Power Quality Improvement Using SEPIC Converter Optimization: A Review

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Abstract:

Power factor correction (PFC) is a critical aspect of modern power electronics, ensuring efficient and reliable operation of electrical systems. The SEPIC (Single-Ended Primary-Inductor Converter) converter, with its unique buck-boost capability and non-inverted output voltage, has emerged as a promising topology for PFC applications. This paper presents a comprehensive review of research efforts over the last decade focused on optimizing SEPIC converters for PFC. We delve into various control strategies, optimization techniques, and advancements in component technology that have contributed to enhancing the performance of SEPIC-based PFC systems. The review also explores the challenges and future trends in this field, providing valuable insights for researchers and engineers working towards developing high-performance and efficient power electronic solutions.

1. Introduction

The proliferation of non-linear loads in modern electrical systems has led to significant power quality issues, including harmonic distortion and low power factor. Power factor correction (PFC) techniques are essential to mitigate these issues, improve energy efficiency, and comply with regulatory standards [1]. Among various PFC converter topologies, the SEPIC converter has gained popularity due to its distinct advantages, such as buck-boost capability, non-inverted output voltage, and inherent input-output isolation [2].

This review paper aims to provide a comprehensive overview of the research progress in SEPIC converter-based PFC over the last decade. We explore various control strategies, optimization techniques, and advancements in component technology that have contributed to enhancing the performance of SEPIC-based PFC systems. The paper also discusses the challenges and future trends in this field, providing valuable insights for researchers and engineers working towards developing high-performance and efficient power electronic solutions.

2. SEPIC Converter Fundamentals

The SEPIC converter is a DC-DC converter topology that can provide an output voltage that is either higher or lower than the input voltage. It is characterized by two inductors and a capacitor connected in a unique configuration, enabling both buck and boost operation. The basic circuit diagram of a SEPIC converter is shown in Figure 1.

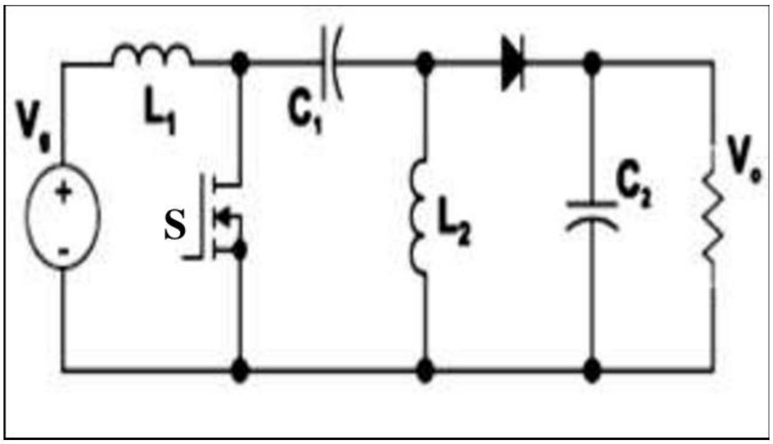

Figure 1- SEPIC Converter Circuit Diagram

The SEPIC converter operates in two modes: continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In CCM, the current through the inductors remains continuous throughout the switching cycle, while in DCM, the inductor current falls to zero during a portion of the switching cycle. The voltage gain of the SEPIC converter is given by:

Vout / Vin = D / (1-D)

where D is the duty cycle of the switching signal.

3. SEPIC Converter for Power Factor Correction

The SEPIC converter can be effectively utilized for PFC applications by incorporating a suitable control strategy. The control objective is to shape the input current to follow the input voltage waveform, thereby achieving a high power factor. This is typically achieved by employing a closed-loop control system that regulates the output voltage and input current simultaneously.

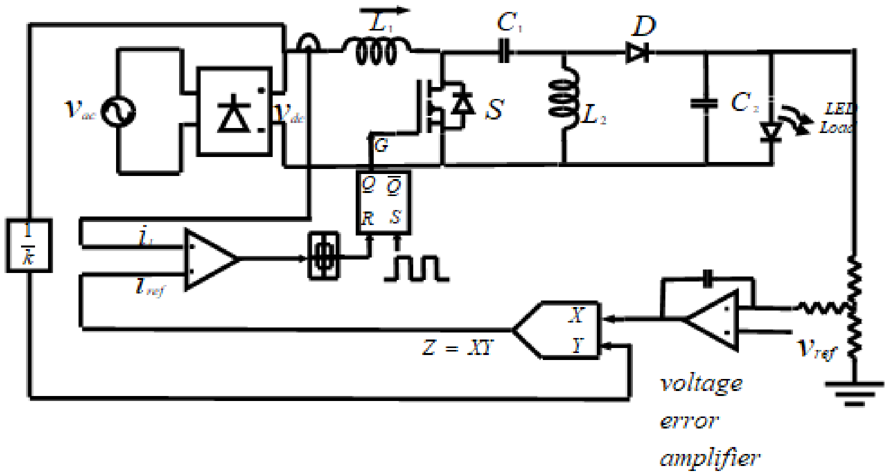

Figure 2- Sepicbased PFC System Block Diagram.

Figure 2 illustrates a typical block diagram of a SEPIC-based PFC system. The control system consists of two loops: an outer voltage loop and an inner current loop. The voltage loop regulates the output voltage to the desired value, while the current loop shapes the input current to follow the input voltage waveform.

4. Control Strategies for SEPIC-based PFC

Various control strategies have been proposed in the literature to achieve high power factor and efficient operation of SEPIC-based PFC systems. Some of the commonly used control techniques include:

- **Average Current Mode Control (ACM):** This is a widely used control technique that regulates the average value of the inductor current to achieve PFC. ACM offers good stability and dynamic response but suffers from limitations in terms of input current distortion and switching frequency limitations [3].

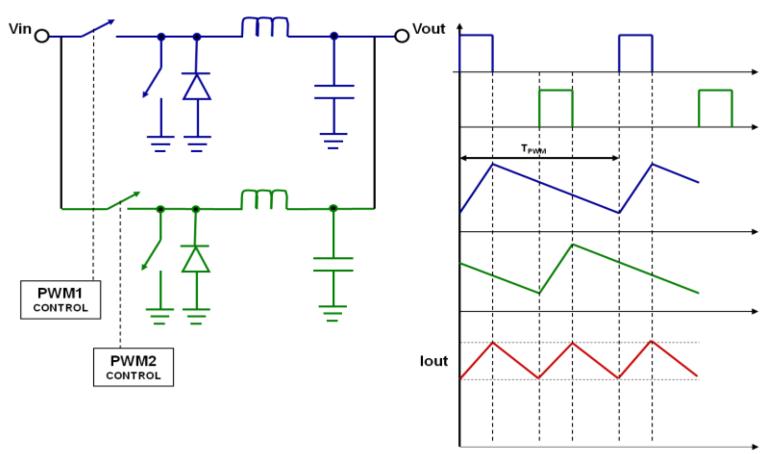

Figure 3- Average Current Mode Control (ACM) Waveform.

- **Peak Current Mode Control (PCM):** PCM regulates the peak value of the inductor current and offers faster transient response compared to ACM. However, PCM is susceptible to subharmonic oscillations and requires slope compensation to ensure stability [4].

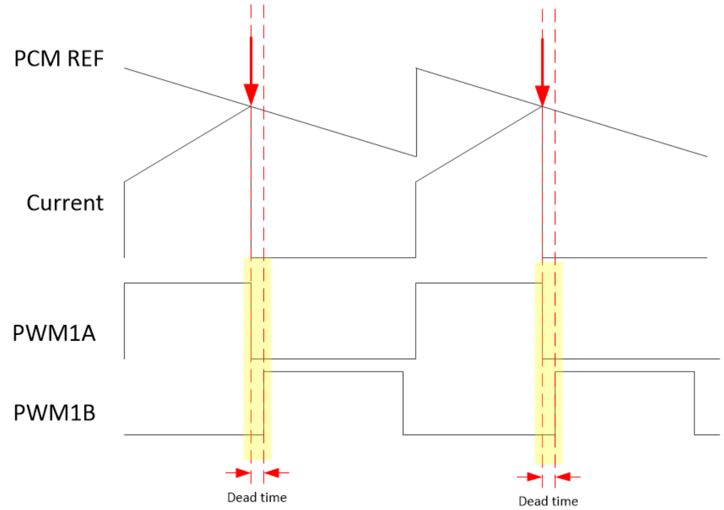

Figure 4- Peak Current Mode Control (PCM) Waveform.

- **Hysteresis Current Control (HCC):** HCC maintains the inductor current within a hysteresis band, providing fast dynamic response and inherent current limiting. However, HCC suffers from variable switching frequency and increased switching losses [5].

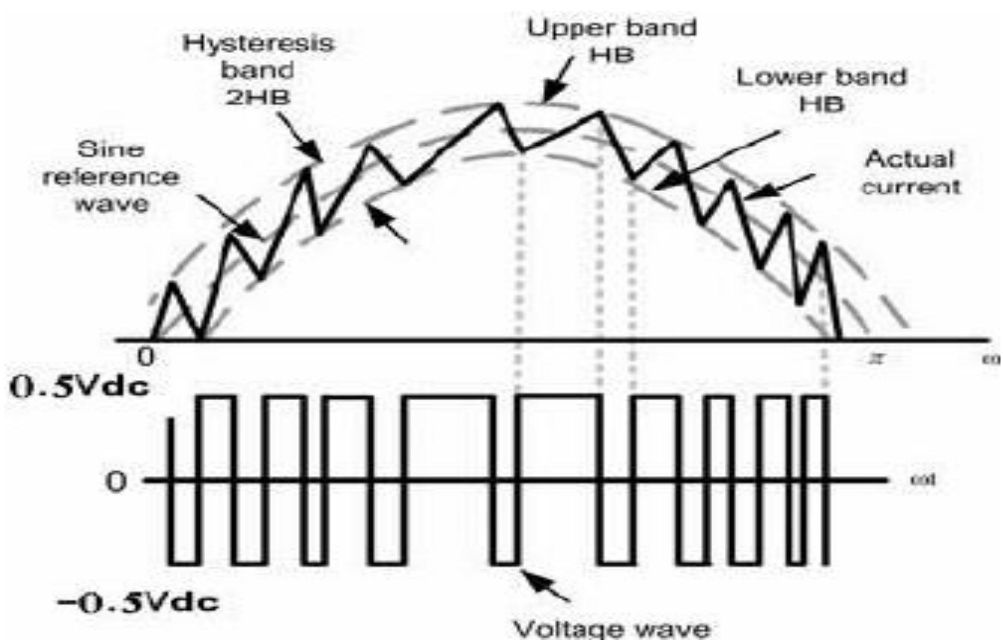

Figure 5- Hysteresis Current Control (HCC) Waveform.

- **Sliding Mode Control (SMC):** SMC is a robust control technique that offers excellent dynamic performance and insensitivity to parameter variations. However, SMC can lead to chattering phenomenon and requires careful design of the sliding surface [6].

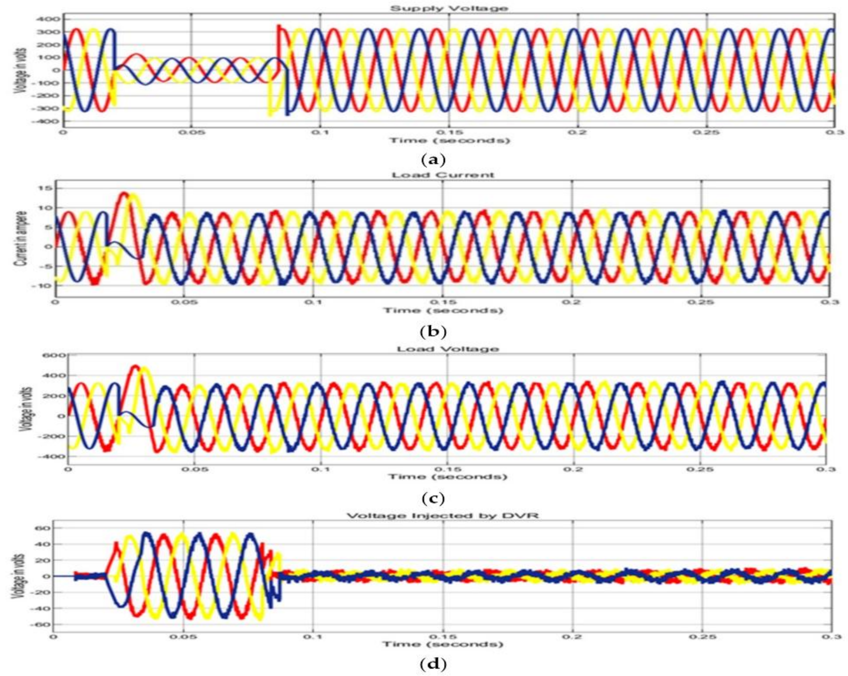

Figure 6- Sliding Mode Control (SMC) Waveform.

- **Predictive Control:** Predictive control techniques, such as Model Predictive Control (MPC), offer optimal control performance by predicting the future behavior of the system. However, predictive control requires accurate system modeling and can be computationally intensive [7].

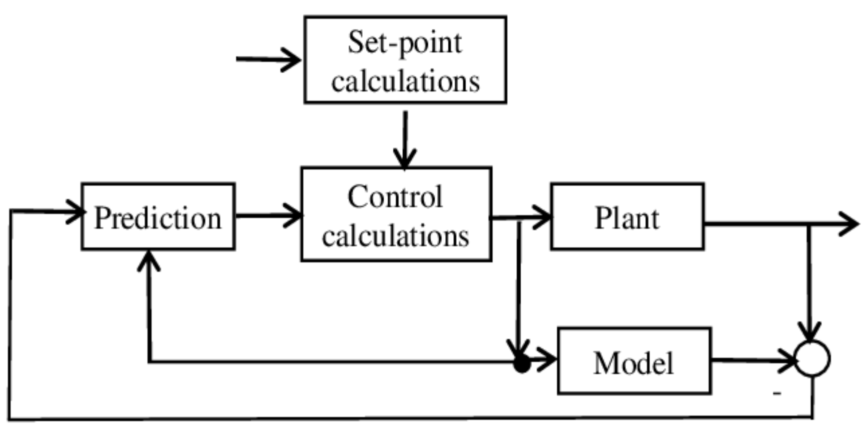

Figure 7- Model Predictive Control (MPC) Block Diagram.

5. Optimization Techniques for SEPIC-based PFC

In addition to control strategies, various optimization techniques have been employed to enhance the performance of SEPIC-based PFC systems. These techniques aim to improve efficiency, reduce harmonic distortion, and minimize component size and cost. Some of the key optimization techniques include:

- **Soft-switching techniques:** Soft-switching techniques, such as Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS), aim to reduce switching losses by turning on or off the switches when the voltage or current across them is zero. This improves efficiency and reduces electromagnetic interference (EMI) [8].
- **Passive component optimization:** Optimizing the values of passive components, such as inductors and capacitors, can significantly impact the performance of SEPIC-based PFC systems. Techniques like integrated magnetics and coupled inductors can help reduce component size and improve efficiency [9].
- **Active component optimization:** Selecting appropriate switching devices with low on-resistance and fast switching speeds can contribute to improved efficiency and reduced switching losses [10].
- **Control parameter optimization:** Optimizing the control parameters, such as gains and time constants, can enhance the dynamic response and stability of the PFC system [11].
- **Multi-objective optimization:** Multi-objective optimization techniques, such as genetic algorithms and particle swarm optimization, can be employed to simultaneously optimize multiple performance parameters, such as efficiency, power factor, and total harmonic distortion (THD) [12].

6. Advancements in Component Technology

Advancements in component technology have played a crucial role in improving the performance of SEPIC-based PFC systems. Some of the key advancements include:

- **Wide bandgap semiconductors:** Wide bandgap semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), offer superior performance compared to traditional silicon devices. They exhibit lower on-resistance, higher switching speeds, and higher operating temperatures, enabling higher efficiency and reduced switching losses [13].

- **Digital signal processors (DSPs):** DSPs offer advanced control capabilities and flexibility in implementing complex control algorithms. They enable precise control of the SEPIC converter, leading to improved power factor and reduced THD [14].
- **Advanced passive components:** Advancements in passive component technology have led to the development of smaller, lighter, and more efficient inductors and capacitors. This has contributed to reducing the size and weight of SEPIC-based PFC systems [15].

7. Challenges and Future Trends

Despite significant progress in SEPIC-based PFC, several challenges remain, and future research efforts are focused on addressing these challenges and exploring new avenues for improvement. Some of the key challenges and future trends include:

- **High-frequency operation:** Operating SEPIC converters at higher switching frequencies can lead to reduced component size and improved dynamic response. However, high-frequency operation also increases switching losses and EMI. Future research is focused on developing new control techniques and component technologies to enable efficient high-frequency operation [16].
- **Wide input voltage range:** Many applications require PFC systems to operate over a wide input voltage range. This poses challenges in terms of control design and component selection. Future research is focused on developing robust control strategies and adaptive techniques to address these challenges [17].
- **Integration and miniaturization:** There is a growing demand for compact and integrated PFC solutions. Future research is focused on developing integrated circuits (ICs) that combine the control circuitry and power stage of the SEPIC converter, leading to smaller and more efficient PFC systems [18].
- **Advanced control techniques:** The development of advanced control techniques, such as artificial intelligence (AI) and machine learning (ML), can further enhance the performance of SEPIC-based PFC systems. These techniques can enable adaptive control, fault diagnosis, and self-optimization capabilities [19].

8. Conclusion

This paper has presented a comprehensive review of the research progress in SEPIC converter-based PFC over the last decade. We have explored various control strategies, optimization techniques, and advancements in component technology that have contributed to enhancing the performance of SEPIC-based PFC systems. The review has also highlighted the challenges and future trends in this field, providing valuable insights for researchers and engineers working towards developing high-performance and efficient power electronic solutions.

The SEPIC converter has emerged as a promising topology for PFC applications due to its unique advantages, such as buck-boost capability, non-inverted output voltage, and inherent input-output isolation. Continued research efforts in this field are expected to lead to further improvements in efficiency, power factor, and dynamic response of SEPIC-based PFC systems, contributing to the development of more reliable and sustainable power electronic solutions.

References:

[1] IEEE Standard 1459-2010, "IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions," 2010.

[2] M. Kazimierczuk and D. Czarkowski, "Resonant Power Converters," 2nd ed. Hoboken, NJ, USA: Wiley, 2011.

[3] R. W. Erickson and D. Maksimovic, "Fundamentals of Power Electronics," 2nd ed. Norwell, MA, USA: Kluwer, 2001.

[4] V. Vorperian, "Simplified analysis of PWM converters using model of PWM switch. II. Discontinuous conduction mode," IEEE Trans. Aerosp. Electron. Syst., vol. 26, no. 3, pp. 497–505, May 1990.

[5] K. H. Liu and F. C. Y. Lee, "Zero-voltage switching technique in DC/DC converters," IEEE Trans. Power Electron., vol. 5, no. 3, pp. 293–304, Jul. 1990.

[6] H. Sira-Ramirez, "Sliding motions in bilinear switched networks," IEEE Trans. Circuits Syst., vol. 34, no. 8, pp. 919–933, Aug. 1987.

[7] J. Rodriguez and P. Cortes, "Predictive Control of Power Converters and Electrical Drives," Chichester, U.K.: Wiley, 2012.

[8] F. Z. Peng, "ZVS full-bridge converter with a phase-shifted PWM scheme and active clamp," IEEE Trans. Ind. Appl., vol. 32, no. 4, pp. 874–882, Jul./Aug. 1996.

[9] R. Severns and G. Bloom, "Modern DC-to-DC Switchmode Power Converter Circuits," New York, NY, USA: Van Nostrand Reinhold, 1985.

[10] B. J. Baliga, "Fundamentals of Power Semiconductor Devices," Berlin, Germany: Springer, 2008.

[11] K. Ogata, "Modern Control Engineering," 5th ed. Upper Saddle River, NJ, USA: Pearson, 2010.

[12] S. N. Sivanandam and S. N. Deepa, "Introduction to Genetic Algorithms," Berlin, Germany: Springer, 2008.

[13] J. Millán, P. Godignon, X. Perpiñà, A. Pérez-Tomás, and J. Rebollo, "A survey of wide bandgap power semiconductor devices," IEEE Trans. Power Electron., vol. 29, no. 5, pp. 2155–2163, May 2014.

[14] B. Akin, "Digital Signal Processing Techniques for Power Electronic Converters," New York, NY, USA: Academic, 2012.

[15] J. D. van Wyk and F. C. Lee, "Power electronics technology—The coming revolution," in Proc. IEEE Int. Power Electron. Conf. (IPEC), Jun. 2010, pp. 3–10.

[16] X. Huang, F. C. Lee, Q. Li, and W. Chen, "High-frequency, high-efficiency GaN-based interleaved CRM bidirectional buck/boost converter with wide input and output voltage ranges," IEEE Trans. Power Electron., vol. 31, no. 7, pp. 5074–5084, Jul. 2016.

[17] A. Prodic, D. Maksimovic, and R. W. Erickson, "Design and implementation of a digital PWM controller for a high-frequency switching DC-DC power converter," in Proc. IEEE Appl. Power Electron. Conf. Expo. (APEC), Mar. 2001, pp. 893–899.

[18] Y. Chen, F. C. Lee, L. Amoroso, and H.-P. Wu, "A resonant boost power factor correction converter for high-power applications," IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1728–1736, Apr. 2012.

[19] S. Mohagheghi, A. Gabash, and P. Li, "A review of control techniques for power electronic converters in microgrids," Renew. Sustain. Energy Rev., vol. 140, pp. 127199-1-127199-22, 2021.