric vehicle application." Energy Reports 10 (2023): 3882-3907.

Gautam, Shivam Prakash, et al. "A Survey on Fault Tolerant and Diagnostic Techniques of Multilevel Inverter." IEEE Access (2023).

NV, Vinay Kumar. "A comprehensive survey on reduced switch count multilevel inverter topologies and modulation techniques." Journal of Electrical Systems and Information Technology 10.1 (2023): 1-24.

Athwer, Abdulkarim, and Ahmed Darwish. "A Review on Modular Converter Topologies Based on WBG Semiconductor Devices in Wind Energy Conversion Systems." Energies 16.14 (2023): 5324.

Deng, Junpeng, et al. "A review of system topologies, key operation and control technologies for offshore wind power transmission based on HVDC." IET Generation, Transmission & Distribution (2023).

Marignetti, Fabrizio, et al. "Current Source Inverter (CSI) Power Converters in Photovoltaic Systems: A Comprehensive Review of Performance, Control, and Integration." Energies 16.21 (2023): 7319.

Pragati, Abha, et al. "A Comprehensive Survey of HVDC Protection System: Fault Analysis, Methodology, Issues, Challenges, and Future Perspective." Energies 16.11 (2023): 4413.

Zhang, Bin-Long, et al. "Fault Current Limitation with Energy Recovery Based on Power Electronics in Hybrid AC-DC Active Distribution Networks." IEEE Transactions on Power Electronics (2023).

Manoj, P., A. Kirubakaran, and V. T. Somasekhar. "A Quasi-Switched Capacitor Based Grid-connected PV Inverter with Minimum Leakage Current." IEEE Journal of Emerging and Selected Topics in Power Electronics (2023).

Khanzadeh, Babak, Torbjörn Thiringer, and Yuriy V. Serdyuk. "Loss reduction at partial loads of multi-level DAB converters using adjusted switching patterns." IEEE Transactions on Industry Applications (2023).

Vardhan, Aanchal Singh S., and U. K. Sinha. "Control strategies and performance analysis of doubly fed induction generator for grid-connected wind energy conversion system." Electrical Engineering (2023): 1-22.

Liu, Hao, et al. "A Reduced Switch Hybrid Multilevel Converter With Coordinated Control Method for Current Distortion Mitigation and Capacitor Voltages Balancing." IEEE Journal of Emerging and Selected Topics in Power Electronics (2023).

Thadkapally, Karunakar, et al. "The hybrid solar energized back-to-back high voltage direct current modular converter for distributed networks." Bulletin of Electrical Engineering and Informatics 13.1 (2024): 88-97.

Haghighian, Saiedeh Khadem, et al. "A Seventeen-Level Step-up Switched-Capacitor Based Multilevel Inverter with Reduced Charging Current Stress on Capacitors for PV Applications." IEEE Access (2023).

Krishnamoorthy, Umapathi, et al. "Performance Analysis of Harmonic-Reduced Modified PUC Multi-Level Inverter Based on an MPC Algorithm." Inventions 8.4 (2023): 90.

Kumari, Akanksha, et al. "A single source five-level switched-capacitor based multilevel inverter with reduced device count." e-Prime-Advances in Electrical Engineering, Electronics and Energy 5 (2023): 100235.

Ezhilarasan, G., et al. "An empirical survey of topologies, evolution, and current developments in multilevel inverters." Alexandria Engineering Journal 83 (2023): 148-194.

Yang, Junfeng, et al. "Online adaptive SHE algorithm for multilevel converters and implementation with embedded control system." Energy Reports 9 (2023): 1190-1202.

Thakur, Sachin, Kamalkant Sharma, and Akhil Gupta. "Automatic Observation and Detection of Faults for Solar Photovoltaic Systems with Multilevel Inverter Topology." 2023 2nd Edition of IEEE Delhi Section Flagship Conference (DELCON). IEEE, 2023.