Efficiency Optimization and Power Quality Enhancement in Power Conversion Systems with SEPIC and PI Control Design

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Abstract. The SEPIC (Single Ended Primary Inductance Converter) converter is a highly versatile and efficient solution to correct the power factor in AC-DC conversion systems, and it has become increasingly popular due to its performance and ease of use. It is well-suited for high voltage conversion applications. The integration of a PI controller can further improve its performance. PI controller can regulate the SEPIC converter's output voltage, maintaining a stable output voltage even under changing load conditions. However, efficiency and power quality are two critical considerations in power conversion systems, as they both impact the performance and reliability of these systems. This paper offers a comprehensive overview of utilizing SEPIC and PI control for optimizing efficiency and enhancing power quality in power conversion systems.

Keywords: SEPIC converter · PI controller · efficiency and power quality

1 Introduction

Power conversion is a critical component of many electrical systems, as it involves converting electrical energy from one form to another [1]. A rectifier is a type of power converter that is used to convert AC power to DC power. Rectifiers have a wide range of applications in various fields, including power supplies, battery charging systems, welding equipment, medical equipment, the automotive industry, solar power systems, military and aerospace, and many others. To suit the specific requirements of an application, different types of rectifiers such as half-wave rectifiers, full-wave rectifiers, controlled rectifiers like SCR and PWM rectifiers, and high-frequency rectifiers are used, which vary in their output voltage, current, and power factor. The power factor of the load is a measure of the efficiency with which the load uses the power that is supplied to it. A low power factor results in increased losses in the distribution system, reduced efficiency, and increased costs for the electrical system. When designing an electrical system, it is crucial to take into account the impact of the rectifier on the power factor, as utilities may impose extra charges for a low power factor in certain instances [2]. However, the rectifier's effect on the power factor of the electrical system in which it is

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used is generally to decrease the power factor. The traditional method of converting AC to DC through a full-wave diode bridge and the capacitor is phased out because of the presence of harmonic currents [3, 4]. The input current waveform is discontinuous and contains high-frequency harmonics, which leads to a low power factor. The voltage and current waveform shape supplied to the load impacts the power factor. More sinusoidal waveform will generally have a higher power factor than a rectifier with a pulsed output waveform [5]. To overcome this a DC-DC converter can be integrated to the rectifier.

SEPIC (Single Ended Primary Inductance Converter) is a type of DC-DC power converter that is used to convert a high-voltage [6], low-current source to a low-voltage, high-current source. Unlike traditional DC-DC converters, the SEPIC converter can operate with both positive and negative input voltages. This feature makes the SEPIC converter an attractive option for use in power conversion systems that require a high voltage conversion ratio. It is commonly used in power supply applications where the input voltage source may vary widely and needs to be regulated [7]. The SEPIC converter works by using a combination of inductors and capacitors to convert the voltage from the input source to a different level and then regulate the output voltage to a constant level [8]. On the other hand, PI control is a type of control algorithm used in control systems to regulate the behavior of a system. It is a type of feedback control system that uses both proportional and integral control actions to control the behavior of a system. The proportional action provides a quick response to changes in the error signal, while the integral action helps eliminate steady-state error and improve the system's stability. The PI controller is widely used in control applications where fast response time, stability, and precision are important.

SEPIC and PI control can be used together in a PFC application to rectify an AC input voltage and provide a regulated DC output voltage with an improved power factor and reduced harmonic distortion. SEPIC converter is used as a front-end PFC stage to rectify the AC input voltage and convert it to a regulated DC voltage by using an inductor and capacitor, while the PI controller regulates the DC output voltage by continuously monitoring the difference between the desired output voltage and the actual output voltage, and adjusting the duty cycle of the converter accordingly [9].

By combining the SEPIC converter and the PI controller, a PFC stage can be implemented that provides a high-power factor, reduces input current harmonic distortion, and improves the overall efficiency of the power supply.

2 Working of SEPIC

Figure 1 indicates the Circuit diagram of SEPIC with design parameters (i) L1 = 2mH, (ii) L2 = 1Mh, (iii) C1 = 10μF, (iv) C2 = 6000μF, (v) R_L = 50Ω, (vi) Switching frequency = 50kHz.

2.1 Mode 1

Initially, the capacitor C1 is fully charged. In the Fig. 1 when the switch is on inductor L1 stores the energy from the supply voltage V and the current starts flowing through the short circuit path as it offers less resistance. Inductor L2 gets charged due to the stored energy of capacitor C1.

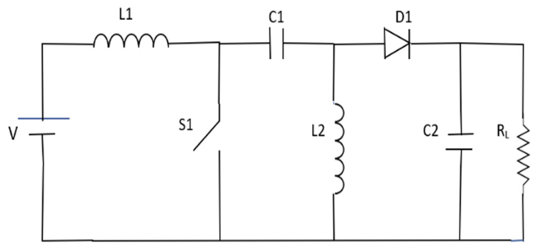


Fig. 1. Circuit diagram of SEPIC

2.2 Mode 2

When the switch is off, the inductor L1 reverses its polarities and C1 gets charged up since it discharged its energy in ON condition. The inductor L2 also changes its polarities and due to this diode D1 becomes forward-biased.C2 starts charging due to the already stored energy in L2 during the ON condition. Once, the capacitor C2 gets fully charged the same voltage is appeared across the load and has the same polarity as that of the supply. SEPIC and buck-boost converters are similar i.e., they can step up and also steps down the voltage, but unlike Buck-boost converters, SEPIC converters give an output that is non-inverted [10].

3 Methodology

Figure 2 indicates a SEPIC (Single Ended Primary Inductor Converter) with a PI (Proportional-Integral) controller integrated to the rectifier as a power factor correction (PFC) circuit, the following steps occur from the rectifier to the load:

Rectification: The AC input voltage is rectified to produce a DC voltage by the full-wave rectifier. But, due to the harmonics that are generated in the current waveform, the power factor decreases.

Power factor correction: The PI controller regulates the input current to bring it into phase with the input voltage, which improves the power factor of the input current. This is accomplished by adjusting the duty cycle of the switch to control the input current and maintain it in phase with the voltage.

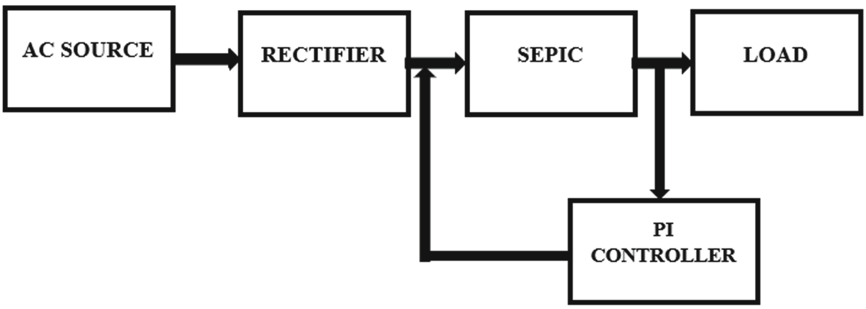


Fig. 2. Block diagram of proposed model

Conversion: The DC voltage from the rectifier is converted to the desired output voltage by the SEPIC converter. This involves a voltage conversion process that adjusts the voltage level, as well as a filtering process that removes any residual ripple.

Regulation: The PI controller regulates the output voltage to maintain it at the desired level by adjusting the duty cycle of the switch. This results in a well-regulated output voltage with a low level of harmonic content. The PI controller parameters are $K_p = 0.3$, $K_i = 3$.

Load connection: The output of the SEPIC converter is connected to the Resistive load, which is supplied with the regulated DC voltage. The output voltage is stabilized and maintained at the desired level, even under changing load conditions.

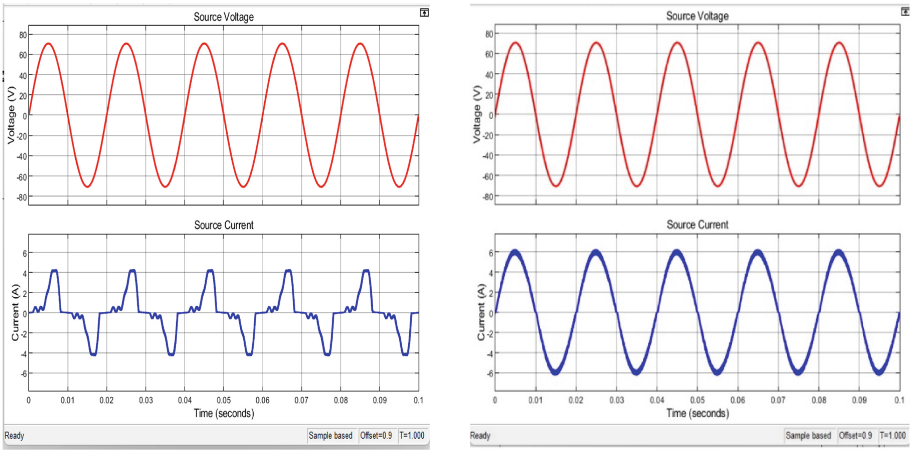
The system under consideration is SEPIC converter which is a DC-to-DC converter, meaning that it takes a DC input voltage and converts it to a different DC output voltage. The inductor and capacitor work together to shape the input into an AC-like waveform that resembles a sinusoidal waveform. It can be made through the use of a PI controller in conjunction with a SEPIC converter. The PI controller adjusts the duty cycle of the switch to control the output voltage and maintain it at the desired level, and it also regulates the input current to bring it into phase with the input voltage, which improves the power factor of the input current. It also reduces the voltage fluctuations and harmonics. If the output voltage deviates from the desired level, it adjusts the duty cycle to bring the output voltage back to the desired level. By adjusting the duty cycle, the amount of energy stored in the inductor and capacitor of the SEPIC converter gets changed.

Efficiency in power converters can be improved by reducing power losses in the system. There are several ways to achieve this, including reducing switching losses, reducing conduction losses, and optimizing the control strategy. The proposed PI controller is designed to regulate the output voltage and input current, which can indirectly lead to reduced power losses and improved efficiency. By controlling the voltage and current waveforms, the controller can reduce switching losses and conduction losses in the system.

The advantage is that it provides both voltage conversion and power factor correction in a single, compact circuit, which makes it a cost-effective and efficient solution for a wide range of applications. Additionally, the PI controller ensures stable and accurate regulation of the output voltage and input current, resulting in a clean and well-regulated DC voltage. Use of a PI controller also provides improved output voltage regulation, which helps to reduce voltage fluctuations that can affect the performance of the load. This improved voltage regulation, in combination with the improved power factor, results in a power conversion system with higher efficiency and better power quality.

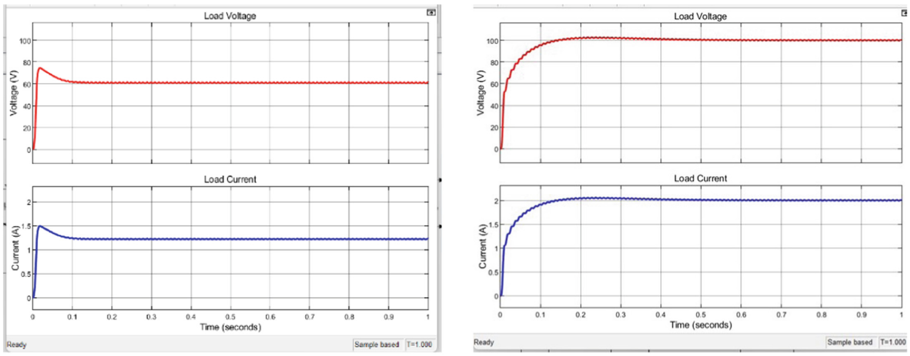
4 Results and Discussion

The simulated results with the PI controller and without the controller are analyzed and it can be noted that the harmonics in the current waveform are reduced when the control circuit is present as shown in Fig. 3. Since the harmonics are reduced then it can be said the that the power factor is improved. Similarly, in Fig. 4 the output of the DC voltage is improved. Above all, the total harmonic distortion value Fig. 5 which was 66.18% when there was no pi controller is decreased to an acceptable range. The Total Harmonic Distortion value is obtained as 2.67% due to the action of pi controller.



(a) **(b)**

Fig. 3. Simulated results of source current and source voltage. **(a)** Without control circuit. **(b)** With control circuit

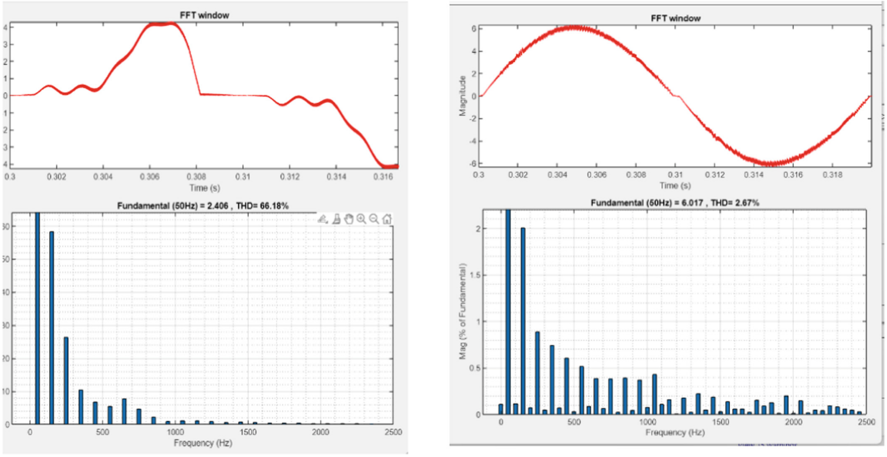


(a) **(b)**

Fig. 4. Simulated Results of load current and load voltage **(a)** Without control circuit. **(b)** With control circuit

5 Conclusion

SEPIC converter as PFC can increase the power factor by making the current waveform at the input in phase with the voltage waveform to the load. THD value decreased from 66.18% to 2.67%. Without the control circuit, the input current is unregulated and can contain harmonics that contribute to the high THD. But, the PI controller regulates the input current waveform, reducing its distortion and thus reducing the THD of the overall system. The load voltage and current are also improved, which further increases the efficiency from 82.09 to 95.1. Hence SEPIC topology and PI control provide improved regulation compared to traditional SEPIC converters, making it a promising solution for various power conversion applications. Furthermore, integrating a rectifier with the



(a) **(b)**

Fig. 5. THD Analysis (**a**) Without control circuit THD = 66.18%. (**b**) With control circuit THD = 2.67%

SEPIC-PI system can provide a high-quality DC output, making it suitable for a wide range of applications, including renewable energy systems, power supplies, and battery chargers systems. This research paper has explored the analysis, and implementation of SEPIC-PI with rectifier demonstrated the potential of this configuration for high-performance power conversion.

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