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Power Quality Improvement Using Fuzzy Based AC-DC Cuk Converter

V.Satyanarayana Naik
M.Tech Student Scholar
Department of Electrical and Electronics Engineering,
Narasaraopet Engineering College, Narasaraopet, Guntur (Dt); A.P, India
Dr.R.V.D.Rmama Rao
Professor, Department of Electrical & Electronics Engineering,
Narasaraopet Engineering College, Narasaraopet, Guntur (Dt),AP,India

Abstract:
A single stage single switch AC/DC converter is an integration of input current shaper and a DC/DC cell with a shared controller and one active switch. The converter is applicable for digital input power supply with high input power factor and tight output voltage regulation. The Improved Power Quality AC-DC Converters (IPQCs) provides enhanced power quality in terms of improved power factor and reduced Total Harmonic Distortion (THD) at the utility interface. This paper addresses comparison of power factor correction techniques for high frequency isolation based single phase PI and fuzzy logic controlled based Buck-Boost AC-DC Cuk Converter, which consists of only one switch resulting in reduced THD and improved power factor. With an awareness of modern design trends towards improved performance, the proposed converter is designed for low power rating and low output voltage. To validate the design of the converter at the primary stage, simulation is performed at lower as well as at higher loads.

Key words: *AC-DC Converters, power quality, THD, power factor correction, control techniques, Fuzzy logic controller (FLC).*

1.Introduction

An ac to dc converter is an integral part of any power supply unit used in the all electronic equipments. Also, it is used as an interface between utility and most of the power electronic equipments. These electronic equipments form a major part of load on the utility. Generally, to convert line frequency ac to dc, a line frequency diode bridge rectifier is used. To reduce the ripple in the dc output voltage, a large filter capacitor is used at the rectifier output. But due to this large capacitor, the current drawn by this converter is peaky in nature. This input current is rich in low order harmonics. Also, as power electronics equipments are increasingly being used in power conversion, they inject low order harmonics into the utility.

Due to the presence of these harmonics, the total harmonic distortion is high and the input power factor is poor. Due to problems associated with low power factor and harmonics, utilities will enforce harmonic standards and guidelines which will limit the amount of current distortion allowed into the utility and thus the simple diode rectifiers may not in use. So, there is a need to achieve rectification at close to unity power factor and low input current distortion. Initially, power factor correction schemes have been implemented mainly for heavy industrial loads like induction motors, induction heating furnaces etc., which forms a major part of lagging power factor load. However, the trend is changing as electronic equipments are increasingly being used in everyday life nowadays. Hence, PFC is becoming an important aspect even for low power application electronic equipments.

In view of stringent requirements of power quality at the input AC mains and their increased applications, a new breed of converters have been developed using Solid-state self-commutating devices such as MOSFET ,IGBT, GTO, etc. Such converters are classified as Boost, Buck, Buck-Boost AC-DC converters and are referred to as improved power quality converters. IPQC technology has matured at a reasonable level for AC-DC conversion with reduced harmonic currents, high power factor, low Electro Magnetic Interference (EMI) and Radio Frequency Interference (RFI) at input AC mains and well regulated good quality DC output to feed loads ranging from fraction of kW to MW power ratings. This paper deals with the Cuk Converter which acts as an automatic current wave shaper. The Cuk Converter presents an attractive solution for AC-DC conversion with high frequency isolation. It offers all the benefits of Buck-Boost topology with high level of power quality [2]. The Cuk Converter is analyzed using two techniques; Multiplier approach and Voltage Follower approach.

In Multiplier approach, there are two control loops: one controls the output voltage and the other controls the input current. To provide output voltage regulation, a multiplier circuit is used to control the amplitude of the sinusoidal current reference signal in accordance with the output voltage error. The Voltage Follower approach provides a simple control scheme requiring only one voltage control loop. In this approach, the on time of the converter is controlled by the output voltage error signal.

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic closed loop appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances [3]. With respect to their successful methodology implementation, control closed loop Cuk converter will get the good efficiency of the converter. This kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage output respectively. The introduction of voltage output in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose.

2. Circuit Configuration And Opearting Principles

The circuit configuration of the proposed AC-DC converter is shown in Fig.1. The capacitor C1 and C2 ensure that no DC voltage is applied to transformer primary or secondary windings. The high frequency isolation transformer draws a small magnetizing current and negligible energy stored in magnetizing inductance. Also, it provides voltage adjustment for better control and safety on load equipment. The input filter is required to reduce the ripple in the input current and power factor correction. For the PWM control of the converter, Voltage Follower Approach and Average Current Control Techniques are applied.

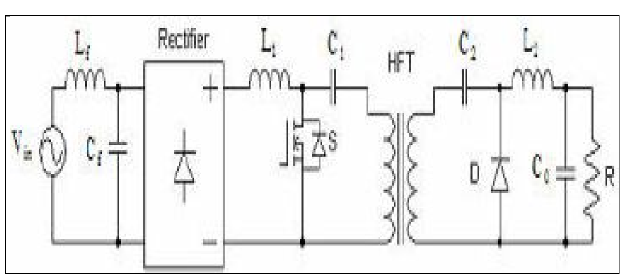

Figure 1: Single-phase, single switch Cuk Buck-Boost AC-DC Converter

2.1.Voltage Follower Approach

In this approach, as shown in Fig.2, the internal current loop is completely eliminated, so that the switch is operated at constant on-time and frequency. This control technique allows unity power factor when used with converter topologies like fly back, Cuk and Sepic. Instead, with the boost PFC this technique causes some harmonic distortion in the line current. The advantages of this technique include constant switching frequency, no need of current sensing, simple PWM control.

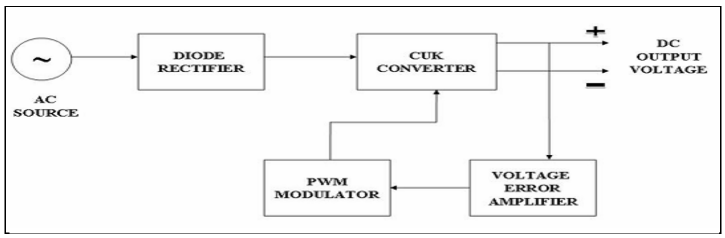

Figure 2: Block Diagram of Voltage Follower Approach

2.2.Average Current Control Technique

This method allows a better input current waveform. Here the inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop tends to minimize the error between the average input current and its reference. This reference is usually obtained by multiplying a scaled replica of the rectified line voltage Vg times the output of the voltage error amplifier, which sets the current reference amplitude as shown in Fig.3. In this way, the reference signal is naturally synchronized and always proportional to the line voltage which is the condition to obtain unity power factor. The advantages of this technique includes Constant switching frequency, No need of compensation ramp, Control is less sensitive to commutation noises, Better input current waveforms than for the peak current control.

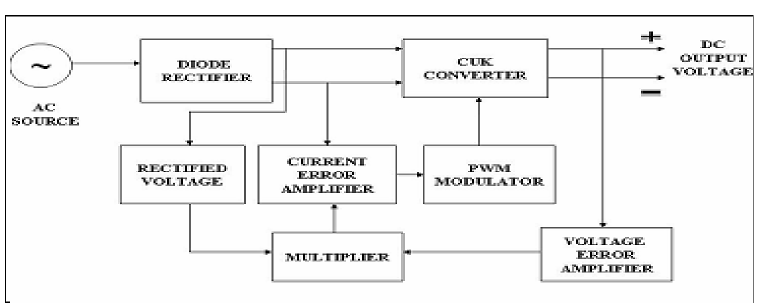

Figure 3: Block Diagram of Average Current Control Technique

3. Introduction To Fuzzy Logic Controller

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc Cuk converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc Cuk converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc Cuk converters. The basic scheme of a fuzzy logic controller is shown in Fig 4 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

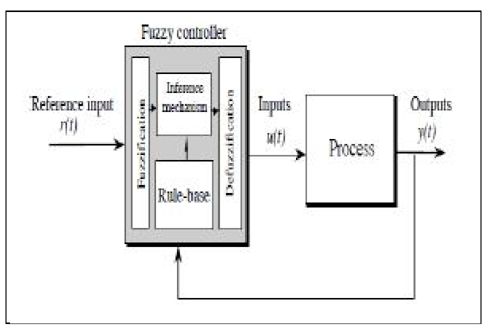

Figure 4: General structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

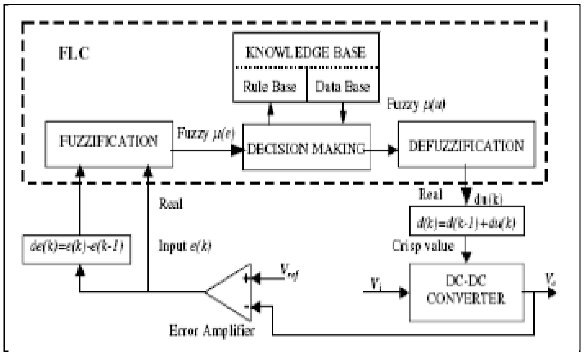

Figure 5: Block diagram of the Fuzzy Logic Controller (FLC)for dc-dc converters

3.1.Fuzzy Logic Membership Functions

The dc-dc Cuk converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

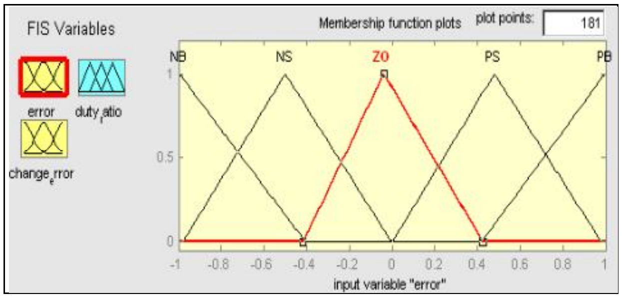

Figure 4: The Membership Function plots of error

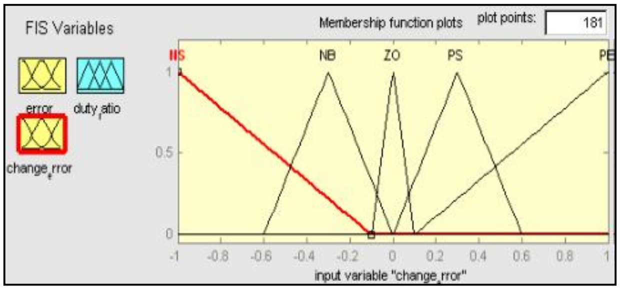

Figure 5: The Membership Function plots of change error

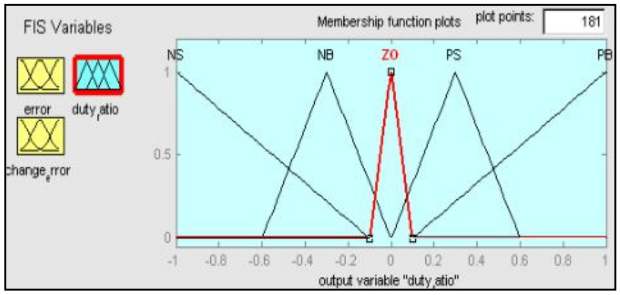

Figure6: The Membership Function plots of duty ratio

3.2.Fuzzy Logic Rules

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table I as per below:

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

Table 1: Table rules for error and change of error

4.Matlab/Simulink Modelling And Simulation Results

The importance of simulation is apparent for the preliminary design of the system. System behavior and performance can be predicted with the help of simulation. To verify and investigate the design and performance of the preliminary stage, here the simulation is carried out by two cases 1. Proposed AC to DC Cuk Converter with conventional PI controller 2. Proposed AC to DC Cuk Converter with intelligence Fuzzy Logic controller (FLC).

4.1.Case 1: Proposed AC to DC Cuk Converter with conventional PI controller

4.1.1.Voltage Follower Approach

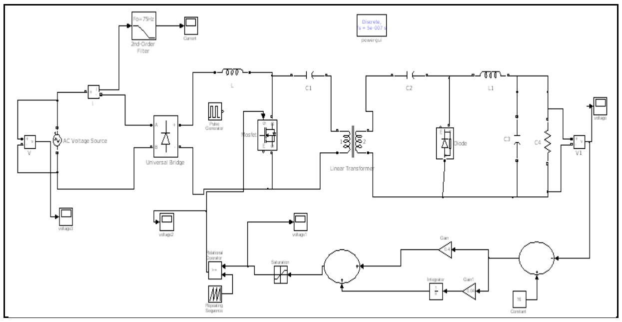

Figure 7: Matlab/Simulink model of Proposed AC to DC Cuk Converter with conventional PI controller with voltage follower approach

Fig.7 shows the Matlab/Simulink model of Proposed AC to DC Cuk Converter with conventional PI controller with voltage follower approach

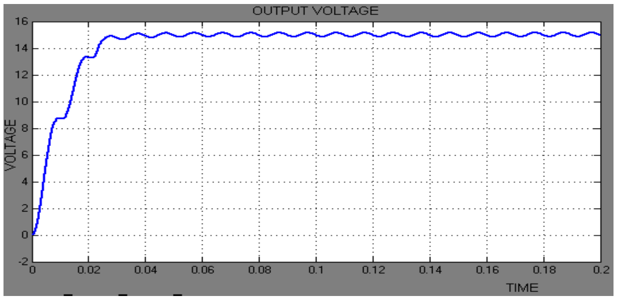

Figure 8: Output voltage of Cuk converter

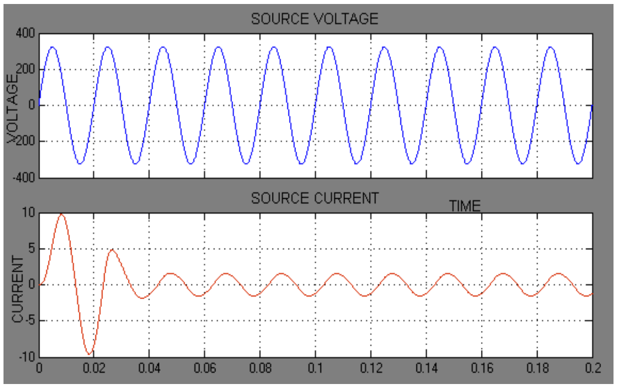

Figure 9: Source voltage and source current

Fig.8 , 9 shows the output voltage of the cuk converter and source voltage and source current, there is no distortion in current and voltage, both we get sinusoidal waveform.

4.1.2 Average Current Control Technique

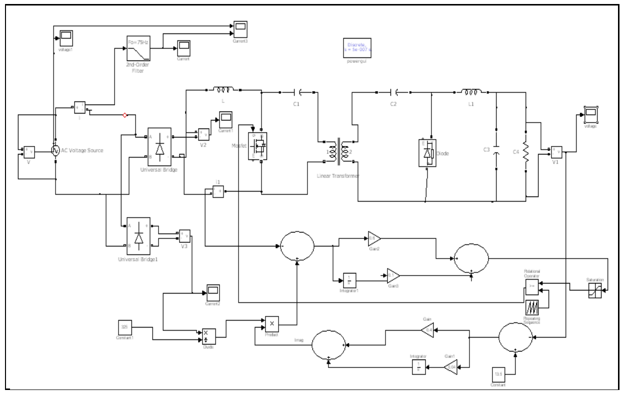

Figure 10: Matlab/Simulink model of Proposed AC to DC Cuk Converter with conventional PI controller with Average Current Control Technique

Fig.10. shows the Matlab/Simulink model of Proposed AC to DC Cuk Converter with conventional PI controller with Average Current Control Technique

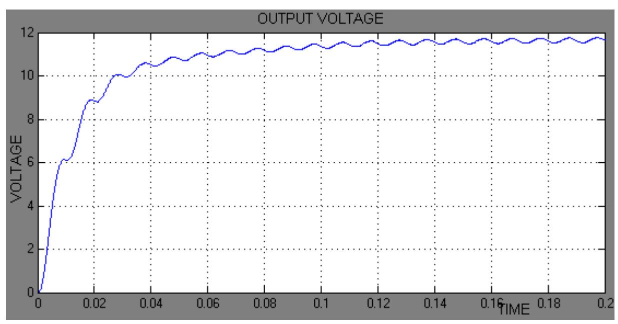

Figure 11: Output voltage of the Cuk converter

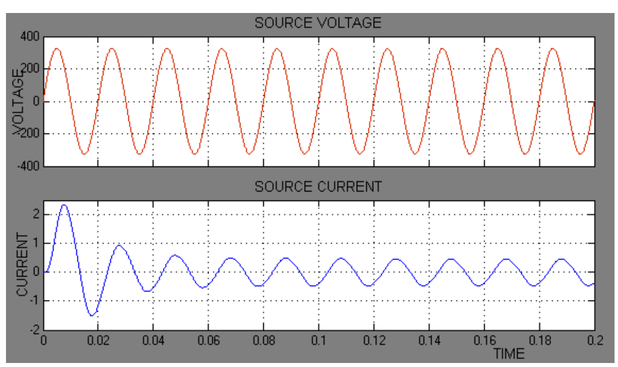

Figure 12: Source voltage and source current

Fig.11, 12, shows the output voltage of the cuk converter and source voltage and source current, there is no distortion in current and voltage, both we get sinusoidal waveform.

4.2.Case 2 : Proposed AC to DC Cuk Converter with Intelligence Fuzzy Logic controller (FLC).

4.2.1.<u>Voltage Follower Approach</u>

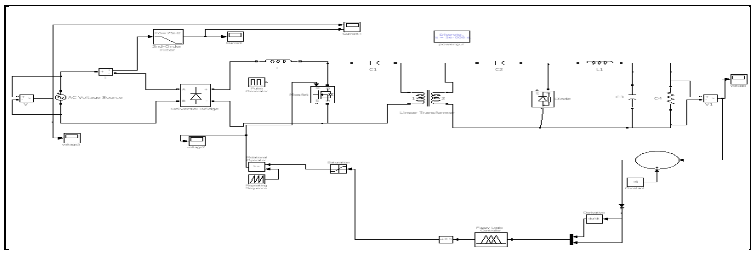

Figure 13: Matlab/Simulink model of Proposed AC to DC Cuk Converter with Intelligence Fuzzy Logic controller with voltage follower approach

Fig.13. shows the . Matlab/Simulink model of Proposed AC to DC Cuk Converter with Intelligence Fuzzy Logic controller with voltage follower approach

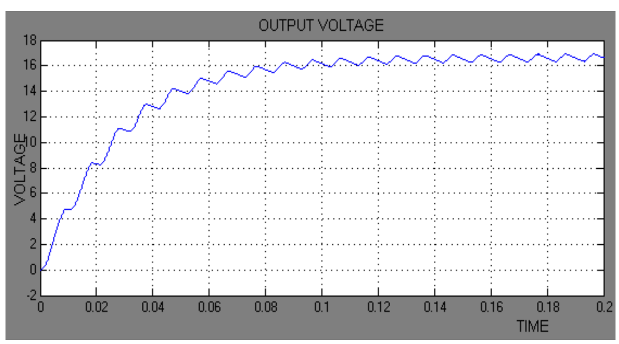

Figure 14:output voltage

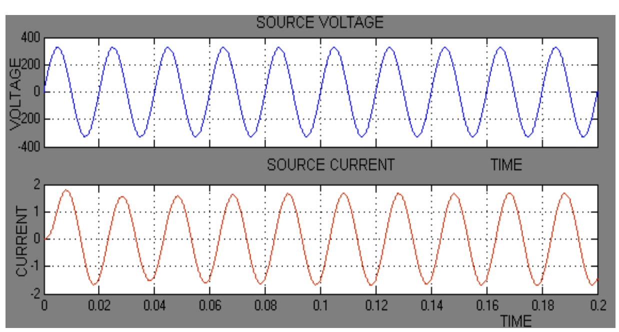

Figure 15:Source voltage and source current

Fig.14,15 shows the output voltage of the cuk converter and source voltage and source current, there is no distortion in current and voltage, both we get sinusoidal waveform.

4.2.2.<u>Average Current Control Technique</u>

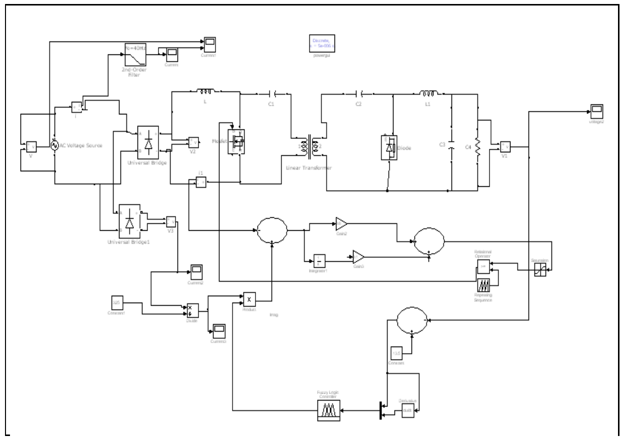

Figure 16: Matlab/Simulink model of Proposed AC to DC Cuk Converter with Intelligence Fuzzy Logic controller with Average Current Control Technique

Fig.16. shows the Matlab/Simulink model of Proposed AC to DC Cuk Converter with Intelligence Fuzzy Logic controller with Average Current Control Technique

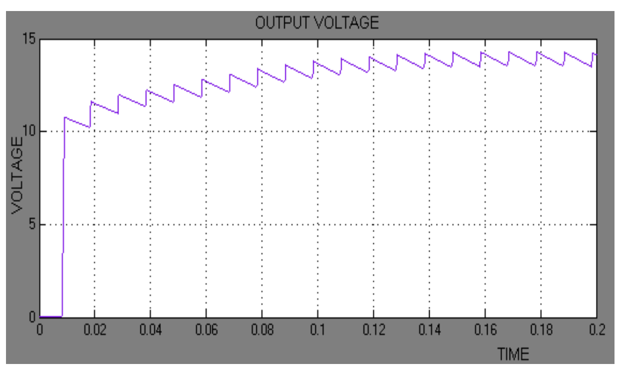

Figure17:Output Voltage of Cuk Converter

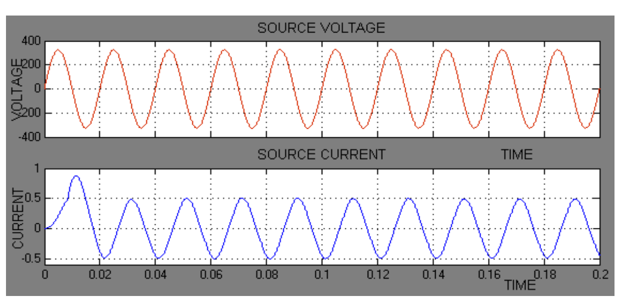

Figure 18: Source voltage and source current

Fig.17,18, shows the output voltage of the cuk converter and source voltage and source current, there is no distortion in current and voltage, both we get sinusoidal waveform.

5.Conclusion

The design and simulation of AC-DC Cuk converter with conventional PI controller and fuzzy logic controller with high frequency transformer isolation to feed the load has been carried out using Voltage Follower Approach and Average Current Control Technique. With this design converter, simulation has been done in Matlab/Simulink platform.. Simulated results shows the improved performance of the proposed high frequency isolated AC/DC Cuk Converter in terms of sinusoidal supply current and improved power factor of AC mains. It has been observed that the Cuk Converter based on pi and intelligence controller based Average Current Control Technique provides an improved power quality when compared with the voltage follower approach and also the Cuk Converter acts as Power Factor Pre-regulators (PFP) with higher reliability.

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