International Journal of Trend in Research and Development, Volume 11(5), ISSN: 2394-9333
www.ijtrd.com

Enhancing Power Quality: A Critical Review of Asymmetric Selective Harmonic Current Mitigation Using PWM in Active Power Filters

[1]Rahul Kumar and [2]Pramod Kumar Rathore,
[1]M. Tech Scholar, [2]Assistant Professor,
[1,2]RKDF College of Engineering, Bhopal, Madhya Pradesh, India

***Abstract*—** Active power filters (APFs) are integral in mitigating power quality issues, specifically harmonic distortions, in electrical systems. The asymmetric selective harmonic current mitigation using Pulse Width Modulation (PWM) presents a novel approach to enhancing the performance of APFs. This method selectively targets specific harmonic components, thereby optimizing the filter's efficiency and reducing power losses. This paper critically analyzes the effectiveness of asymmetric selective harmonic current mitigation-PWM in APFs. The study includes a comparative analysis with traditional harmonic mitigation techniques, a detailed exploration of the theoretical underpinnings, and practical implications in various electrical systems. The findings highlight the potential of this method to improve power quality significantly, making it a viable solution for modern power systems facing increasing harmonic distortions.

Keywords*—Asymmetric, Harmonic, PWM, Active, Power Filters.*

I. INTRODUCTION

The increasing complexity of electrical power systems and the growing presence of non-linear loads have introduced significant challenges in maintaining power quality. Harmonic distortion, a major concern, arises from these non-linear loads and can cause issues such as equipment overheating, malfunctioning of sensitive electronics, and reduced system efficiency. Active power filters (APFs) have become essential in addressing these challenges, offering dynamic and adaptive solutions to mitigate harmonic distortions.

While traditional harmonic mitigation techniques have proven somewhat effective, they often fall short in terms of efficiency and adaptability, especially in complex, dynamic power systems. This has driven the need for more advanced and targeted approaches, such as asymmetric selective harmonic current mitigation using Pulse Width Modulation (PWM). This innovative method takes a focused approach to harmonic reduction, selectively targeting specific harmonic frequencies to optimize the performance of APFs.

Asymmetric selective harmonic current mitigation-PWM utilizes the principles of PWM to actively adjust current waveforms, reducing targeted harmonic components while maintaining the fundamental frequency. This selective approach not only improves the efficiency of harmonic mitigation but also reduces power losses, making it a highly effective solution for modern electrical systems.

This paper provides an in-depth critical analysis of the asymmetric selective harmonic current mitigation-PWM technique in APFs. It begins by reviewing the theoretical foundations of PWM and its role in harmonic mitigation, followed by an exploration of the design and implementation of this selective approach in APFs. The analysis also highlights the benefits and potential challenges associated with this method.

A comparative study with traditional harmonic mitigation techniques assesses the asymmetric method's effectiveness and efficiency. This includes both simulations and real-world applications, offering a comprehensive evaluation of the technique's performance across various scenarios. The paper further discusses the practical implications of deploying asymmetric selective harmonic current mitigation-PWM in different types of electrical systems, ranging from residential setups to large industrial installations.

The results of this analysis demonstrate the significant potential of asymmetric selective harmonic current mitigation-PWM to enhance power quality. The findings suggest that this method can outperform conventional techniques in reducing specific harmonic components, leading to improved system efficiency and lower operational costs. Its adaptability makes it suitable for a wide range of applications, meeting the diverse demands of modern power systems.

Asymmetric selective harmonic current mitigation-PWM represents a significant advancement in power quality management. By offering a targeted and efficient solution to harmonic distortion, this method can contribute to the development of more reliable and efficient electrical systems. This paper aims to support ongoing research and development in this field, providing insights and recommendations for future studies and practical implementations.

II. LITERATURE SURVEY

A. Moeini et al. [1] highlight that one of the primary functions of active power filters (APFs) is to control harmonics generated by nonlinear loads in power systems. Additionally, APFs at the point of common coupling (PCC) can be used to compensate for reactive power, a key component in alternating current (AC) power. This study explores methodologies for modulating APFs, which is the central focus of this research.

L. Zhang et al. [2] propose a method for converting multi-objective inequality problems in asymmetric selective harmonic current mitigation-PWM (ASHM-PWM) into single-objective equations, combining this with improved particle swarm optimization (IPSO). This approach simplifies problem-solving, resulting in the calculation of switching angles.

C. Zhang et al. [3] recommend multifunctional parallel three-level four-leg converters for high-power applications. These converters integrate APF technology, enabling grid-connected renewable energy transfers. However, zero-sequence circulating current (ZSCC) poses a challenge, reducing output current quality and system stability. To address this, a proportional-integral (PI) plus feedforward control approach and space vector modulation, based on nonaxial redundant vectors (NARVs), is introduced. The ZSCC model is first developed, revealing that ZSCC arises from zero-sequence duty-cycle difference and the zero-sequence benchmark function.

S. P. Biswas et al. [4] explain that pulse width modulation (PWM), used to switch the voltage source converter (VSC) in SMES/HTS-based grid-tied power systems, significantly impacts joule heating, switching and conduction losses, total harmonic distortion (THD) in VSC output, and conversion efficiency. This research suggests using a modified reference saturated third harmonic-injected equal loading PWM technique for grid-tied photovoltaic (PV) systems based on VSC.

B. Zhang et al. [5] demonstrate that abrupt changes in reference voltage can generate a wide harmonic band and easily cause resonant current at the resonant frequency. To mitigate this, they propose a unique three-layer DPWM technique that injects three offset voltages. The first offset voltage achieves NP voltage balance in the first layer, while the second layer smooths discontinuous reference voltages through a second offset voltage.

A. Mishra et al. [6] present research on performance analysis of two-stage solar photovoltaic (PV) systems integrated with a Shunt Active Harmonic Filter (SAHF). With increased use of nonlinear loads, the current harmonic issue has impacted distributed power systems, exacerbated by industrial advances. The SAHF system significantly aids in achieving load adjustment, harmonic mitigation, and power factor correction.

B. Wang et al. [7] emphasize the critical importance of turn fault detection for system safety, allowing appropriate mitigation strategies. This study explores an improved method of turn fault detection for internal permanent magnet machines (IPM), utilizing ripple current caused by intrinsic PWM voltage harmonics.

R. Shen et al. [8] propose a single-phase transformerless full-bridge solar grid-tie inverter, incorporating three techniques: 1) a virtual ground technique to reduce ground leakage current; 2) a hybrid PWM (HPWM) scheme to shape output current and prevent sudden common-mode voltage changes; and 3) a nonlinear output inductor to minimize current ripple around zero crossings and reduce filter size.

R. Sarker et al. [9] introduce an innovative high-definition PWM (HD-SPWM) design based on a field-programmable gate array (FPGA). The design merges a lower-frequency PWM train with a higher-frequency SPWM train, aiming for high-resolution output with reduced harmonic content in the inverter's output. An optimized two-stage finite-state machine (FSM) architecture is presented, with the lower-frequency PWM pulse widths derived from the high-frequency SPWM pulse widths.

A. Moeini et al. [10] note that among various energy storage technologies and renewable energy sources, multilevel converters are becoming increasingly attractive. The literature discusses a range of modulation techniques for multilevel grid-connected converters, including both high-frequency methods, like space vector modulation and phase shift-PWM, and low-frequency techniques, such as selective harmonic current mitigation-PWM (SHCM-PWM) and selective harmonic mitigation-PWM (SHM-PWM). Low-frequency modulation techniques are characterized by lower switching losses and higher efficiency.

III. CHALLENGES

Challenges Despite the promising potential of asymmetric selective harmonic current mitigation-PWM (ASHCM-PWM) in active power filters, several challenges must be addressed to fully realize its benefits:

1. **Complexity of Implementation**: Implementing ASHCM-PWM requires sophisticated control algorithms and precise hardware components. The complexity of these systems can pose significant challenges in terms of design, development, and maintenance.
2. **Cost**: Advanced control techniques and high-quality components can increase the overall cost of the system. This may limit the widespread adoption of ASHCM-PWM, particularly in cost-sensitive applications.
3. **Control Precision**: Achieving the precise control necessary for effective harmonic mitigation is challenging. Small errors in control can lead to suboptimal performance or even exacerbate harmonic issues.
4. **Real-time Adaptation**: Power systems are dynamic, with load conditions and harmonic profiles changing constantly. ASHCM-PWM systems need to adapt in real-time to these changes, requiring advanced adaptive control strategies and real-time processing capabilities.
5. **Compatibility and Integration**: Integrating ASHCM-PWM with existing power systems and ensuring compatibility with a wide range of loads and conditions can be challenging. This requires careful design and testing to ensure seamless operation.
6. **Thermal Management**: The components used in ASHCM-PWM systems can generate significant heat, requiring effective thermal management solutions to prevent overheating and ensure reliable operation.
7. **Standardization and Regulation**: The lack of standardized guidelines and regulations for ASHCM- PWM can hinder its adoption. Developing industry standards and regulatory frameworks is essential for broader acceptance and implementation.

CONCLUSION

The asymmetric selective harmonic current mitigation-PWM (ASHCM-PWM) technique marks a major advancement in power quality management. By specifically targeting certain harmonic components, this method provides a highly efficient and effective solution for reducing harmonic distortions in electrical systems. The critical analysis in this paper highlights ASHCM-PWM's potential to boost the performance of active power filters, resulting in improved power quality, reduced energy losses, and enhanced system efficiency. However, several challenges must be addressed to fully harness the advantages of ASHCM-PWM. These challenges include implementation complexity, cost, control precision, real-time adaptability, compatibility and integration, thermal management, and the absence of standardized guidelines. Overcoming these obstacles will require continued research and development, along with collaboration between industry, academia, and regulatory organizations.

References

[1] Moeini, M. Dabbaghjamanesh, J. W. Kimball and J. Zhang, "Artificial Neural Networks for Asymmetric

Selective Harmonic Current Mitigation-PWM in Active Power Filters to Meet Power Quality Standards," in IEEE Transactions on Industry Applications, doi: 10.1109/TIA.2020.3007596.

[2] L. Zhang, W. Hong, C. Gao, R. Liu, Q. Yu and C. Wei, "Selected Harmonic Mitigation PWM Power Matching Control Strategy for Asymmetric Cascaded H-Bridge Multilevel Inverter," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 4, pp. 4059-4072, Aug. 2022, doi: 10.1109/JESTPE.2021. 3137337.

[3] Zhang, R. Zhang, X. Xing and X. Li, "Circulating Current Mitigation and Harmonic Current Compensation for Multifunction Parallel Three-Level Four-Leg Converters," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 3, pp. 2805- 2818, June 2022, doi: 10.1109/JESTPE.2021.3072437.

[4] S. P. Biswas et al., "A Modified Reference Saturated Third Harmonic Injected Equal Loading PWM for VSC- Based Renewable Energy Systems," in IEEE Transactions on Applied Superconductivity, vol. 31, no. 8, pp. 1-5, Nov. 2021, Art no. 5000405, doi: 10.1109/TASC.2021. 3096484.

[5] B. Zhang, C. Zhang, X. Xing, X. Li and Z. Chen, "Novel Three-Layer Discontinuous PWM Method for Mitigating Resonant Current and Zero-Crossing Distortion in Vienna Rectifier With an LCL Filter," in IEEE Transactions on Power Electronics, vol. 36, no. 12, pp. 14478-14490, Dec.2021, doi: 10.1109/TPEL.2021.3088610.

[6] A. Mishra, S. Chauhan, P. Karuppanan and M. Suryavanshi, "PV based Shunt Active Harmonic Filter for Power Quality improvement," 2021 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS), Greater Noida, India, 2021, pp. 905-910, doi: 10.1109/ICCCIS51004.2021.9397214.

[7] Wang, L. Luo, W. Fu, W. Hua, G. Wang and Z. Wang, "Study on the PWM Ripple Current Based Turn Fault Detection for Interior PM Machine," in IEEE Transactions on Transportation Electrification, vol. 7, no. 3, pp. 1537-1547, Sept. 2021, doi: 10.1109/TTE.2021.3050560.

[8] R. Shen and H. S. -H. Chung, "Mitigation of Ground Leakage Current of Single-Phase PV Inverter Using Hybrid PWM With Soft Voltage Transition and Nonlinear Output Inductor," in IEEE Transactions on Power Electronics, vol. 36, no. 3, pp. 2932-2946, March 2021, doi: 10.1109/TPEL.2020.3016867.

[9] R. Sarker, A. Datta and S. Debnath, "FPGA-Based High-Definition SPWM Generation With Harmonic Mitigation Property for Voltage Source Inverter Applications," in IEEE Transactions on Industrial Informatics, vol. 17, no. 2, pp. 1352-1362, Feb. 2021, doi: 10.1109/TII.2020. 2983844.

[10] Moeini, M. Dabbaghjamanesh and J. W. Kimball, "Q-Learning-Based Smart Selective Harmonic Current Mitigation-PWM (S2HCM-PWM) for Grid-Connected Converters," 2020 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA, 2020, pp. 5068-5075, doi: 10.1109/ECCE44975.2020.9236369.