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Performance Enhancement of CUK Converter for Electric Vehicle Applications

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Abstract: - Utilizing the intrinsic benefits of high voltage gain, bidirectional power flow, and galvanic isolation, the CUK converter is a widely utilized and adaptable DC-DC converter architecture that has found widespread use, particularly in electric vehicle (EV) applications. However, the traditional CUK converters have significant switching losses, high voltage stress, and difficult control. This research examines several approaches to enhance the performance of CUK converters for use in electric vehicle applications. In order to lower switching loss and increase efficiency, soft-switching techniques like Zero-Voltage Switching (ZVS) and ZCS are introduced. To reduce voltage stress and increase power density, multilevel converter topologies such as the Cascaded H-Bridge (CHB) and Flying Capacitor Multilevel Converter (FC-MLC) are presented. In order to improve the converter's performance while preserving stability, this study explores sophisticated control techniques including predictive control and Model Predictive Control (MPC). It explores magnetic design optimization strategies, such as core material selection and the use of magnetic design tools, to lower core losses and improve efficiency. Thermal management techniques like heatsink design and thermal modeling are necessary to prevent overheating-related problems. The CUK converters are the most advantageous for EV applications because they employ enhancing techniques that lead to high efficiency, power density, reliability, and overall system performance. The most recent techniques are reviewed in this research along with their implications for upcoming electric automobiles.

Keywords: PI Controlled DC-DC Converter; MOSFET; Boost converter; cuk Converter.

1. INTRODUCTION

One of the main concerns in the field of battery charging systems is maximizing the power distribution into a converter. Adopting a switched inductor Ćuk converter, which is intended to improve power quality in AC-DC conversion operations, is one viable alternative [9]. This creative project uses a switched inductor Ćuk topology to provide a single-stage power factor correction (PFC) converter. In addition to lowering current stress, increasing efficiency, and requiring fewer components, the design seeks to attain a high voltage gain [9]. It is a strong option for effective energy transmission in charging applications because of these enhancements. Important metrics like Total Harmonic Distortion (THD) and Power Factor (PF) at the AC input side are examined in order to assess the power quality performance of this converter [7], [8]. THD reflects the level of distortion in an alternating signal and is a crucial indication of its harmonic content. The ability of the suggested converter to preserve signal integrity under varied load situations is carefully examined by evaluating both voltage total harmonic distortion (VTHD) and current total harmonic distortion (CTHD), in addition to the overall power factor. When taken as a whole, these metrics reveal how effectively the system maintains effective power supply while reducing unwanted harmonics.

The streamlined single-stage architecture of the switched inductor Ćuk converter makes it stand out since it simplifies the design and increases its usefulness for practical applications. Its resilience and versatility are

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demonstrated by studies of its performance under various loads, guaranteeing steady operation while abiding by power quality regulations [7], [8]. This converter represents a major breakthrough in PFC technology by providing a dependable and affordable battery charging system solution by lowering component count and current stress [9]. Its advantage over conventional converters is still being confirmed by ongoing research, establishing it as a significant advancement in the field of power electronics.

1.1 Overview

Computer hardware and software designed to carry out one or two specialized tasks are combined in an embedded system [10]. Microprocessors and microcontrollers are two essential parts of these systems, each of which has a specific function in embedded product design. Often referred to as general-purpose processors, microprocessors are designed to take in inputs, process them, and then provide the appropriate outputs. Microcontrollers, on the other hand, do more than just handle data; they receive it, process it, connect to other devices, and control the data flow to provide the output [10]. Because of this feature, microcontrollers are very useful in applications that need precise control and connection.

With a particular focus on battery-operated systems, this research aims to improve the Ćuk converter for electric vehicle (EV) applications by integrating a PIC microcontroller [9]. Through precise MOSFET triggering, the design makes use of the microprocessor to provide a sufficient voltage supply to the loads. In this configuration, the PIC microcontroller is essential because it allows for effective power management and voltage regulation that is suited to the requirements of EV systems [9]. This method demonstrates the synergy between advanced embedded control and power electronics in contemporary automotive applications by increasing the performance of the Ćuk converter, which not only increases energy economy but also promotes the dependable operation of battery-powered loads [10].

2. BLOCK DIAGRAM

The project's block diagram and the independent module design are taken into account. Figure 1 displays a block diagram.

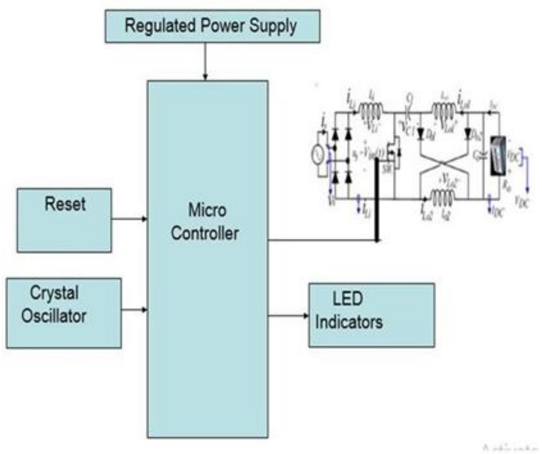

Figure 1: Block diagram showing how to improve the cuk converter for use in electric vehicles.

3. HARDWARE COMPONENTS

The main blocks of this project are:

- Adapter
- Cuk converter
- MOSFET
- Diode Bridge Rectifier,

- Power Factor Correction,
- Cuk converter
- Battery charging

3.1 PIC Microcontroller

The 8-bit CMOS FLASH-based PIC16F72 microcontroller was created to ensure a smooth upgrade path by remaining compatible with previous versions like the PIC16C72, PIC16C72A, and PIC16F872 [10]. With a 200 nanosecond instruction execution speed, this device is effective for real-time applications. Its versatility during development and troubleshooting is increased by its In-Circuit Debugger (ICD) and self-programming features. Accurate analog signal processing is made possible by the microcontroller's five channels of 8-bit Analog-to-Digital (A/D) conversion and two comparators [10].

The PIC16F72's two capture/compare/PWM modules further enhance its capability and are crucial for applications like motor control and power regulation that need for precise timing and pulse-width modulation. Additionally, it has a flexible synchronous serial interface that may be configured as a 2-wire I2C bus or a 3-wire SPI, allowing for communication with a variety of peripherals. Furthermore, a Parallel Slave Port increases its connectivity choices for parallel data transfer, and a USART facilitates serial communication [10]. With these strong attributes, the PIC16F72 distinguishes itself as a potent and versatile embedded system solution that reliably and efficiently serves a wide range of applications [10].

3.2 Cuk converter

In both its ON and OFF stages, the Ćuk converter, a specialist DC-DC converter, helps move energy from the source to the load. Similar to the buck-boost converter, it provides flexibility in voltage management by producing an inverted output voltage that may be either greater or lower than the input voltage [9]. Applications needing flexible power supply, such battery charging or renewable energy systems, might benefit from this special feature.

To ensure constant power flow, the converter works by storing energy in its constituent parts during the ON phase and releasing it to the load during the OFF phase. Its design sets it apart from other converters since it uses an inductor and capacitor to provide an inverted output and smooth energy transfer. Regardless of whether the output must rise above or fall below the input, this capacity is very useful in situations requiring exact voltage changes [9].

The non-isolated Ćuk converter's structure is depicted schematically, emphasizing the placement of parts such as switches, capacitors, and inductors that make it possible for it to operate. This graphic is an essential tool for comprehending the converter's actual use in power electronics as it clearly illustrates how it accomplishes its voltage inversion and control [9].

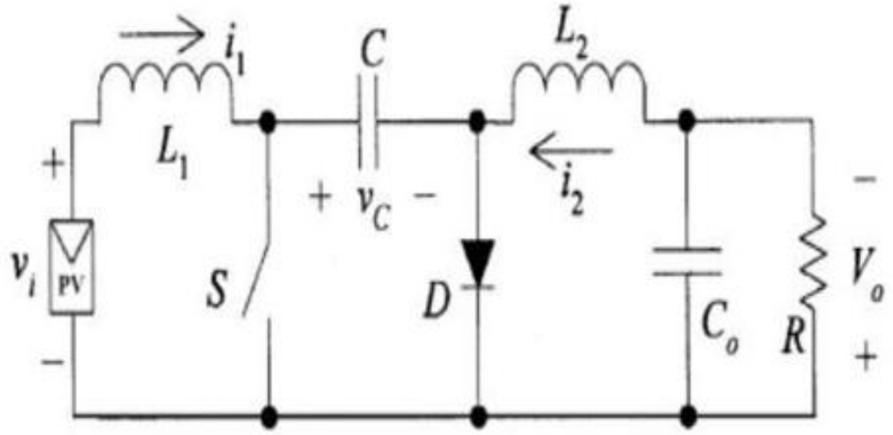

Fig 2: Schematic of non-isolated CUK converter.

3.3 MOSFET

One kind of field-effect transistor distinguished by its MOS (metal-oxide-semiconductor) arrangement is the MOSFET, or metal-oxide-semiconductor field-effect transistor. Because of its effectiveness in regulating electrical impulses, this semiconductor device is essential to contemporary electronics [12]. The MOSFET is typically a three-terminal component with a source (S), drain (D), and gate (G). Together, these terminals control the device's current flow, making it a crucial component of circuits that need switching or amplification. The control point in this architecture is the gate terminal, where the conductivity between the source and drain is modulated by an applied voltage. This exact control with little power loss is made possible by the MOS structure, which consists of a metal gate isolated from the semiconductor by an oxide layer [12]. The MOSFET offers adaptability in applications such as power converters and microcontrollers by allowing or blocking current passage from the drain to the source by varying the voltage at the gate.

Its three-terminal design increases its usefulness in analog and digital circuits and makes integration into other systems easier. The MOSFET's extensive application in technology, ranging from industrial systems to consumer electronics, is highlighted by its effective management of electrical signals [12].

4. PROJECT OF THE SCHEMATIC DIAGRAM

The PIC16F872 microcontroller's schematic diagram and interface with each module are taken into account.

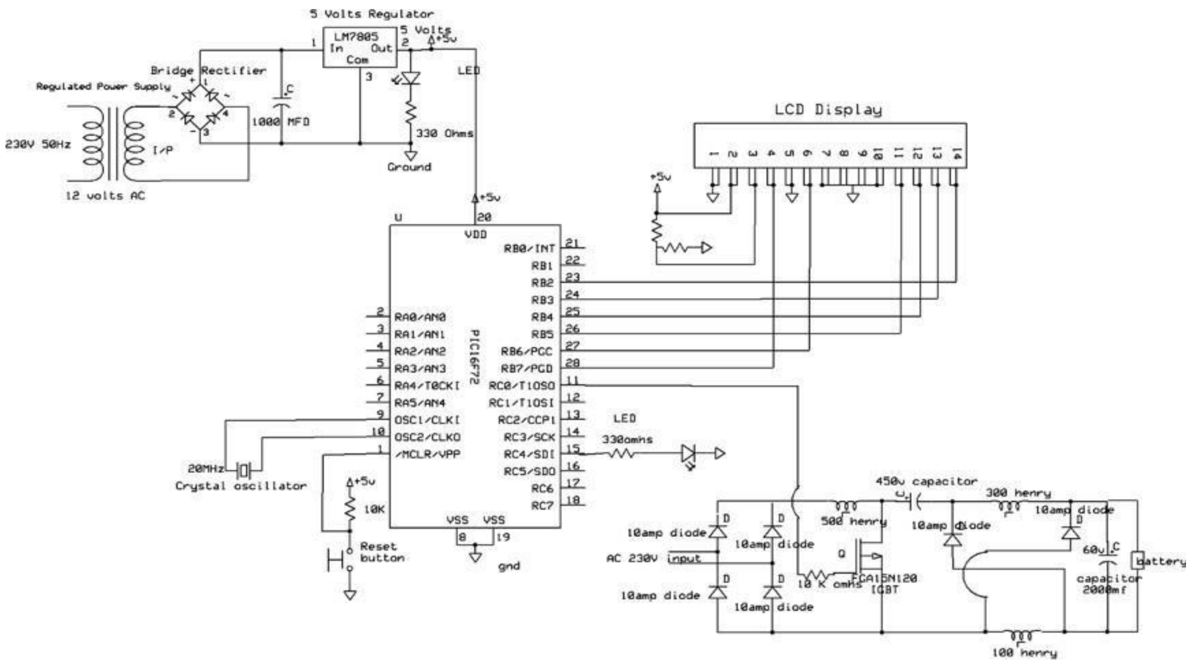

Figure 3 shows the schematic diagram for improving the CUK converter for use in EV applications.

5. ADVANTAGES AND DISADVANTAGES

5.1 Advantages:

1. This research proposes a single-stage switching inductor Cuk converter-based power factor correction converter that has fewer components, high efficiency, low current stress, and high step-down gain [9].
2. Quick reaction [14].
3. Cost-effective and efficient design [10].
4. Minimal power use [14].

5.2 Disadvantages:

1. All components interface extremely sensitively with the microcontroller [6].

5.3 Applications:

1. Suitable for increasing the power factor at all loads [5].
2. Industrial loads can be handled [5].
3. Suitable for charging batteries in EV systems [2].

6. RESULT

With the help of crucial parts like inductors and capacitors, the project "Enhancement of Ćuk Converter in EV Vehicle Applications" aims to create a switching inductor-based power factor correction (PFC) converter [9]. With power factor adjustment at the AC supply input, this creative design seeks to provide a steady, controlled DC output voltage. The converter improves efficiency and power quality by streamlining the energy transfer process, which makes it ideal for electric vehicle (EV) systems that depend on steady and dependable power supply.

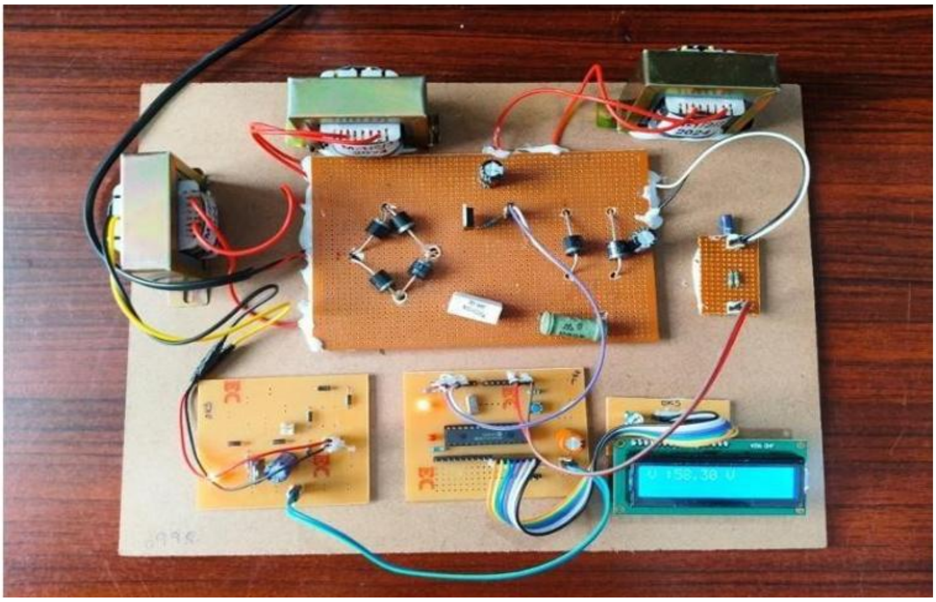

Fig. 4: perspective prototype

The ability of this converter to operate in continuous current mode (CCM) regardless of operating conditions ensures a constant and uninterrupted flow of current throughout the circuit, which is one of its main benefits [11]. Particularly in situations where load requirements fluctuate, as is typical in EV applications, this mode of operation improves system performance while decreasing ripple. Adding a switching inductor to the Čuk converter architecture enhances its ability to control voltage and correct power factor, and it also resolves common problems with AC-DC conversion [9].

This concept improves power electronics for sustainable mobility by offering a system that reconciles efficiency, component simplicity, and dependable performance in real EV scenarios [11].

7. CONCLUSION

A novel AC-DC converter based on switching inductor Čuk has been developed with the aim of enhancing power quality, specifically for battery charging applications [9]. A constant and manageable output voltage that readily adapts to changes in load and supply is the aim of this state-of-the-art technology. To confirm its functionality, it was subjected to a battery of simulations under a wide range of loading scenarios. The results prove that this converter maintains a constant voltage.

its output remains constant regardless of changes in input supply or load demands, proving its reliability and adaptability for practical use in charging systems.

To assess the converter's power quality, important metrics such as Total Harmonic Distortion (THD) and Power Factor (PF) on the AC input side were meticulously checked [7], [8]. Important for efficient energy transfer in battery charging systems, these indices provide a comprehensive understanding of the converter's ability to minimize harmonic distortion and maximize power usage. The simulation results show that the converter can keep up with high power quality standards, which means that it will work more efficiently and with less signal distortion in all kinds of situations.

The performance of the converter was also tested extensively in steady-state and transient conditions to ensure its robustness throughout several operation phases. It maintained stability and power quality by continually regulating voltage in steady-state situations and by showing resilience to sudden variations in transients [9]. With its dual-condition evaluation, the converter is shown to be efficient and versatile, making it a good choice for electric vehicle or renewable energy system battery charging. According to the THD and PF tests, this Čuk converter uses a switching inductor design to minimize harmonic interference and enhance voltage control [7], [8].

7.1 FUTURE SCOPE

Several changes are in the works that could make the current system better in the long run. One upgrade that can simplify the design and save expenditures by offering a variable voltage control option is the integration of a buck-boost converter [15]. Additionally, in applications requiring exact precision, new control systems such as Field-Oriented Control (FOC) have the potential to enhance power flow management accuracy and ensure optimal performance. This approach would be highly useful in systems that need exact regulation of electrical properties.

A second promising direction is the implementation of IoT technologies, which enable predictive maintenance and remote monitoring. With the help of IoT capabilities, the system might improve operational uptime, provide insights into data in real-time, and scale more efficiently for various use cases, from small-scale installations to larger deployments [2]. Improved user experience and reliability might be achieved through this link by enabling proactive problem-solving before they worsen.
To fulfill the expanding environmental goals, it may be game-changing to modify the system to incorporate renewable energy sources, such as solar-powered charging. This adjustment would aid in sustainability efforts by making use of renewable energy sources, decreasing reliance on traditional power networks, and supporting ecologically sensitive applications such as charging electric cars [2]. This upgrade would present the system as a forward-thinking option for cleaner technologies.
Finally, a Digital Signal Processor (DSP) controller upgrade can substantially improve the system's performance. The architecture would be more suited for demanding industrial environments where dependable performance is vital if higher power levels could be managed with a DSP update [5]. This upgrade would expand the spectrum of potential uses, from heavy machinery to cars, by providing the processing power.

must efficiently manage complex, high-energy operations. Together, these upcoming enhancements—accuracy via FOC, cost-effective design through buck-boost integration, scalability driven by the Internet of Things, compatibility with renewable energy, and power capacity enabled by digital signal processing—lay out a plan to make the system more flexible, sustainable, and relevant to industry. those cited in [15], [2], and [5].

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