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Bridge less CUK with Output Voltage Regulation

Jafar Ali, K.Prakash

Dept. of EEE, Bharath University, Chennai, Chennai, Tamil Nadu, India

Associate Professor, Dept. of EEE, Bharath University, Chennai, Tamil Nadu, India

ABSTRACT: A bridgeless single-phase AC to DC Power Factor Correction (PFC) rectifiers based on CUK topology is discussed in this paper. Compared to the conventional converter the bridgeless circuit lack the input diode bridge. Only two semiconductors is working during one switching cycle and hence the conduction losses are minimized. CUK rectifier is designed to work in Discontinuous Conduction Mode (DCM) to achieve almost a unity power factor and low total harmonic distortion of the input current.

I. INTRODUCTION

The input supply voltage for a power electronic application is a AC sine wave of frequency 50Hz. This input should be converted to DC to enable the working of power electronic devices. [1]The circuits which convert supply ac voltage to a particular dc voltage required by the power electronic devices are called rectifiers. Rectifiers with diodes and thyristors can be constructed and for these circuits large output capacitors are needed to reduce the output voltage ripple and these capacitors will be charged to the peak value of the input voltage. So the current will be large and discontinuous. Hence these rectifiers will draw highly distorted current from the supply and cause a low power factor.

In order to improve the power factor, many Power Factor Corrections (PFC) circuit are present such as active power factor correction and passive power factor correction. In passive PFC, passive elements like capacitors and inductors are introduced to improve the nature of the line current.[2-4] An active PFC is a power electronic device designed to control the amount of power drawn by a load and obtains a power factor as close as possible to unity. Commonly any active PFC design functions by controlling the input current in order to make the current waveform follow the supply voltage waveform. The active power factor correction (PFC) circuits are widely used to effectively draw the energy from the mains via an AC to DC converter. These PFC circuits normally consists of full bridge diode rectifier and DC-DC converter.

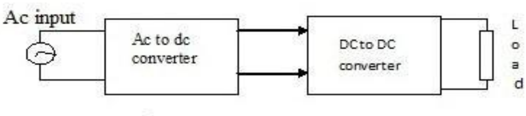

Figure 1: Basic power factor correction circuit

The losses can be reduced by eliminating the diode bridge. The circuit which does not have diode bridge is called bridgeless rectifiers.[5] Here at every instant of the switching period the current flow through minimum number of power semiconductor switches. Accordingly, the converter conduction losses can be significantly reduced and higher efficiency can be obtained, as well as cost savings. Several bridgeless PFC rectifiers have been introduced using buck boost and SEPIC converter. Similar to the boost converter, the SEPIC converter has the disadvantage of discontinuous output current resulting in a relatively high output ripple [6]. Bridgeless circuits with boost converter and buck converters are present. In boost converter the dc output voltage is higher than the peak input voltage and it cannot be used for low power application such as for telecommunication [7]. By using the buck converter the input current does not track the input voltage at zero crossing of the input voltage [8]. Also, buck PFC converter results in an increased

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total harmonic distortion (THD) and a reduced power factor.

In my work bridgeless cuk rectifier is studied and simulated. The closed loop control of output voltage is done using fuzzy controller. The performance of the controller is verified.
Here during the positive half cycle switch Q_1 is turned on. The current flowing path during this half cycle of supply voltage is through L_1, Q_1, C_1 and D_{01}. D_p is active during this cycle and it connects AC source to the output. [9]During the negative half cycle switch Q_2 is turned on. The current flowing path during the negative half cycle of supply voltage is through L_2, Q_2, C_2 and D_{02}. Dn is active during this cycle and it connects AC source to output. Here D_p or D_n connects the output voltage bus to input and thus common mode EMI noise emission can be eliminated.

Control signals for the switch Q_1 and Q_2 are shown in the figure 3. Here the two switches can be controlled by the same control signals and hence the control circuitry is simple.

1.1. OPERATING PRINCIPLE

The circuit operation during the positive and negative cycle of input voltage is same. Due to this symmetry of operation it is sufficient to analyze the circuit operation during any one half cycle ie, positive half cycle. For the analysis of the circuit certain assumptions are made:- Input voltage is sinusoidal, components are ideal, all capacitors are large enough to reduce switching voltage ripple.[10]

The converter is operated in the Discontinuous Conduction Mode (DCM). There are several advantages for DCM mode of operation. These advantages include natural near-unity power factor, the power switches are turned ON at zero current, and the output diodes (D_{01} and D_{02}) are turned OFF at zero current. Thus, the losses due to the turn-ON switching and the reverse recovery of the output diodes are considerably reduced.[11-12]

Conversely, DCM operation significantly increases the conduction losses due to the increased current stress through circuit components. As a result, this leads to one disadvantage of the DCM operation, which limits its use to low-power applications. The circuit operation is divided into three distinct operating stages during one switching period. The modes of operation are:

Stage1: In this stage Q_1 is turned on. The circuit operation is shown in figure 4. The current V_{C1} will flow through the switch and hence D_p is forward biased. The diode D_{01} is reverse biased by reverse voltage (V_{ac} + V_0). D_{02} is reverse biased by output voltage V_0. The current through inductors i_{L1} and i_{L01} increases linearly with input voltage. Current through inductor i_{L02} is zero due to constant voltage across C_2. The inductor currents i_{L1} and i_{L01} are

$$di_{Ln}/dt = V_{ac}/L_n;\ n = 1;\ 01 \quad (1)$$

The peak current through the active switch Q1 is given by

$$I_{Q1;pk} = (V_m * D_1 * T_s)/L_e \quad (2)$$

where V_m is the peak amplitude of the input voltage V_{ac}, D_1 is the switch duty cycle, and L_e is the parallel combination of inductors L_1 and L_{01} .

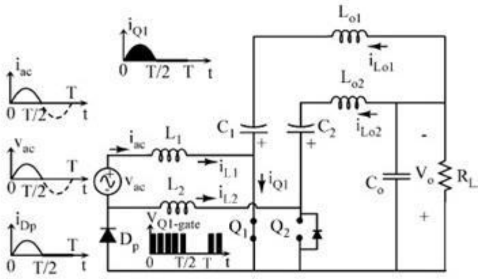

Figure 4: State 1 operation

Stage3:- During this interval both the switch and diode are revere biased. The circuit operation is shown in figure 6. The inductors act as a current source and hence voltage across the inductors is zero. The current i_{L1} charges the

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capacitor. This stage ends when Q_1 is turned on.

II. OUTPUT REGULATION USING FUZZY CONTROLLER

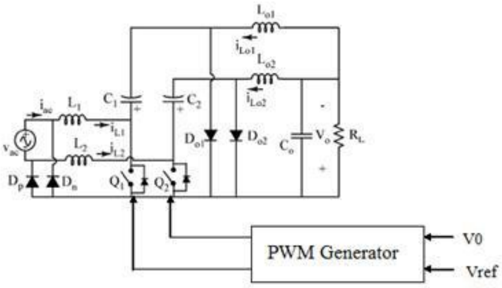

Figure 8: Basic output voltage regulation loop

Basic output voltage regulation loop is shown in figure 8. The output voltage can be controlled using closed loop control. A fuzzy control system is a control system based on fuzzy logic which is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1 There are three steps for a fuzzy control- Fuzzification, Rule base, defuzzification. The fuzzy controller has two inputs, the error and change in error. Fuzzification is the first step in the fuzzy control.[13-14] Here the membership functions are designed for the input. The process of converting a crisp input value to a fuzzy value is called fuzzification. Seven membership functions are taken with trapezoidal shape.
Seven fuzzy levels or sets are chosen for error (e), change in error (_e) and the output.

1)NL-Negative Large 2)NM-Negative Medium 3)NS-Negative Small 4)ZE-Zero Equal

Second step is to provide the rule controlling the working of a Fuzzy system. Fuzzy control rules are obtained from the analysis of the system behavior. Depending on the operating conditions different control laws can be made and this will improve the performance of the system. The fuzzy rules are based on the following criteria

1. When the output of the converter is far below the set point, the change of duty ratio must be large so as to bring the output to the set point quickly.

2. When the output of the converter is approaching the set point, a small change of duty ratio is necessary.

3. When the output of the converter is near the set point and is approaching it rapidly, the duty ratio must be kept constant so as to prevent overshoot.

Membership functions for error, change in error and output is shown in figures 9, 10, 11 respectively [12].

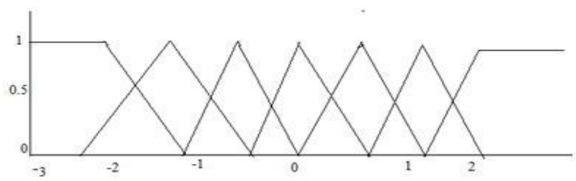

Figure 9: Membership function for error

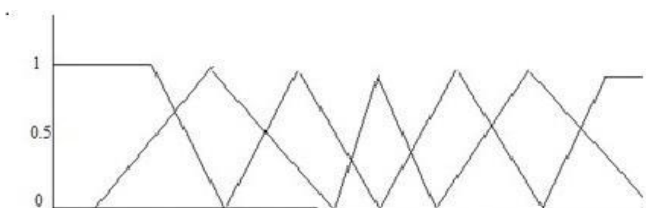

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Figure 11: Membership function for output

< Ke_crit_max, the converter operates in both modes: CCM near the peak value of the input line voltage and DCM near the zero crossing of the input line voltage.

V. SIMULATED PERFORMANCE

The circuit is simulated using MATLAB in Open loop mode and closed loop mode. PI controller and Fuzzy logic controller is employed to control the circuit. The parameters taken for the simulation are

1) RMS input voltage: 230V

2) Supply frequency: 50HZ

The input voltage and current waveform for the bridgeless cuk rectifier is shown in figure 12. The input current is tracking the input voltage.

The THD obtained is 25%. The inductor current waveforms are shown in figure 13. Current through Diode D_p and D_n is shown in figure 14. The output voltage is shown in figure 15. Output voltage waveform is constant at 48V. The output voltage regulation is done using Fuzzy controller. The output voltage for fuzzy controller is shown in the figure 16. The output voltage remains constant at 400V which is the reference voltage. So the controller is tracking the reference voltage.

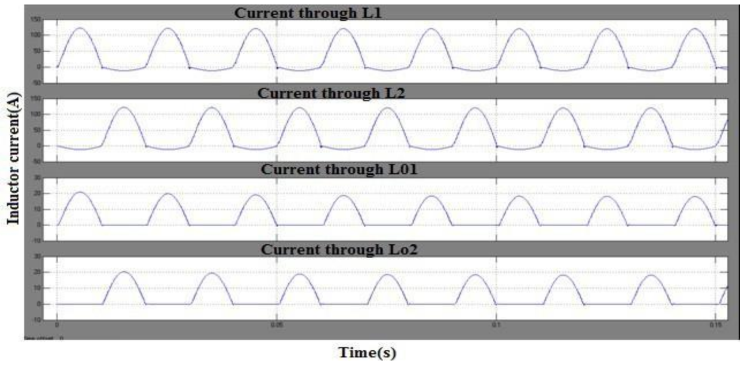

Figure 13: Inductor current waveforms in open loop mode

VI. CONCLUSION

A single phase AC to DC bridgeless CUK rectifier is discussed and simulated. Performance of the converter is verified by simulation and experimental results. The bridgeless CUK rectifier is simulated in MATLAB/SIMULINK in both open loop mode and closed loop mode.

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