

Advanced Series Active Power Filtering Using NPC Five-Level Inverter: A Performance Evaluation

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Abstract—The emergence of nonlinear loads has become a significant issue to the quality of power on modern electrical networks, causing harmonics, voltage distortion, and low power factor. To overcome these problems, this paper proposes a series active power filter (SAPF) which is a Neutral Point Clamped (NPC) five-level inverter. The design proposed injects compensating voltages into the system to minimise content of harmonic and enhance the stability of the voltage. The inverter is capable of generating smoother output with reduced Total Harmonic Distortion (THD) than the traditional two-level systems by employing the advanced control approach. The model is constructed and simulated using MATLAB/Simulink under varied operating environment. Simulation findings validate that the NPC five level inverter improves the power quality, dynamic response and provides a reliable protection of sensitive loads.

Index Terms—Series Active Power Filter (SAPF), NPC Inverter, Multilevel Topology, Harmonic Reduction, Power Quality, MATLAB/Simulink

I. INTRODUCTION

Power systems have become serious problems with regard to power quality due to the growing use of nonlinear and sensitive electronic loads which include harmonics, voltage distortion and poor power factor. As a remedy to these problems, dedicated power devices such as active power filters (APFs) and unified power quality conditioners (UPQCs) have been invented. Of these, series active power filters are important to offer protection to sensitive loads by injecting compensating voltages and enhancing the quality of power at the distribution level.

A number of researches have addressed various inverter topologies and control mechanisms to enhance the performance of series APFs. Chennai (2023) noted that multilevel neutral point clamped (NPC) inverters with smart control can greatly eliminate harmonics and voltage distortion, other than offering a superior compensation with changing load environments [1]. On the same note, Chennai (2023) used a modified p-q approach with NPC inverters of 5- and 7-levels demonstrating that the higher the level, the better the compensation but the more complex the approach.

There is also the use of fuzzy logic controllers to improve the work of APF. Chennai (2022) revealed that 3-level fuzzy control and 5-level NP controllers with inverters have better dynamic response and lower THD than the conventional PI controllers [3]. Expanding this idea, Chennai (2024) has considered systems of UPQC with 5- and 7-level NPC inverters, where the series APF is significant in reducing voltage disturbances and demonstrated the benefits of multilevel structures in load voltage quality [4].

Additional developments were the application of a seven-level NPC inverter with fuzzy control, which provided a strong compensation in variations of loads and retained sinusoidal forms [5]. Other authors like Suresh (2023) applied NPC based active filters in grid connected systems, which proved to be effective in reducing harmonic as well as improving the quality of current [6]. Also, ANFIS and other intelligent control schemes have been experimented in APFs and UPQCs based on NPCs, which further confirm their applicability to power quality improvement [7][8][9][10].

This paper will suggest a developed series active power filter with a five-level NPC inverter operated by a refined smart algorithm. The design is designed to have reduced harmonic distortion, enhanced dynamic response, and enhanced voltage compensation over conventional techniques. Simulation findings prove that the suggested system is effective in eliminating the problem of PQ even in varied loading conditions, which offers a more stable and efficient solution to the modern distribution networks.

II. LITERATURE SURVEY

Chennai (2023) examined series active power filters with various NPC multilevel inverter topologies associated with intelligent control. The paper has shown that multilevel inverters are able to produce cleaner voltage with less harmonic than two-level systems. The filter was enabled to rapidly adapt to alterations in dynamic loads due to intelligent controllers such as ANN or fuzzy logic. This renders the system to be more flexible and effective in real time applications. The paper found that, NPC hardware together with smart control provides good power quality and increased dynamic performance [1].

The other article written by Chennai (2023) was devoted to the implementation of a modified p-q approach to reference signal generation in series APFs with 5- and 7-level NPC inverters. It also made the new approach better in terms of harmonic detection and voltage compensation. This was the case with the results of the simulation which indicated that the more collection of levels used the more harmonic cancellation and less distortion. The higher levels however required more complicated control and high implementation cost. This paper has highlighted the trade-off between the performance of the system and hardware effort in the real design [2].

Chennai, 2022 investigated the operation of series APFs using 3-level or 5-level NPC inverters and operated using a fuzzy logic system. The reason why the fuzzy logic was selected was that it is able to deal with nonlinearities and uncertainties compared to the conventional PI controllers. It was found that the results displayed quicker transient response and reduced harmonic distortion, primarily in the 5-level inverter. The comparison has shown that the topology

of high level has a superior filtering capability and quality of the waveform. This research emphasized the significance of adopting a fuzzy control system with multilevel inverters in a practical PQ solutions [3].

Chennai (2024) examined a system with a series leg of two NPC five- and seven-level inverters to design the series leg. Because UPQC is a combination of series and shunt filter, the series element was very important in the disturbance of voltage. It was demonstrated that multilevel NPC inverters enhanced injected voltage waveforms, which guarantee lower levels of sag, swell, and distortion on the load side. The 7-level system was more effective than the 5-level yet with more control and circuit complexity. This paper showed the benefit of NPC topologies in series APFs in UPQC systems [4].

Another series APF with a seven-stage NPC inverter and fuzzy control was introduced by Chennai (2024), too. The fuzzy controller offered adaptive control that did not need an accurate system model. The results of simulation indicated that this design resulted in minimal voltage distortion and stable operation even when there was a sudden change of load. The multilevel inverter provided any sinusoidal voltage that was more smooth whereas fuzzy logic provided flexibility. It was demonstrated that the combination would be one of the most effective and stable solutions to power quality improvement [5].

Suresh (2023) presented an active power filter that is attached to the grid with a neutral-point-clamped inverter structure. The design of the NPC served to collect voltages on both sides of the DC link, and to obtain stable multilevel output. The system has been tested on the basis of harmonic elimination and correction of current waveforms in grid connected cases. Findings revealed the obvious enhancement of the existing quality and adherence to harmonic standards. The paper offered useful information about the application of NPC inverters in active filter of current grids to be reliable and efficient in the real-time operational condition [6].

III. PROPOSED METHOD

The proposed technique seeks to enhance the quality of power within the distribution system through adoption of a Series Active Power Filter (SAPF) which is a Neutral Point Clamped (NPC) inverter

with 5 levels. The SAPF adds a compensating voltage across the supply, so that sensitive loads are not subjected to harmonics, voltage sags, swells and other disruptions. This method enables the load side to be left in a near sinusoidal waveform with distorted conditions of supply.

The five-level NPC inverter produces more than two voltage levels as compared to the conventional two-level inverter, which produces smoother waveforms with lower Total Harmonic Distortion (THD). This renders the system more efficient in the solution of problems of power quality. MATLAB/Simulink modeling and simulation have been done to prove the performance of the method.

There are five stages of NPC Inverter that have been developed in order to make the inverter a practical instrument in electric power generation.

3.1 NPC Five-Level Inverter Subsystem.

The proposed SAPF is made up of the five-level NPC inverter. It generates stepped voltage which is similar to sinusoidal waveform. The inverter is a distributor of the voltage to multiple levels, reducing harmonic distortion and enhancing system-wide efficiency. Furthermore, NPC structure is used to equalize the voltage on either side of the DC link capacitors and thus stability is maintained during operation.

3.2 Controller Subsystem

Identification of the disturbances of the supply voltage and computation of the compensating signal necessary are done in the controller subsystem. Upon a distortion being detected, the controller produces reference voltages to inject into the inverter to add corrective voltages. Smart control techniques can be adopted to suit different load conditions and to enhance the response to transient conditions, e.g. the modified p-q theory or fuzzy logic.

3.3 Overall Operation

The general working principle of the suggested approach may be explained as follows: each time the supply voltage is disturbed, the controller recognizes the disturbance and orders the inverter to produce a corresponding compensating voltage. This offsetting waveform is then commuted in-series with the supply such that the summed resultant that is presented to the load is virtually distortion-free. By so doing, the sensitive loads obtain a stable and clean sinusoidal supply, despite unstable input power.

3.4 Pros of the Proposed System.

The proposed SAPF with five-level NPC inverter greatly minimizes the harmonic content of the voltage, fast rectifies the voltage sags and swells, and supplies the sensitive loads with a constant supply. The outcome of the simulation confirms that the design results in better dynamic performance and increase the power quality during steady and varying loads.

IV. RESULTS

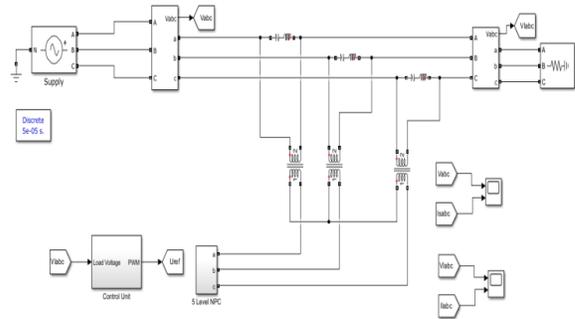


Figure 4.1: Five-Level NPC Inverter output.

This figure displays the stepped output waveform of the NPC inverter. The form is much like sinusoidal wave, and it demonstrates that harmonic distortion is minimized as compared to the case of a two-level inverter.

5- level NPC Subsystem:

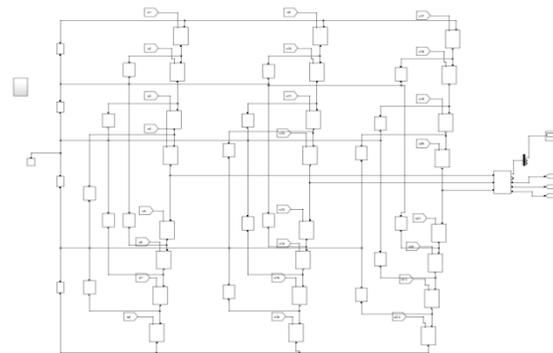


Figure 4.2: The Controller Subsystem Response.

This value is an indication of what the controller does when there is a voltage disturbance. It produces compensating signals in a short time to stabilise the output.

Dependent: The compensated load voltages of a capacitor are determined by the capacitor's voltage and the constant loading capacitance.

This number depicts the compensated load voltage. The waveform is even and almost sinusoidal, which proves that the filter reconstructs the quality of supply voltage.

Controller Subsystem:

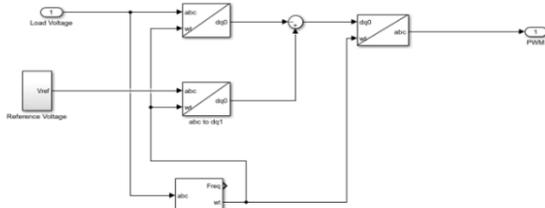


Fig. 4.4: Harmonic Spectrum Load Voltage.

This value depicts the harmonic spectrum of the input and output of the filtering. The system is effective as can be seen in the noticeable decrease in Total Harmonic Distortion (THD).

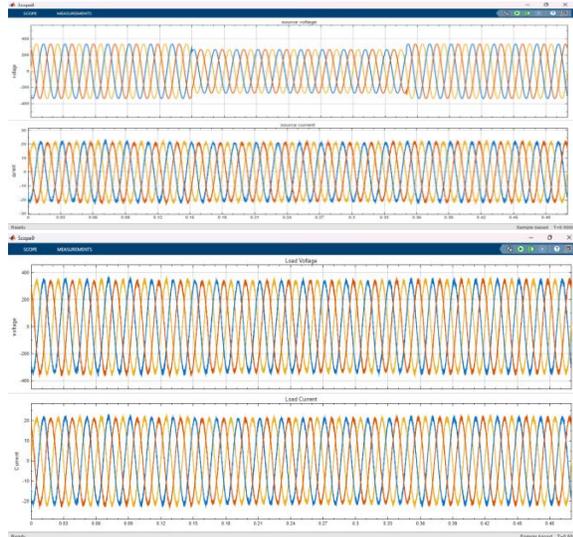


Figure 4.5: Response to Voltage Sag Dynamically.

This value demonstrates the system performance at the electrodes voltage sag. The inverter injects counter voltage immediately such that the load is still supplied with stable power.

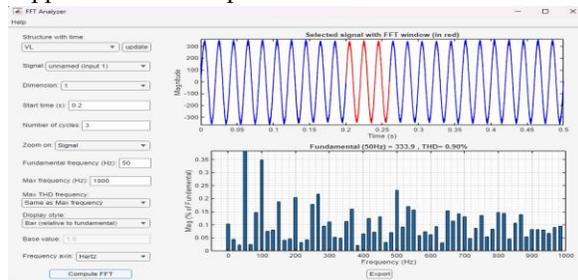


Figure 4.6: Response to Dynamic Response in the Voltage Swell.

This figure demonstrates the behavior of the system to a voltage swell. This is added to have the corrective voltage to ensure safe and stable load-side voltage.

V. CONCLUSION

This paper shows that series active power filtering achieved by using a five level NPC inverter is an effective method of enhancing power quality within a distribution system. The multilevel design suppresses the harmonic distortion and stabilized voltage levels better than the two-level inverters. The proposed solution also has superior dynamic performance, and is therefore applicable to real time application with changing load conditions. The results of simulations indicate that such a system has the capability of sustaining sinusoidal voltages and enhancing the overall efficiency, which is worthwhile in the past decades in which the delivery of energy is critical due to the need to be reliable and clean.

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