Comparative Analysis Between SEPIC and Cuk Converter for Power Factor Correction

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***Abstract*—The aim of this paper is to give a comparative analysis between the two converter topologies namely Single Ended Primary Inductance Converter (SEPIC) and Cuk converter used for Power Factor Correction (PFC). MATLAB/Simulink models of SEPIC and Cuk converter are developed to improve the power factor at the input side as well as the voltage regulation at the output side. Hysteresis Current Control (HCC) technique is used for input PFC and Fuzzy Logic Controller (FLC) or Proportional Integral Controller (PIC) is adopted for regulation of the output voltage. The proposed system is tested at both steady state, transient condition and its performance is then estimated and compared in terms of various parameters like, Total Harmonic Distortion (THD), Input Power Factor (IPF), output voltage ripple for Fuzzy Logic and PI Controller.**

Keywords—FLC, PIC, SEPIC Converter, Cuk Converter, PFC,HCC.

I. Introduction

According to the international standards and for the best power transfer and utilization, PFC has become a necessity. To get a dc output voltage we use a rectifier and a parallel capacitor [1] as depicted in Fig.1(a). The source voltage and source current is shown in Fig.1(b).Fig.1(b) depicts a pulse shaped input current with much harmonics content causing a very poor power factor. Owing to Electro Magnetic Interference (EMI) problem either via conduction or radiation process of AC line voltage along with the allied fundamental distortions, due to this the harmonic currents are quite undesirable. If a number of such loads are connected to the supply then the problem is more severe. The IEEE and IEC are some international entities to define or standardize the permissible limits of the harmonic content in line current such as IEEE 519 and IEC 61000-3-2 [2]. The aim here is to design an AC to DC power converter to overcome these power quality issues and to obtain Unity Power Factor (UPF) at the AC input mains and a very close regulation of the dc output voltage [3-7]. So, for small power uses in single phase supplies, DC-DC converters are used which are switch based and controlled accordingly to ensure UPF at the mains side. The main motive is to emulate a resistive circuit when seen from mains side and improved power factor. Theoretically there exist three families of non-isolated converter topologies which are Buck, Boost and Buck-Boost topology [8-9]. The Buck topology is generally used when low output voltage is required but has high frequency commuted current at input. Due to commuted nature it exhibits a discontinuous current, and hence should be connected with high speed recovery circuit. The major drawback faced by Buck topology is the inclusion of a filter of high frequency range within the diode bridge and the power source. The filtering inductor causes a gradual variable current in the input end. On the other hand Boost converter topology provides high output voltage and leads to over-voltage stress at the switches [10]. The third family is Buck-Boost topology and finds its applications in power factor correction circuits. It includes Cuk and SEPIC converter [11-12]. These converters differ from each other by the output voltage polarity. In case of Cuk converter the position of free-wheeling diode and the inductor is reversed from that of the SEPIC converter to obtain reversed output voltage polarity. The current work presents two different structures namely SEPIC and Cuk type PFC circuit to improve the input side power factor of the diode bridge rectifier with low THD of source current and decreased voltage ripple at output [13-20]. The entire modelling and the design scheme of IPF rectified AC to DC power converters are carried out in the MATLAB/Simulink environment.

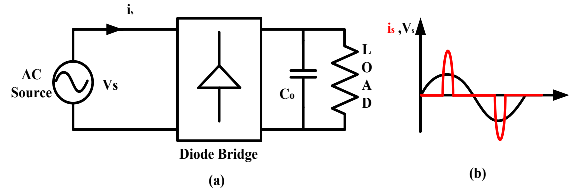

Fig. 1.(a) AC to DC Rectifier (b) Source Voltage and Current Waveform

II. Circuit Description And Equations of Design

To improve the power factor at the input and to get a regulated voltage at the output we have to interface a DC-DC (SEPIC or Cuk) converter in between the bridge

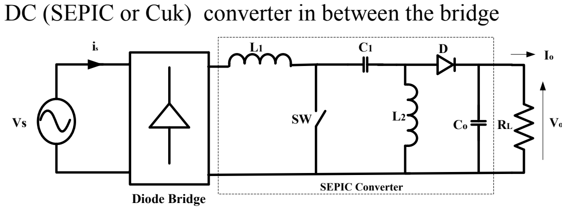

Fig 2. SEPIC converter topology

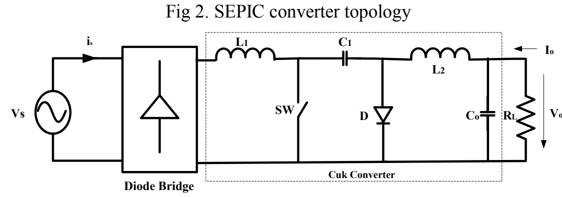

Fig 3. Cuk converter topology

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rectifier and the load. The basic circuits of suggested AC to DC power converters are depicted in Fig.2 (SEPIC) and Fig.3(Cuk) respectively. By adopting this topologies with a low level DC-bus voltage, input current ripple can be decreased, which is rare in case of conventional Buck /Boost converter. Adequate coupling coefficient value based design of SEPIC or Cuk converter can be achieved with implementation of inductors of input and output on the same former core of magnetic material. In both the converter when inductors L_1 and L_2 stores energy during switch on period which causes linear increase of inductor current and output capacitor supply power to the load and diode is reverse biased. When switch is off diode gets forward biased and stored energy of the inductor is supplied to the load. TABLE I presents all the fundamental equations required for the modelling of different portions of the converter. Where v_s is the rms source voltage, d is the duty cycle, ΔiL represents inductor current ripple, Δv_c , Δv_o are the voltage ripple of the output voltage and capacitor voltage respectively. f_s is the switching frequency. P_o is the output power , V_o is the output voltage.

TABLE I. DESIGNED EQUATION FOR SEPIC AND CUK CONVERTER

PARAMETER	SEPIC	CUK
L_1	$\frac{v_s * d}{\Delta iL_1 * f_s}$	$\frac{v_s * d}{\Delta iL_1 * f_s}$
L_2	$\frac{v_s * d}{2 * \Delta iL_2 * f_s}$	$\frac{v_s * d}{\Delta iL_2 * f_s}$
C_1	$\frac{iL_2 * d}{\Delta v_{C_1} * f_s}$	$\frac{I_0 * (1-d)}{\Delta v_{C_1} * f_s}$
C_o	$\frac{P_o}{4\pi * f_s * V_o * \Delta v_o}$	$\frac{v_s * d}{8 * f_s^2 * L_2 * \Delta v_o}$

III. DIFFERENT METHODS OF PFC

There are two objective of PFC: 1.To get a regulated voltage at the output. 2. The current at the input must be a sine wave. To achieve the first objective we have to use a feedback loop at the output. There are two methods to achieve the second objective. First method is called "Multiplier Approach" and the second is called "Voltage Follower Approach". In Multiplier Approach, a feedback loop of input-current is used to govern the DC to DC power converter to function as an input voltage programmed current sink as shown in Fig.4. In this paper Multiplier Approach is used. Multiplier Approach Control are further sub-divided into four different methods for generating the gate pulse for the SEPIC and Cuk converter, such as:

1. HCC
2. Peak Current Control
3. Average Current Control
4. Borderline Current Control.

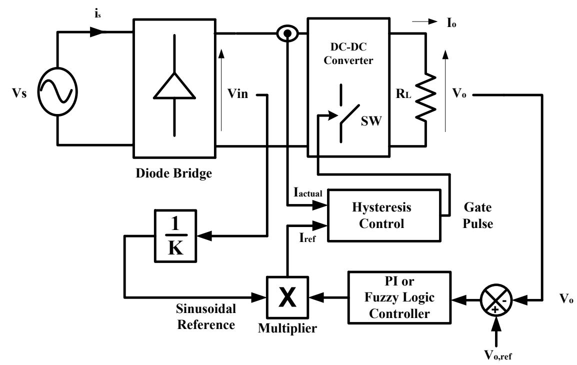

Fig.4. Multiplier Approach Control

Comparing with the above four method HCC provides very low distorted waveforms of input current and does not need any ramp compensation hence here we will take Hysteresis Control technique. In Fig.5 two sinusoidal current references $I_{P,ref}$ and $I_{V,ref}$ are generated from I_{ref} , which shows the inductor peak and valley current respectively. If the current of inductor falls below $I_{V,ref}$ then the switch is ON and if the current of inductor rises above $I_{P,ref}$ switch is OFF. This control technique provides variable frequency control structure which is the demerits of this method.

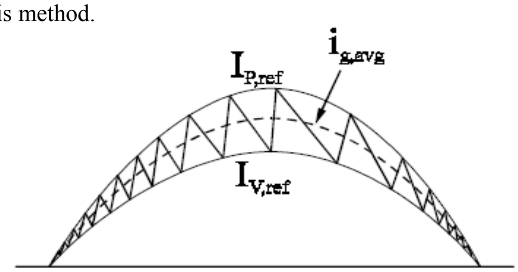

Fig.5. Hysteresis Current Control

IV. PIC FOR OUTPUT VOLTAGE REGULATION

The name itself Proportional Integral Controller is a type of control loop mechanism adopted in continuous modulated operation of control. A PI Controller repeatedly calculate the error in between a Set Point(SP) value and measured Process Value(PV) and get a correction accordingly in PI base. In real time operation it accordingly provides an accurate and respective change of correction to a control function. For example furnace temperature control that it applies a derivative term to effectively correct the error despite of a huge change.

V. FLC FOR OUTPUT VOLTAGE REGULATION

The basic block diagram of the proposed FLC for output voltage regulation of SEPIC and Cuk converter is shown in Fig.6. There are two separate meanings of fuzzy logic. Generally, fuzzy logic is the further application of multivalued logic and is also known as logic system. We can also say fuzzy logic is same as fuzzy sets theory, that which relates to collection of objects with unsharp boundaries and the membership is a point of degree. There is a specific object which degree of membership in a given set which can vary between the range 0 to 1 in fuzzy set theory. Fuzzy logic is based on sound quantitative and also deals with imprecise information and data. Mathematical theory the values of fuzzy variable are expressed by proper english language. Error in voltage of a power converter can be defined in linguistic variables like Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB), and each variable can be defined by varying triangular membership function. Seven fuzzy levels were chosen and were defined by fuzzy set library which values of the error are e and change in error is de. The larger the number of fuzzy levels, the higher the input resolution. We know that a rule is n dimensional and n is the number of variable included in the rule. The sum of rules are known as rule R. FIS editor edits the input and output variables, which are e, de and output. After editing we have to design the membership function for each variable. The final step involves of writing rules in rule editor using the rule given in TABLE II.

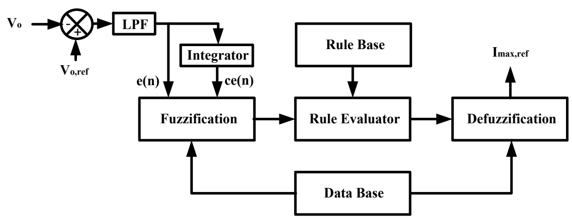

Fig.6.FLC for output voltage regulation of SEPIC and Cuk converter

TABLE II. FUZZY RULES FOR CLOSED LOOP CONTROL OF SEPIC AND CUK CONVERTER

e\de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB

VI. RESULTS AND DISCUSSION

To investigate the performance of the proposed System a simulink model of a SEPIC and Cuk Converter used for power factor correction is developed as shown in Fig.7 and Fig.8 respectively. The designed parameter used in simulation for both SEPIC and Cuk converter are given in TABLE III. The system performance is investigated in five steps. Step:1 when non of these converter is not connected to the system. Step:2 when SEPIC converter is connected to the system with PIC in the feedback loop. Step:3 when SEPIC converter is connected to the system with FLC in the feedback loop. Step:4 when Cuk converter is connected to the system with PIC in the feedback loop. Step:5 when Cuk converter is connected to the system with FLC in the feedback loop.

TABLE III. DESIGNED PARAMETERS OF THE SYSTEM

Parameters	**Values**
Input voltage RMS Value	120V
Supply frequency	50 Hz
L_1 , L_2	1mH, 10m H
C_1 , C_o	10mF, 10mF
Load Power	1kW
Reference Output Voltage	100 V
Switching Frequency	20KHz
Voltage and Current Ripple	0.05
Duty Cycle	0.45

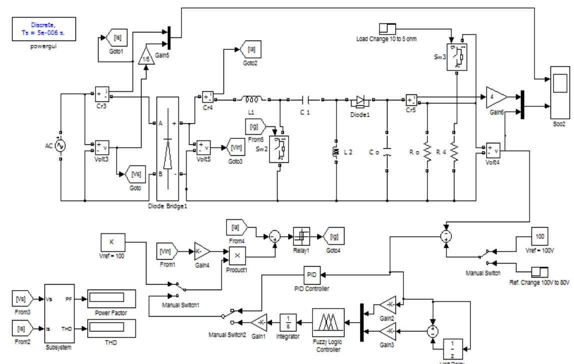

Fig.7. Simulink Model of SEPIC Converter

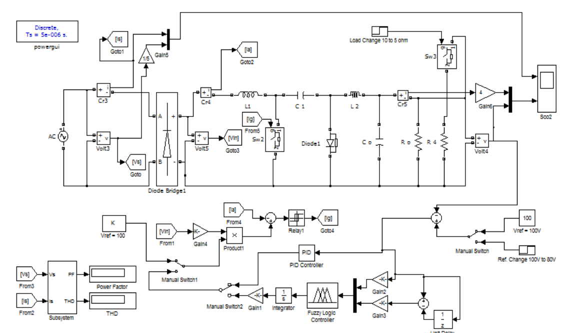

Fig.8. Simulink Model of Cuk Converter

To convert AC to DC we generally connect a bridge rectifier and filter capacitor across the load as shown in Fig.1, simulation result of the same and its harmonic spectrum is depicted in Fig.9 (a-d). To upgrade the efficacy of current at the input and voltage at output SEPIC and Cuk converter is used as discussed in Fig.2 and Fig.3 respectively. To get a regulated voltage at the output and improved input current wave PIC or FLC is used in the output feedback loop. The dynamic response of the system with SEPIC converter used for power factor correction is shown in Fig.10 (a-f) and Fig.11 (a-f) respectively for PIC and FLC in the outer loop. At t = 1sec load resistance is decreased from10Ω to 5Ω and at t = 2sec reference voltage is decreased from 100V to 80V. With this dynamic change the regulated output voltage is obtained which can be clearly seen from Fig.10 (e) and Fig.11 (e) respectively for PIC and FLC. Similarly the dynamic response of the system with Cuk converter used for power factor correction is shown in Fig.12 (a-f) and Fig.13

(a-f) respectively for PIC and FLC in the outer loop. At t = 1sec load resistance is decreased from10Ω to 5Ω and at t = 2sec reference voltage is decreased from -100V to -80V. With this dynamic change the regulated output voltage is obtained which can be clearly seen from Fig.12 (e) and Fig.13 (e) respectively for PIC and FLC. Various performance parameter obtained in simulation for both SEPIC and Cuk converter are given in TABLE IV for comparison.

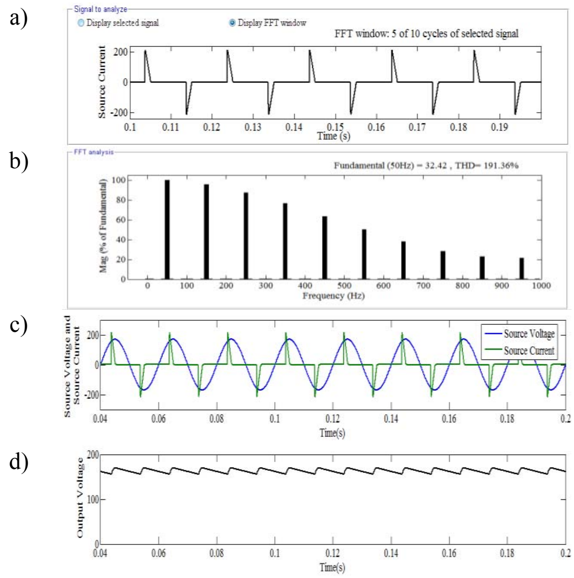

Fig.9.Simulation results of the proposed system without any Converter

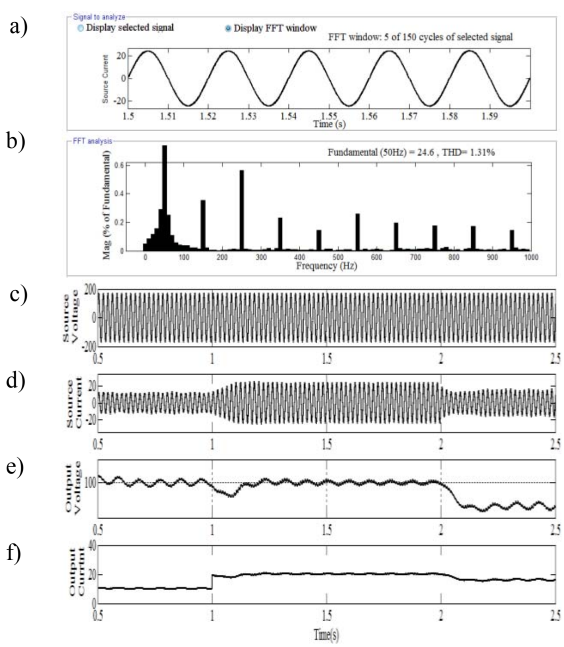

Fig.10.Simulation results of PI Controlled SEPIC Converter

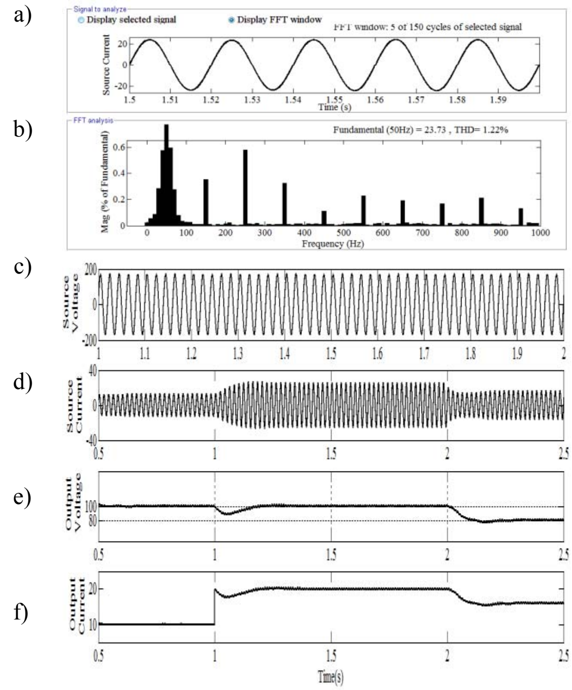

Fig.11.Simulation results of Fuzzy Logic Controlled SEPIC Converter

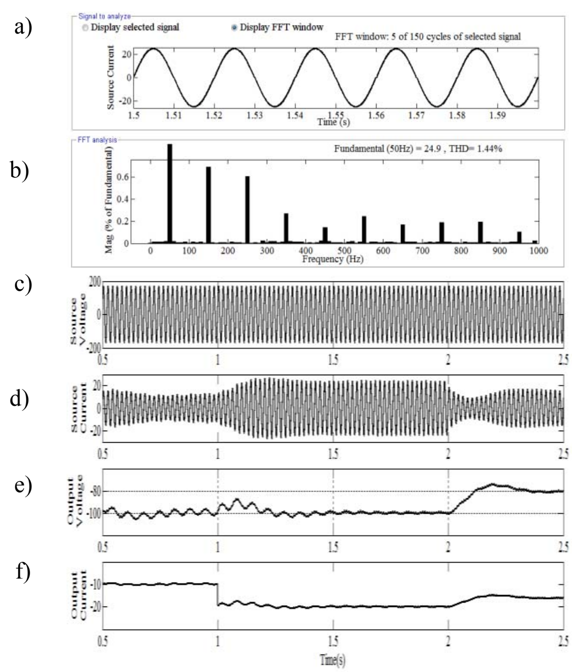

Fig.12.Simulation results of PI Controlled Cuk Converter

a) b) c) d) e) f)

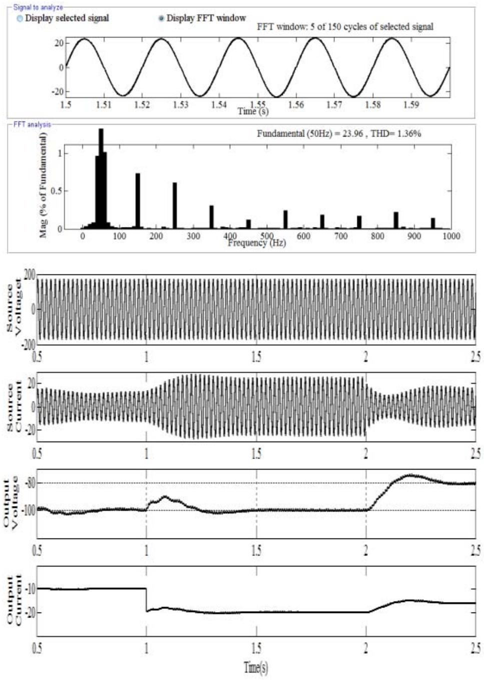

Fig.13.Simulation results of Fuzzy Logic Controlled Cuk Converter

TABLE IV. PERFORMANCE PARAMETERS OF THE SYSTEM UNDER DIFFERENT CONDITION

Performance Parameter	THD %	Power Factor	Output Voltage Ripple %
Different Condition			
Without Cuk Converter	191.36	0.4479	9.2
PI Controlled SEPIC Converter	1.31	0.9995	6.0
Fuzzy Logic Controlled SEPIC Converter	1.22	0.9998	1.5
PI Controlled Cuk Converter	1.44	0.9997	2.2
Fuzzy Logic Controlled Cuk Converter	1.36	0.9997	1.5

VII. CONCLUSION

The design, modelling and simulation of SEPIC and Cuk converter used for power factor correction is considered in MATLAB/Simulink environment. The outcomes of the simulation work provided reduced THD of source current with improved AC mains power factor and decreased output voltage ripple. Comparing with PIC and FLC used in the output feedback loop in both the converter topologies, FLC gives better result in terms of THD of supply current, IPF, it also gives a well regulated output voltage with reduced ripple when load disturbance and reference change occur. Comparing between the two topologies (SEPIC and Cuk) SEPIC converter topology gives better performance compared to Cuk converter topology with an additional advantage of same output voltage polarity. The prototype of the proposed SEPIC and Cuk converter can be developed, that would be attempted as a future work.

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