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Controller For CUK Converter: An Eagle Eye

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CUK converters are designed and are often used in the applications where continuous and stable input and output currents are expected. The reliability and robustness of the converter depends on the efficient controller which assures smooth triggering of the CUK converter. Popularly, sliding mode control, PID, Fuzzy based and Non-Linear techniques are popular as the controlling techniques for the CUK converter. In this research work, it is proposed to implement the smart controller for the CUK converter using the modern ESP32 processor architecture which is in the form of Arduino platform. Through this review-research paper, different techniques which are proposed by distinguished researchers, for controlling the CUK block are discussed in depth.

Keywords— CUK Converter, ESP32, Arduino, PID, Fuzzy Logic Controller.

I. INTRODUCTION

The CUK converter is the circuit which is combining the features of buck converter and boost converter essentially with the low ripple current. Ripple current is the alternating current component of the current which is flowing through the DC circuit. Such non-essential component of the current is mainly introduced due to the switching or fluctuations. The CUK converter is fundamentally is the combination of the buck converter and boost converter is also equipped with the switching device and the mutual capacitance to nullify the effects of the ripple current. The general structure of the CUK converter is depicted through the following diagram.

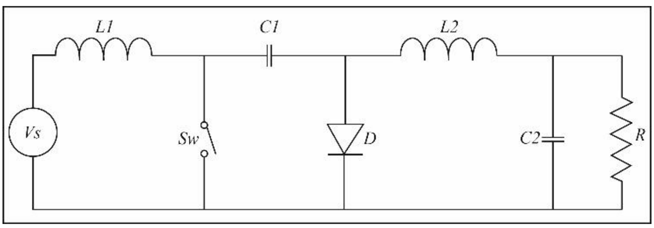

Fig. 1. CUK General Diagram

Here, capacitors are deployed to transfer the energy while inductors are engaged to convert the voltage source in to current source. While the diode is used for commutation purpose. The converter can be operated two distinct modes as continuous mode and discontinuous mode. Through, above CUK converter looks simple and accountable, such traditional circuit suffers current stress on the engaged components and higher switching losses; due to which, it leads to abridged efficiency and the lower reliability at higher power levels.

To address these issues, we have proposed ESP32 based controller for CUK converter which assures higher stability and reduced ripple current. The development process of the proposed controller for CUK will be disclosed in the subsequent paper. In this paper, exhaustive literature analysis is carried out which helps to understand the development in the segment.

II. PREVIOUSLY REPORTED TECHNOLOGY

A new bidirectional transformer with less DC-to-DC converter is proposed that decreases voltage pressure across components and attains ultra-high gain. The proposed converter is based on advanced Cuk and Cuk single ended primary inductor converter topologies along with its functioning principle, expression and steady state investigation. This paper [1] also provides dynamic features of the converter and the structure of closed loop controllers for current and voltage control modes. The experimental outputs are given to show the high efficiency and performance of the proposed topology.

The research paper [2] presented an advanced two-stage bridgeless Cuk converter power factor enhanced light emitting diode drive with a lesser number of components. The proposed light-emitting diode drive was able to attain the supply side unity power factor. The advanced bridgeless Cuk converter based on light light-emitting diode drive is outfitted with input inductance, which optimizes input current harmonics and removes the necessity for outer filters to rectify input current harmonics. The proposed advanced non-bridged Cuk converter with a smaller amount of element count, decreases the dimension of the charger as well as the expenditure of manufacturing. The later stage contained a flyback converter which looks after the light-emitting diode voltage and current and gives the result and input isolation. The proposed converter is designed to function in discontinuous conduction mode.

In the paper, the authors [3] have provided a cost effectual solution applied for improving the power quality in low voltage applications employing power factor modification structured Cuk converter fed brushless DC motor drive whose speed is observed by conflicting the DC bus voltage of voltage source inverter for decreased switching losses. A diode bridge rectifier coupled to a Cuk converter functioning in discontinuous and continuous mode is organized to supervise the DC link voltage with a unity power factor at the AC mains. To establish the best possible mode of function, the efficiency of the presented power factor modification Cuk converter is evaluated under several discontinuous and continuous conduction mode functioning situations.

For a single-stage electric vehicle battery charger, an isolated bridgeless Cuk single ended primary inductor converter is presented. The presented charger structure guarantees fundamental power factor alteration AC mains in discontinuous conduction mode. The presented structure functions more efficiently when used for negative and positive cycles while employing fewer components than the bridgeless Cuk converter. The integration of the Cuk converter and Cuk single ended primary inductor converter through every individual half cycle is to responsible for this. In relationship to the single ended primary inductor converter employed for negative and positive cycles, the result current is also smoothed by the insertion of an output inductor at the Cuk converter side. [4]

The implementation of the diode bridge rectifier fed charger is not tolerated by the international standard. The authors [5]have investigated several topologies for bridgeless Cuk converter and proposed a best bridgeless Cuk converter for electric vehicle chargers. The proposed converter improved the whole effectiveness by removing a single switch and two passive components. For this, the single loop voltage control is replaced with a double loop controller having an internal current loop control and external output voltage control. This converter functions in discontinuous conduction mode to have the expected advantage of zero current switching. Moreover, soft switching has been employed to decrease the switching losses of the proposed topology. Alternatively, electric vehicle battery charging was done with the help of a flyback DC-to-DC converter with steady current and steady voltage control management. This steady current-voltage technique prevents the battery from overheating.

The main objective is to construct a more efficient single input and multiple levels of outcome in a direct current Cuk converter. The proposed converter can assist in converting a lower level of voltage input power source voltage to a great level of direct current output voltage. For the face terminal of a DC to AC inverter, high voltage direct current can be employed as the fundamental power source. Center voltage acquiesces terminals can be utilized to power precise center voltage direct current loads or to charge assistant power sources. The prediction of the succeeding device determinations is utilized in the proposed Cuk direct current to direct current converter graphics. [6]

The authors [7] have presented a new transformer-less high gain direct current to direct current converter. The proposed topology is the combination of the positive output super lift Lou converter and the Cuk converter. The proposed topology has several advantages such as high effectiveness besides the high voltage gain, the common ground point for the input or output terminals, the low region of the topology because of less stored energy, continuous input current, and the low normalized value of the voltage stresses of the semiconductor. This topology has been structured for the continuous conduction mode. The mathematical expressions of both ideal and non-ideal states are provided. Furthermore, this topology is compared with high gain topologies in ideal and non-ideal modes.

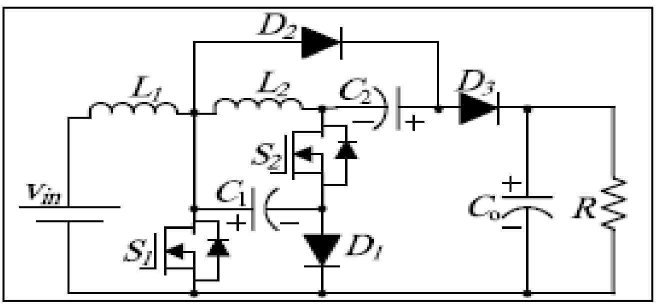

Fig. 2. Proposed Converter Topology

A novel multi-input soft-switching DC to DC Cuk converter is proposed for clean and renewable energy sources. This converter can boost and buck the different voltages of renewable energy sources to generate a steady direct current output voltage in a direct current microgrid. Edge resonant soft switching modes are employed to function better than traditional multi-input Cuk converter. The proposed converter [8] can attain lesser current stress of the switches, higher power effectiveness and a wide range of soft switching. Moreover, the soft switching states can be simply attained as the edge resonant soft switching modes have a wide range of soft switching. The converter independently transfers the produced power from renewable energy sources to the direct current microgrid.

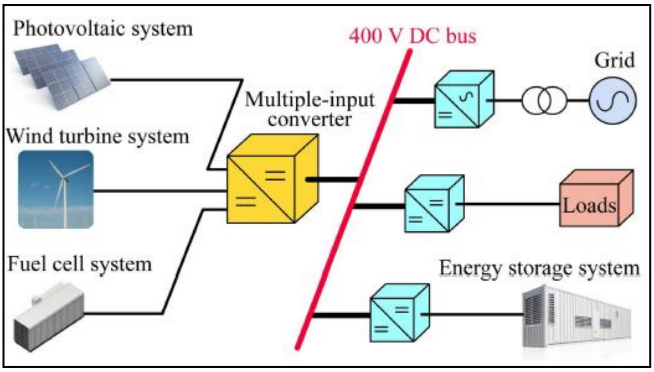

Fig. 3. Proposed Architecture

In this paper, a novel highly trustworthy modular direct current to direct current converter that is well appropriate for medium voltage direct current grid applications is presented. Every power module is structured and controlled in the way that it uses two small film capacitors for transferring the power from the source to the load. This characteristic removes the necessity for large electrolyte capacitors that are susceptible to high temperatures and have high failure rates. Considering the benefit of the leakage inductance of the transformer, the switches advantage of zero current turn-off and soft turn-on. Another benefit of the suggested converter is the probability of having a bidirectional flow of power. An input parallel output series modular configuration is employed to enhance the voltage-blocking ability at the output side and control high currents at the input side of the converter. [9]

Currently, the electronic power system combined with the energy management system is more in demand. Examination, simulation, and authentication of a four-phase interleaved DC to DC converter is done. The designed prototype was employed for single-input multi-output applications. This permit achieving double output voltages of a similar value from a single input direct current voltage and only one power switch. It attained a better dynamic response and less ripple by sustaining its effectiveness. Every converter is associated in parallel form for managing its losses by distributing them amongst more elements, which provides thermal management of the multiphase converter and permits high power values in small dimensions concerning solutions for a single phase. Interleaved function mode and synchronous function mode strategies are applied for better output. [10]

In this paper, the authors [11] have investigated inductor-capacitor inductor filter topology including inductor-capacitor inductor, an inductor-capacitor inductor with damping, and an inductor-capacitor inductor trap filter employed by DC-to-DC isolated Cuk converter. The most important contribution is the design, application and investigation of the inductor capacitor inductor filter, which was not proposed for the DC-DC converter in the survey. For the perfect valuation of the filter a state average mathematical model, a small signal analysis of an isolated Cuk converter for continuous conduction mode operation was done. The practical design and transfer functions of inductor-capacitor inductor-based filter topologies are also presented. To study the effect of filter topology using linear techniques including Bode graphs and root locus, the transfer function of the converter was cascaded with the transfer function of each filter independently. Moreover, every cascaded transfer function and the transfer function of the converter are approved by step responses.

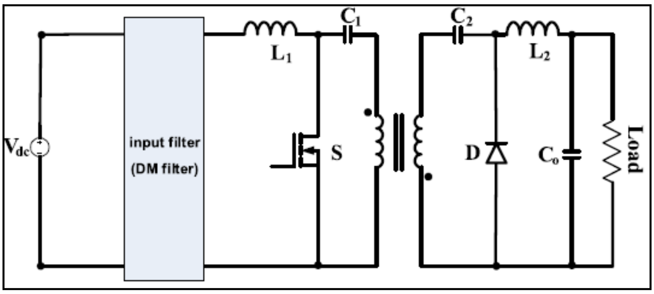

Fig. 4. Circuit Architecture of Isolated Cuk DC to DC Converter

In today's era, the most challenging job is in designing of DC-DC converter that has high voltage gain and small output ripple waves. Due to its continuous conduction mod and its topology, the KY converters have produced a better converter than all the conventional DC-DC converters to overcome this complexity of voltage transfer gain and output ripple waves. The KY converters have several qualities when it was compared with the boost converter with a synchronous rectifier. The KY converter is employed in sustainable power and photovoltaic applications. This paper presented a widespread literature and investigation of the KY converters, which incorporate their topology with control technologies, pulse width modulation method and working activity of KY converters. [12]

For the electrification in rural regions with wind energy availability, the authors have presented a wind energy conversion system. In the proposed system, a three-phase DC-AC converter based on a bridgeless Cuk converter was employed for power extraction from the permanent magnet synchronous generator.

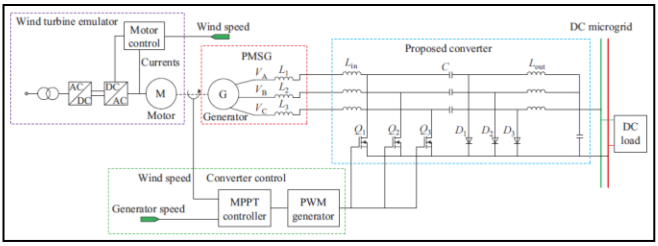

Fig. 5. Wind Energy Emulation and Conversion System

The bridgeless topologies allow the eradication of the front-end diode bridge rectifier. Furthermore, the proposed converter has easy control, fewer elements, and high effectiveness which makes it appropriate for wind energy conversion systems. To emulate a mod-2 wind turbine, a squirrel cage induction motor is employed to implement the permanent magnet synchronous generator-based wind energy conversion system. The converter is constructed to function in the discontinuous inductor current mode for inherent power factor correction and the maximum power point tracking is attained through the tip speed proportion. [13]

Nowadays, the cascaded DC-to-DC converter with several result configurations plays an important role in the DC contribution systems and DC microgrids. Each DC-to-DC converter of any configuration demonstrates complex non-linear dynamic functioning resulting in instability. In this paper, the authors [14] have proposed a cascaded system with a single source boost converter and several load converters that contain Cuk, buck, and one-ended primary inductance converters that are investigated for the complex non-linear divergence experience. An outer voltage feedback loop along with an inner current feedback loop control approach is employed for all the sub-converters in the cascaded system. To elucidate the complex non-linear dynamic functioning, a discrete mapping model is constructed for the presented cascaded system. Finally, each load converter is defined as a fixed power load under reasonable suppositions such as fixed frequency and input voltage.

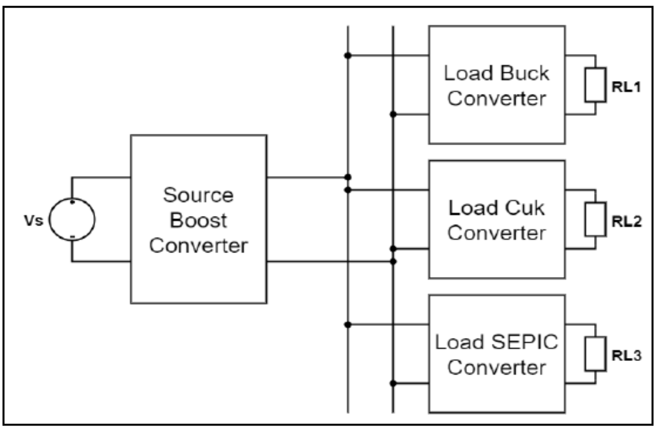

Fig. 6. The Proposed Cascade System

The single-phase matrix converter is employed as some converters like frequency converters and dual converters. The DC-DC converter is generally employed to convert fixed DC to variable DC according to demand. If the result is greater than input it is known as boost operation and if the result is less input, then it is known as buck operation. This paper [15] gives the realization of the Cuk converter using a single-phase matrix converter topology. An advanced switching method is utilized to employ a single-phase matrix converter as a Cuk converter. The Pulse width modulation technique is employed to eradicate the gate pulse of switches. A Cuk converter is known as a DC-to-DC converter in which output voltage from a fixed input DC supply. Cuk converter can be employed as a step-down circuit or step-up circuit. To avoid the spikes of output voltage protected communication method is used.

Currently, DC-to-DC converters are extensively employed in place of voltage divider circuits to control voltage from renewable energy sources. To select a converter for a specific application calculation of the mean period between the effectiveness and failure of the converter becomes significant. The authors have considered three non-isolated DC-to-DC converters for investigation. Comparative analysis for converter effectiveness and mean period amongst Zeta, SEPIC and Cuk are done. Furthermore, relative investigation for Zeta the converter utilizing P channel and N channel MOSFET was performed. The experimental outputs are achieved for power from the photovoltaic panel, power from the converter, power loss in MOSFET and power loss in the converter. The experimental outputs are achieved for power from the photovoltaic panel, power loss in MOSFET, power loss in the converter and power from the converter. [16]

The switched mode power converters for industrial purposes demand high effectiveness and high conversion gain to control large input current and to maintain high output voltage stress. Standalone power systems driven by high negative DC supply voltages play the most essential role in developing remote units for different networks. Self-lift Cuk converter is a high-gain converter with negative output voltage. Because of its element performances while functioning in an open-loop configuration, the DC-to-DC converters generate non-linearities. The authors have presented a comparative performance analysis of a self-liftcuk converter employing several controller methods like fuzzy logic control, PI control and voltage control. [17]

A two-step charging method is proposed with a decreased number of elements for the charging of light electric vehicles with an enhanced power factor. At the supply end, the resistive profile was attained with the proposed charger. The proposed charger contains an advanced non-bridge Cuk converter which is provided with the input inductance as of which the input current harmonics get optimized and the utilization of outer filters for rectification of harmonics is not necessitated. An advanced non-bridge Cuk converter is proposed with a smaller number of elements which also decreases the dimension and price of the charger. An isolated flyback converter was used in a later stage in which the charger was improved with the feature of electrical isolation. The flyback converter takes care of battery performance in various charging modes such as continuous voltage and continuous current. [18]

A solar photovoltaic panel coupled mono stage dual input charger where alternate current mains act as the primary source and it is complemented by the photovoltaic panel, which acts as a secondary source. This panel is derived from a Cuk converter, so it is capable of functioning in boost as well as buck mode. The small signal transfer function of the topology is constructed employing the state space average method. These transfer functions are used to structure the controller and to sustain the power quality at alternating current mains set by the international standard in both steady voltage and steady current mode of charging. According to the changing atmospheric situations, maximum power point tracking at secondary input is adjusted. [19]

In the paper [20], a two-step bridgeless Cuk converter is established and implemented. The proposed converter is simple and cost-effective with very a small number of components. In the initial step, the power factor rectification unit rectifies the voltage along with the unity power factor which enhances the effectiveness and power quality of the power given to the electric vehicle on-board charging unit. Based on the battery state of charge, the rear-end flyback synchronous rectification handles the vehicle battery charging in steady voltage and steady current situations. The electric vehicle charger provides a sinusoidal current waveform through total harmonic distortion. The proposed converter contains a much smaller number of elements without the unwanted capacitor banks as well as traditional diode bridges.

The application of brushless direct current motor drive is rapidly growing due to its characteristics like low maintenance, a wide span of speed, less electrical noise and reliability. brushless direct current motor is an electronically commutated robust three-phase synchronous motor. The brushless direct current motor drive is supplied by single-phase AC and fed through a diode rectifier. A CUK DC to DC converter fed brushless direct current motor drive is explained. A Cuk power factor correction converter is employed to improve the power quality. Speed control is achieved by sustaining a ratio between DC link voltage and speed. The proposed cuk converter is compared with a traditional power factor correction converter and it is found that it is a good alternative solution for low-power applications. [21]

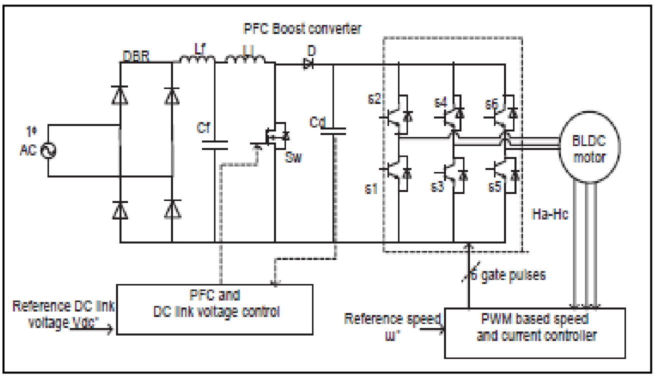

Fig. 7. Boost Power Factor Correction Converter with Steady DC Link Voltage

The authors [22] have introduced an advanced Cuk converter with a two-switched inductor model such as an advanced Cuk converter with XLZ configuration, an advanced Cuk converter with XYL configuration and an advanced Cuk converter with LYZ configuration. The proposed converters have benefits such as inverted results, continuous input current, single switch topologies and high voltage gain. The voltage gain investigation of three configurations is carried out. Furthermore, the comparative analysis of the three converters is made concerning the component count and voltage gain. The experimental results achieve the mathematical examination and authenticate the practicability and functionality of the proposed three converters.

Recently, DC-to-DC converters have been widely employed in various industries and different applications such as uninterrupted power supply, renewable energy sources, electrical trains and electrical vehicle charging stations. The authors have proposed a high gain DC to DC power converter with an additional inserted DC voltage. The inserted voltage helps to attain a high voltage gain contrast to the traditional converters and it handles the maximum voltage gain. The proposed clarification is based on an advanced Cuk converter and it gives the benefit of continuous output current. Furthermore, the clarification eliminates the drawback of the Cuk converter in attaining a high boost factor. The inserted voltage is derived from a similar input voltage through an isolated voltage path without disturbing the continuous input current considerably. [23]

After reviewing different technology, reported by different esteemed authors, the research work can be summarized through the following table.

Table 1. Summarization of the Cited Technology

Methodology	**Description**	**Hurdles**
Advanced single ended primary inductor Cuk converter with extensive voltage conversion [1]	A new transformer-less bidirectional DC to DC converter with its steady state analysis are proposed	Transformer converter increases the voltage stress across the components
Power factor correction based electric vehicle battery charger using Cuk converter [4]	The proposed structure performs more efficiently while employing fewer equipment than the bridgeless Cuk converter design	The bridgeless Cuk converter required a greater number of components for its operation

A Cuk based DC-DC converter for medium voltage direct current applications [9]	Power module is designed with two small film capacitors for transferring the power from source side to load side	Large electrolytic capacitors are sensitive to high temperatures and have high failure rates
Permanent magnet synchronous generator-based wind energy conversion system [13]	The bridgeless topology allows the eradication of the front-end diode bridge rectifier	The unfavourable effects of renewable energy integration into the power grid
Proportional Integral and fuzzy logic for self-lift Cuk converter [17]	Self-lift Cuk converter handler methods are employed to control huge input current and to manage high output voltage stress	The switch mode power converters required high conversion and effectiveness to control huge input current and to manage high output voltage stress
Power quality enhancement of brushless DC motor using Cuk converter [21]	Speed control is improved by sustaining proportionality between speed and DC link voltage	In BLDC drive, current drawn from supply is peaky with large number of harmonics which is due to high valued dc link capacitor uncontrolled charging

III. CONCLUSION

Comprehensive literature review of the different controlling strategies reported by the distinct authors for controlling the CUK converter, highlights the challenges and discloses the advancements which are required in order to gain the stable and efficient outputs. Different strategies have been explored after which we have developed out thought process and proposed an improved controller for CUK converter using embedded system components like ESP32 processor architecture on Arduino platform. The details of the proposed system will be discussed in the subsequent version of the paper.

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