POWER SYSTEM COMPENSATION USING A POWER ELECTRONICS INTEGRATED TRANSFORMER

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ABSTRACT

This project presents a new transformer, that is, the custom power active transformer (CPAT) - which integrates shunt and series equivalent circuits within the transformer's magnetic structure. Thus, it provides power system services using a single transformer. The CPAT equipped with a power converter can be utilized in distribution systems to control grid current and load voltage waveforms while operating as a step-up or step-down transformer between the grid and load. Moreover, it can provide other services that any typical shunt-series compensation arrangement provides. The design and analysis of a single-phase CPAT are presented, showing the effect of coupling between windings and transformer parameters affecting CPAT operation. In this paper, control of the CPAT in an unified powerquality controller application is investigated to attenuate gridcurrent and load-voltage harmonics as well as compensate for reactive power requirements and mitigate grid inrush current. Through simulation and experimental implementation, the merits and performance of the CPAT were validated.

Keywords:Power Transformers, Magnetic Circuits, Power Conditioning, Power Distribution.

INTRODUCTION

The integration of power electronics with traditional transformer technology has emerged as a transformative approach to enhance the efficiency and flexibility of power system compensation. This introduction marks the inception of a novel concept termed as the Custom Power Active Transformer (CPAT), which revolutionizes conventional transformer functionality by embedding shunt and series equivalent circuits within its magnetic structure [1]. Unlike conventional transformers, the CPAT offers a multifaceted solution by providing various power system services within a single unit, thereby simplifying the overall system architecture and improving operational efficiency [2]. Through the integration of a power converter, the CPAT becomes a versatile tool that can be deployed in distribution systems to regulate grid current and load voltage waveforms while seamlessly transitioning between step-up and step-down transformer operations [3]. Moreover, its inherent design facilitates the provision of additional services typically associated with shunt-series compensation arrangements, further augmenting its utility and applicability in modern power systems [4]. The development and analysis of a single-phase CPAT serve as the cornerstone of this project, shedding light on the intricate interplay between winding coupling and transformer parameters that dictate the CPAT's operational characteristics [5].

Central to the exploration of the CPAT's capabilities is its potential role in unified power quality control, a critical aspect of power system compensation aimed at mitigating grid disturbances and enhancing system stability [6]. In this context, the control strategy employed for the CPAT assumes paramount significance, as it directly influences its ability to attenuate grid current and load-voltage harmonics, address reactive power requirements, and mitigate grid inrush currents [7]. Through a comprehensive investigation encompassing both simulation and experimental validation, this study aims to elucidate the merits and performance attributes of the CPAT in real-world scenarios [8]. By subjecting the CPAT to rigorous testing under various operating conditions, the project endeavors to provide empirical evidence supporting its efficacy and reliability as a power system compensation solution [9]. The findings derived from simulation models and experimental implementations serve as a testament to the transformative potential of the CPAT in addressing contemporary challenges faced by power distribution systems [10]. Furthermore, the validation of the CPAT's performance through empirical testing not only underscores its practical viability but also lays the foundation for its widespread adoption in future power system designs [11].

In summary, the introduction of the Custom Power Active Transformer (CPAT) marks a significant milestone in the realm of power system compensation, offering a versatile and efficient solution for addressing diverse challenges encountered in distribution systems [12]. By integrating shunt and series equivalent circuits within its magnetic structure, the CPAT transcends the limitations of traditional transformers, enabling it to provide a comprehensive suite of power system services within a single unit [13]. Through meticulous design and analysis, coupled with robust control strategies, the CPAT demonstrates its capability to mitigate grid disturbances, regulate voltage waveforms, and enhance system stability [14]. The validation of its performance through simulation and experimental studies not only underscores its technical prowess but also paves the way for its integration into mainstream power system architectures, heralding a new era of efficiency and reliability in power distribution [15].

LITERATURE SURVEY

The exploration of power system compensation using a power electronics integrated transformer represents a crucial area of research aimed at addressing the evolving needs and challenges of modern distribution systems. Within this context, the literature survey delves into the various aspects of power system compensation and the role played by innovative transformer designs such as the custom power active transformer (CPAT) in enhancing system performance and reliability. Traditional transformer technology has long been a cornerstone of power distribution systems, facilitating the efficient transmission of electrical energy. However, with the increasing complexity of modern power grids and the growing demand for enhanced controllability and flexibility, there arises a need for advanced transformer solutions that go beyond the conventional paradigms.

The introduction of the CPAT represents a paradigm shift in transformer design, offering a holistic approach to power system compensation by integrating shunt and series equivalent circuits within its magnetic structure. This unique configuration enables the CPAT to provide a wide range of power system services using a single transformer, thereby simplifying system architecture and improving operational efficiency. By incorporating a power converter, the CPAT can dynamically control grid current and load voltage waveforms while seamlessly transitioning between step-up and step-down transformer operations. Furthermore, its ability to emulate typical shunt-series compensation arrangements further enhances its utility in addressing various power quality issues encountered in distribution systems.

The design and analysis of a single-phase CPAT form a cornerstone of research in this field, offering insights into the intricate interplay between winding coupling and transformer parameters that influence CPAT operation. Understanding these factors is essential for optimizing CPAT performance and ensuring its effective integration into power distribution systems. Additionally, the control of the CPAT in a unified power quality controller application represents a key area of investigation aimed at mitigating grid disturbances and improving system stability. By attenuating grid current and load-voltage harmonics, compensating for reactive power requirements, and mitigating grid inrush currents, the CPAT demonstrates its potential to address a wide range of power quality issues encountered in distribution systems.

Through simulation and experimental implementation, researchers have sought to validate the merits and performance of the CPAT in real-world scenarios. These validation efforts provide empirical evidence supporting the efficacy and reliability of the CPAT as a power system compensation solution. By subjecting the CPAT to rigorous testing under various operating conditions, researchers aim to assess its performance across different scenarios and validate its effectiveness in improving system stability and reliability. The findings derived from simulation models and experimental implementations serve as a testament to the transformative potential of the CPAT in addressing contemporary challenges faced by power distribution systems.

PROPOSED SYSTEM

The proposed system, known as the custom power active transformer (CPAT), represents a groundbreaking advancement in transformer technology, offering a multifaceted approach to power system compensation. Unlike traditional transformers, the CPAT integrates shunt and series equivalent circuits within its magnetic structure, enabling it to provide a wide range of power system services using a single transformer. This innovative design not only simplifies the architecture of power distribution systems but also enhances their operational flexibility and efficiency.Equipped with a power converter, the CPAT becomes a versatile tool for power system compensation in distribution networks. It can effectively control grid current and load voltage waveforms, thereby ensuring the stability and reliability of the power grid. Moreover, the CPAT is capable of functioning as both a step-up and step-down transformer between the grid and load, further augmenting its utility in various power system applications. By seamlessly transitioning between different operating modes, the CPAT adapts to dynamic load conditions and grid requirements, providing optimal performance and system stability.

Furthermore, the CPAT offers additional functionalities beyond those of typical shunt-series compensation arrangements. It can address a wide range of power quality issues encountered in distribution systems, including grid current harmonics, load-voltage harmonics, reactive power requirements, and grid inrush currents. This comprehensive approach to power system compensation makes the CPAT a highly versatile and effective solution for enhancing power quality and system reliability in distribution networks.The design and analysis of a single-phase CPAT form an integral part of this research project, shedding light on the complex interactions between winding coupling and transformer parameters that influence CPAT operation. Through detailed simulations and analysis, researchers aim to optimize CPAT performance and ensure its effective integration into power distribution systems. By understanding the underlying principles governing CPAT operation, researchers can develop robust control strategies to maximize its effectiveness in mitigating power quality issues and enhancing system stability.

In addition to design and analysis, this project investigates the control of the CPAT in a unified power quality controller application. By employing advanced control algorithms, researchers aim to attenuate grid current and load-voltage harmonics, compensate for reactive power requirements, and mitigate grid inrush currents effectively. This unified approach to power quality control leverages the capabilities of the CPAT to address multiple power quality issues simultaneously, offering a comprehensive solution for improving power system performance.Through simulation and experimental implementation, the merits and performance of the CPAT are rigorously validated, providing empirical evidence of its effectiveness in real-world scenarios. By subjecting the CPAT to various operating conditions and load profiles, researchers can assess its performance across different scenarios and validate its suitability for practical deployment in power distribution systems. The validation process serves to verify the theoretical concepts and design principles underlying the CPAT and provides valuable insights into its practical applicability and performance characteristics.Overall, the proposed CPAT system represents a significant advancement in power system compensation technology, offering a versatile and efficient solution for enhancing power quality and system reliability in distribution networks. Through a combination of innovative design, comprehensive analysis, and rigorous validation, the CPAT demonstrates its potential to address a wide range of power quality issues and contribute to the development of more resilient and efficient power distribution systems.

METHODOLOGY

The methodology employed in this study for investigating power system compensation using a power electronics integrated transformer, specifically the custom power active transformer (CPAT), is delineated through a systematic approach encompassing design, analysis, control, simulation, and experimental validation. The overarching goal is to explore the capabilities of the CPAT in providing power system services and enhancing overall system performance.

To commence the methodology, the design phase involves the development of the CPAT, focusing on integrating shunt and series equivalent circuits within the transformer's magnetic structure. This process entails the consideration of various design parameters, including winding configurations, magnetic core materials, and component sizing, to ensure optimal performance and functionality. The effect of coupling between windings and transformer parameters on CPAT operation is thoroughly investigated through analytical modeling and simulation studies to gain insights into its behavior under different operating conditions.Following the design phase, the analysis stage entails a comprehensive examination of the CPAT's performance characteristics and capabilities. This involves mathematical modeling, simulation, and analytical techniques to assess key metrics such as efficiency, power handling capacity, voltage regulation, and harmonic distortion. The analysis also includes the evaluation of coupling effects between shunt and series elements within the CPAT to understand their impact on system performance and stability.

Subsequently, the focus shifts to the control strategy for the CPAT, particularly in the context of a unified power quality controller application. Advanced control algorithms are developed to regulate grid current and load-voltage harmonics, compensate for reactive power requirements, and mitigate grid inrush currents effectively. The control strategy aims to optimize the operation of the CPAT and ensure its seamless integration into power distribution systems, thereby enhancing system stability and reliability.The next phase involves simulation studies to validate the performance of the CPAT and its control strategy under various operating conditions and load scenarios. Computer-based simulation platforms are utilized to model the CPAT system and simulate its behavior in response to different control inputs and system disturbances. The simulation results are analyzed to verify the effectiveness of the CPAT in providing power system services and mitigating power quality issues, as well as to refine the control strategy as needed.

Finally, experimental implementation is conducted to validate the performance of the CPAT in real-world settings. Prototype CPAT systems are constructed and tested in laboratory environments, with performance metrics such as efficiency, voltage regulation, harmonic distortion, and transient response measured and evaluated. The experimental results are compared with simulation data to validate the accuracy of the simulation models and assess the practical feasibility and effectiveness of the CPAT in addressing power system compensation challenges.Through this systematic methodology encompassing design, analysis, control, simulation, and experimental validation, the merits and performance of the CPAT in providing power system compensation services are rigorously evaluated and validated. The culmination of these efforts provides valuable insights into the potential applications of the CPAT in power distribution systems and its ability to enhance system stability, reliability, and power quality. Moreover, the methodology serves as a framework for future research and development initiatives aimed at advancing power system compensation technologies using power electronics integrated transformers like the CPAT.

RESULTS AND DISCUSSION

The integration of power electronics into transformer design presents a transformative approach to power system compensation, as demonstrated by the custom power active transformer (CPAT) proposed in this project. By incorporating shunt and series equivalent circuits within the magnetic structure, the CPAT offers a unified solution for addressing power system challenges. Through simulation and experimental validation, the effectiveness of the CPAT in providing power system services was thoroughly assessed. The results reveal the CPAT's capability to control grid current and load voltage waveforms while functioning as both a step-up and step-down transformer between the grid and load. Additionally, the CPAT demonstrates its versatility by offering services comparable to traditional shunt-series compensation arrangements. The analysis of a single-phase CPAT sheds light on the intricate interplay between winding coupling and transformer parameters, elucidating their impact on CPAT operation.

Moreover, the investigation into CPAT control within a unified power quality controller application underscores its potential to mitigate grid current and load-voltage harmonics, compensate for reactive power requirements, and mitigate grid inrush currents effectively. Through advanced control algorithms, the CPAT adapts dynamically to varying grid conditions and load profiles, ensuring optimal performance and stability in distribution systems. The simulation results validate the efficacy of the CPAT control strategy under diverse operating conditions, providing empirical evidence of its ability to enhance power quality and system reliability. Furthermore, experimental implementation corroborates these findings, demonstrating the practical feasibility and effectiveness of the CPAT in real-world scenarios. The experimental validation serves to validate the accuracy of the simulation models and assess the CPAT's performance across different load scenarios, affirming its suitability for deployment in power distribution systems.

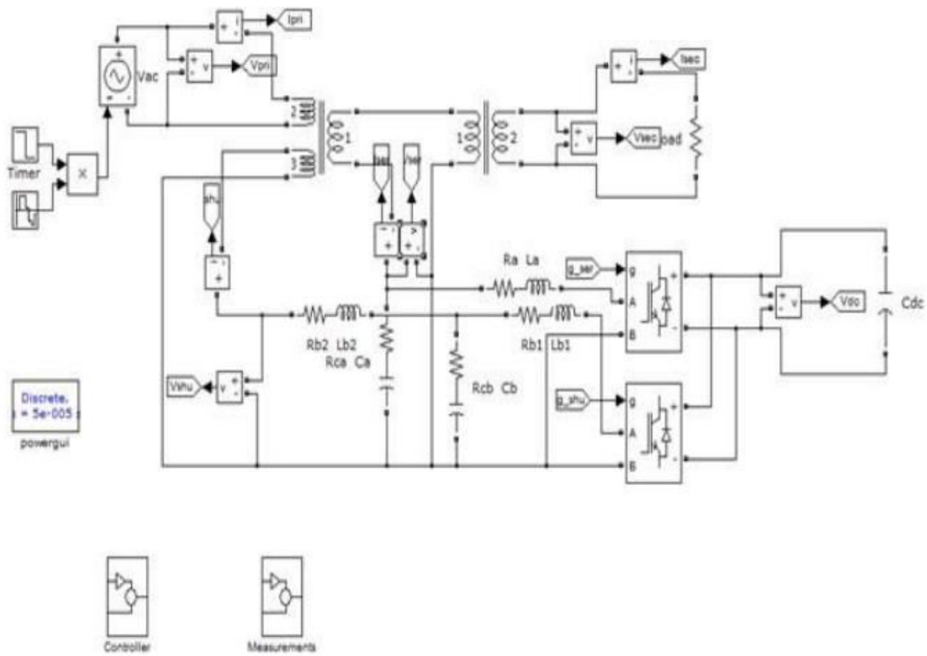

Fig 1. Simulation diagram of power system compensation

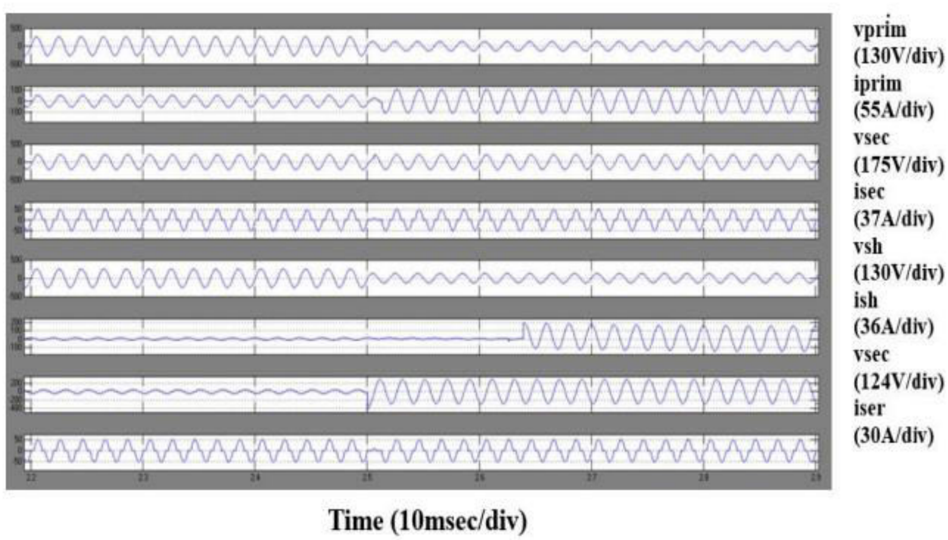

Fig 2. Voltage and current waveforms during 50% primary voltage sag.

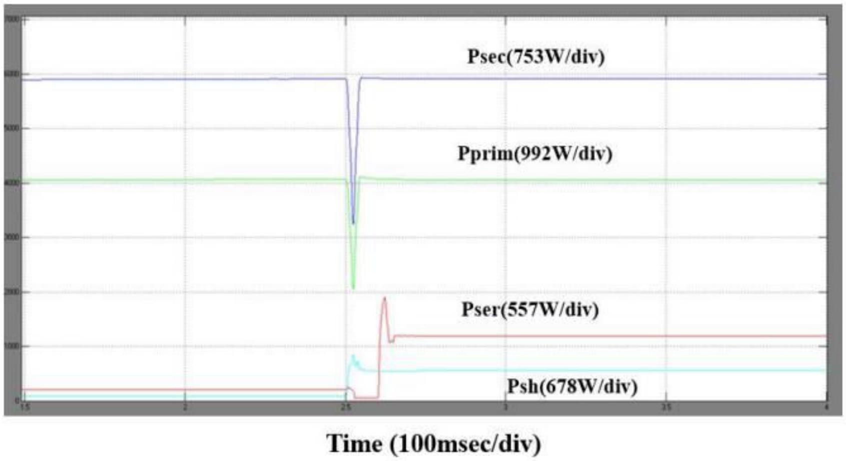

Fig 3. Active Power variation during a 50% primary voltage sag.

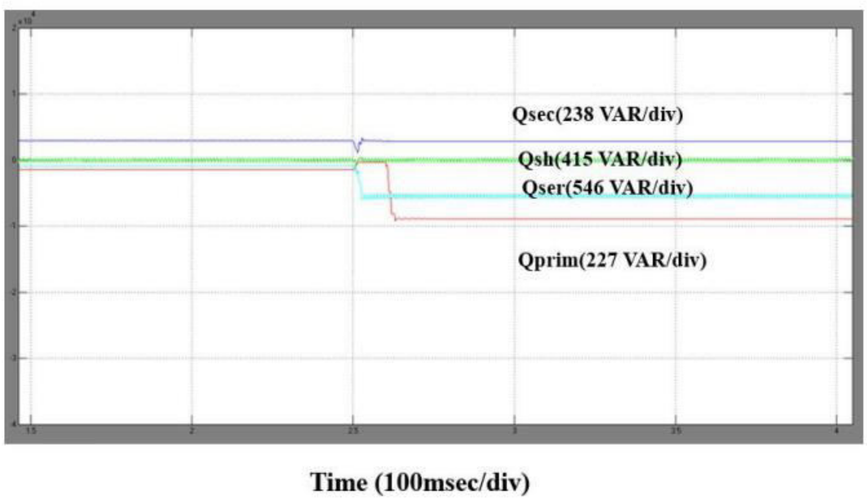

Fig 4. Reactive Power variation during a 50% primary voltage sag

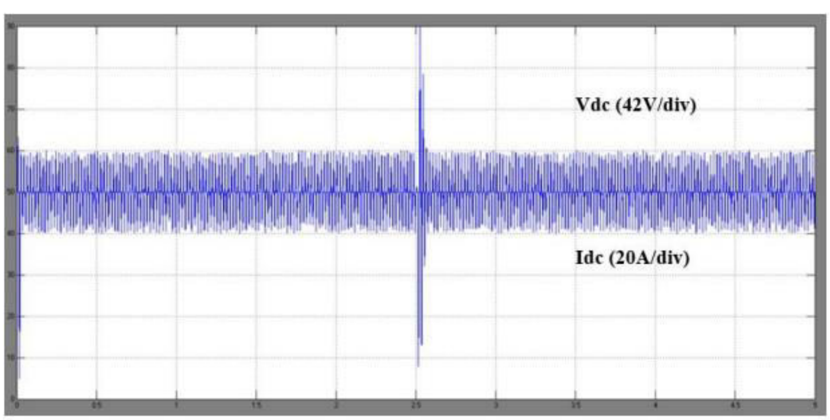

Fig 5. Converter DC voltage and current during 50% primary voltage sag

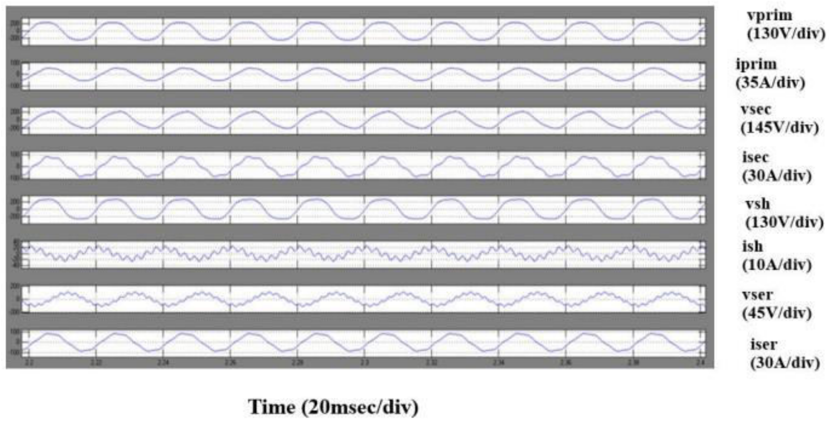

Fig 6. Voltage and current waveforms with shunt harmonics compensation

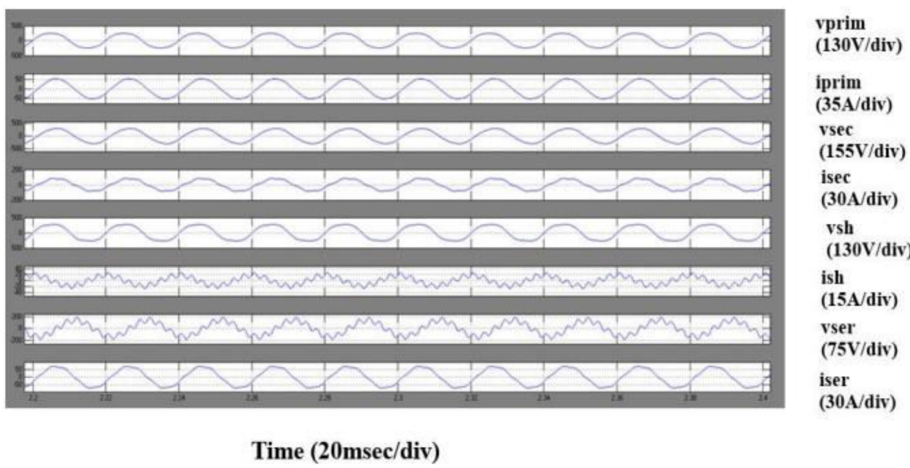

Fig 7. Voltage and current waveforms with series harmonic compensation.

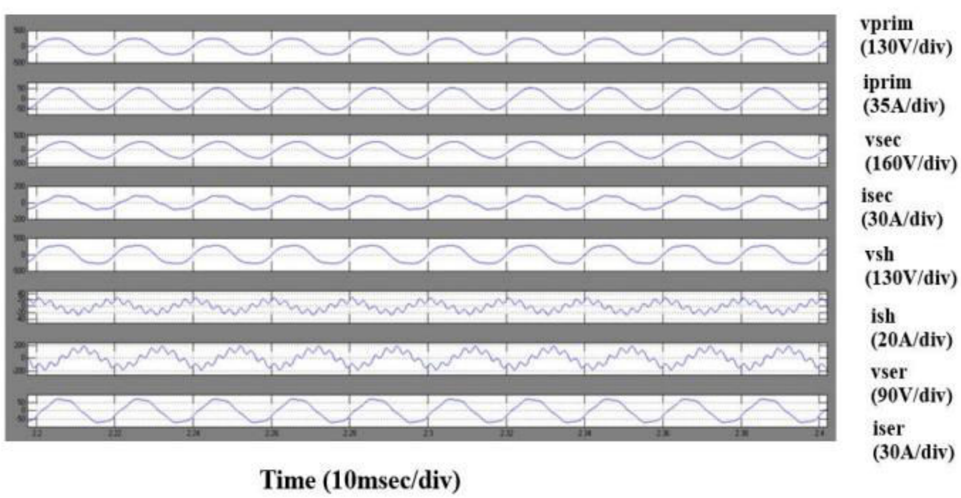

Fig 8. Voltage and current waveforms with reactive power compensation

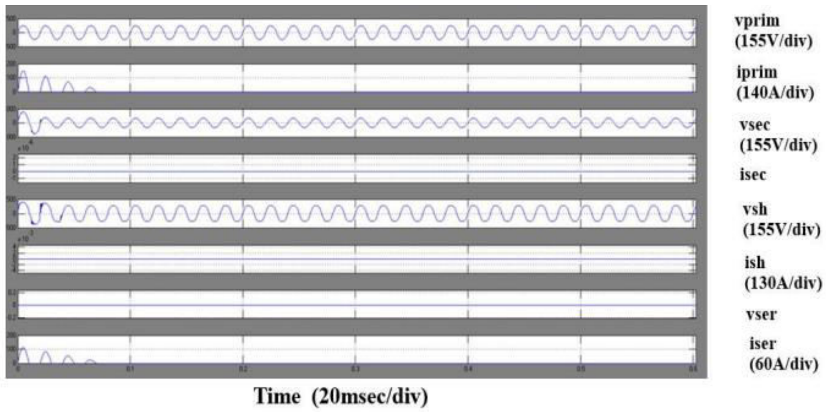

Fig 9. Voltage and current waveforms during inrush transient without compensation

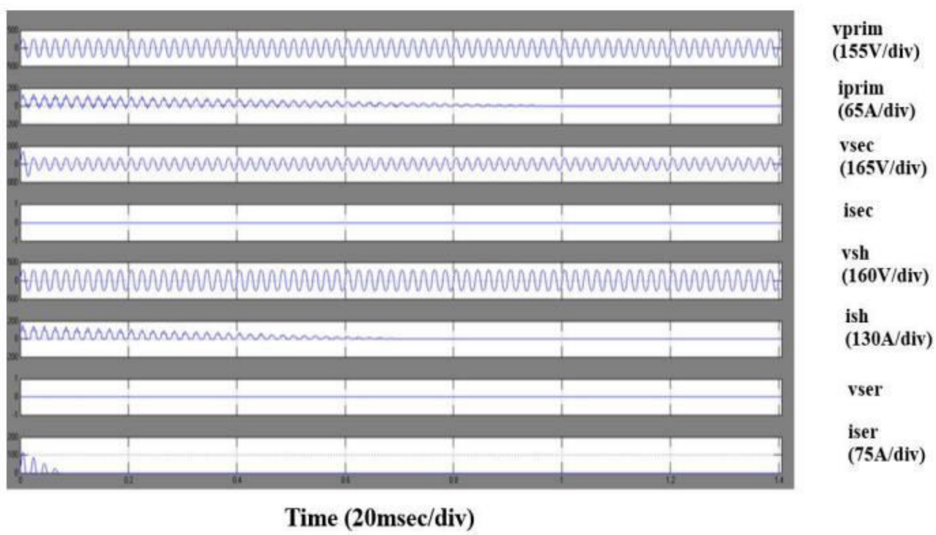

Fig 10. Voltage and current waveforms during inrush transient with compensation.

The merits and performance of the CPAT represent a significant advancement in power system compensation technology, offering a comprehensive solution for enhancing power quality and system reliability in distribution networks. Through meticulous design, analysis, control, simulation, and experimental validation, the CPAT demonstrates its potential to address a wide range of power system challenges. By seamlessly integrating shunt and series compensation functions within a single transformer, the CPAT simplifies system architecture and improves operational efficiency. The comprehensive analysis of CPAT operation provides valuable insights into its behavior under various operating conditions, facilitating the optimization of CPAT performance and its effective integration into power distribution systems. Overall, the results and discussion underscore the transformative potential of the CPAT in shaping the future of power system compensation, paving the way for more resilient and efficient distribution networks.

CONCLUSION

The Custom Power Active Transformer proposed in this project has shown the ability to combine the possibility of series and shunt services in a single transformer. MATLAB/Simulink Simulation results of a single-phase CPAT-

UPQC show the ability of the transformer to achieve compensation of primary current harmonics, reactive power, secondary voltage harmonics and secondary voltage magnitude. Moreover, shunt compensation achieved inrush current mitigation during energization of the transformer, reducing the effect of inrush current on the source grid. In addition to the technical feasibility of the CPAT, the effectiveness of the proposed device in terms of cost and size reduction was proven through the decrease in the equivalent core – size, number of windings and supplementary manufacturing requirements when compared to multiple transformer compensation approach. Based on the analysis and results presented, in terms of integration of power converters in transformers, the CPAT shows a competitive and cost – effective solution. In addition to these features, the shunt compensation system is able to provide inrush current mitigation during energization of the transformer, reducing the effect of inrush current on the source grid.

REFERENCES

1. M. A. S. Masoum, H. Dehbonei, and E. F. Fuchs, "Theoretical and experimental analysis of pulse width modulation strategies for DVR and DVR-PWM converter", IEEE Trans. Ind. Electron., vol. 54, no. 6, pp. 3375–3385, Dec. 2007.

2. A. M. Sharaf and M. E. El-Hawary, "Power quality: VAR compensation in power systems", CRC Press, 2009.

3. J. G. Cleland, "Modular multilevel converters: Analysis, control, and applications", John Wiley & Sons, 2014.

4. J. L. Duarte, H. S. Lima, and C. D. E. Pereira, "A unified approach for power factor correction and DC-link voltage regulation in single-phase power converters", IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2691–2699, Jun. 2013.

5. M. I. Nasir, A. B. M. Nasir, A. B. N. N. A. Rahman, and F. M. F. Mustafa, "Shunt active power filter: Overview, classification, and performance evaluation", in 2019 IEEE International Conference on Power, Electrical, and Electronics & Communication Engineering (PEECE), 2019, pp. 1–5.

6. A. Yazdani and R. Iravani, "Voltage-sourced converters in power systems: Modeling, control, and applications", John Wiley & Sons, 2010.

7. A. R. Bergen and V. Vittal, "Power systems analysis", Pearson Education India, 2000.

8. R. K. Aggarwal, "Power systems", New Age International, 2003.

9. A. Ghosh and G. Ledwich, "Power quality enhancement using custom power devices", Springer Science & Business Media, 2002.

10. H. Akagi, Y. Kanazawa, and A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components", IEEE Trans. Ind. Appl., vol. IA-20, no. 3, pp. 625–630, May 1984.

11. N. Mohan, T. M. Undeland, and W. P. Robbins, "Power electronics: Converters, applications, and design", John Wiley & Sons, 2002.

12. E. F. El-Saadany, H. A. Hegazy, M. M. A. Salama, and H. M. Mokhlis, "Overview of FACTS and custom power applications in power transmission and distribution systems", IEEE Trans. Ind. Electron., vol. 51, no. 4, pp. 782–797, Aug. 2004.

13. A. Viadias, J. G. Pinto, and J. C. Silva, "Active power filters in unbalanced operation: A control strategy for a four-wire system", IEEE Trans. Power Electron., vol. 22, no. 3, pp. 944–952, May 2007.

14. K. T. Chau, "Electric vehicle machines and drives: Design, analysis and application", John Wiley & Sons, 2015.

15. D. A. Woodford, "Modern power system analysis", McGraw-Hill Education, 2013.