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Fuzzy Based CUK Converter Fed DC Drives

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ABSTRACT

Background: Performance of CUK Converter**. Objective:** Simulation of a bridgeless Power Factor Correction Cuk converter fed DC drive is presented using Fuzzy controller. **Results:** The proposed approach is expected to provide better voltage regulation for dynamic load conditions. **Conclusion:** The proposed PFC converter fed drive is analyzed and simulated using MATLAB- Simulink. In this paper, Simulation of a bridgeless Power Factor Correction Cuk converter fed DC drive is presented using Fuzzy controller. The proposed strategy is designed to produce regulated variable DC output voltage. The Cuk converter is gaining popularity as a LED driver because it does not require additional power conversion stage. The simulation study indicates the superiority of fuzzy control over the conventional control methods. The proposed approach is expected to provide better voltage regulation for dynamic load conditions. Merits of the proposed power converter include improved power factor, less harmonic content, less switching loss, simpler control strategy and unidirectional power flow. The proposed PFC converter fed drive is analyzed and simulated using MATLAB-Simulink.

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INTRODUCTION

In recent years, there has been increasing interest in the development of efficient control strategies to improve dynamic behavior of DC–DC converters. Switching dc-dc converters are highly non-linear plants. The non-linearity are mainly due to the switching actions and the parameter variations caused by external disturbances. In order to achieve the necessary regulation, a controller in a feedback loop is needed. However, some models are non-minimum phase systems. Besides, perturbations are often so large that the small signal approximation cannot be valid. In order that the regulated converter has good transient and steady-state responses, controllers with the following properties are desirable: (1) it does not rely on an accurate model of the plant, (2) it is robust to the uncertainties of the plant parameters. Controllers are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In recent years, fuzzy logic controllers had been used in many areas. Unlike conventional controllers, a fuzzy logic controller does not require an exact model of the plant. Instead, a set of linguistic rules is used to derive the control strategy. These rules come from knowledge and properties of the plant and affect directly the performance of the controller. Hence, a fuzzy logic controller can be more capable of tackling plants with parameter uncertainties and/or undesirable non-linearity than conventional controllers. The Literature (Alejo, D., 2003; Brkovic and S. Cuk, 1992; Cuk and R.D. Middle brook, 1977; Dai, H. Ye, 2004) deals with the conventional and their control circuits. The discussion of new methods is in (Dianguo, W. Wei, 2008). To overcome the harmonics and to improve the efficiency of the system were discussed in (Hung, J.C., 2008; Mattavelli, P., 1997). The basic of proposed system is in (Mahdavi, M. and H. Farzanehfard, 2011; Rubai, A., 2005; Sabzali, E.H. Ismail, 2011; Su, J. Zhang and Z. Lu, 2010; Wei, W., 2008). The above literature does not deal with DC drive fed from bridgeless PFC Cuk converter. In the present work an attempt is made to find the performance of Bridgeless PFC Cuk converter fed DC drive using fuzzy logic controller.

State Space Analysis of CUK Converter:

The Cuk converter is a step-down/step-up converter based on a switching boost-buck topology. Essentially, the converter is composed of two sections, an input stage and an output stage. The schematic of the Cuk

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converter is presented in Fig 01. Basically a controller was designed & the performance of the Cuk model was examined. A state space block diagram for the Cuk model is shown in Fig.02. The state space equations were determined to be:

$$\begin{aligned} \dot{x} &= Ax + Bv_g + B_d d \\ v_o &= Cx \\ x &= \begin{bmatrix} v_2 & v_1 & i_2 & i_1 \end{bmatrix}' \end{aligned} \qquad (1)$$

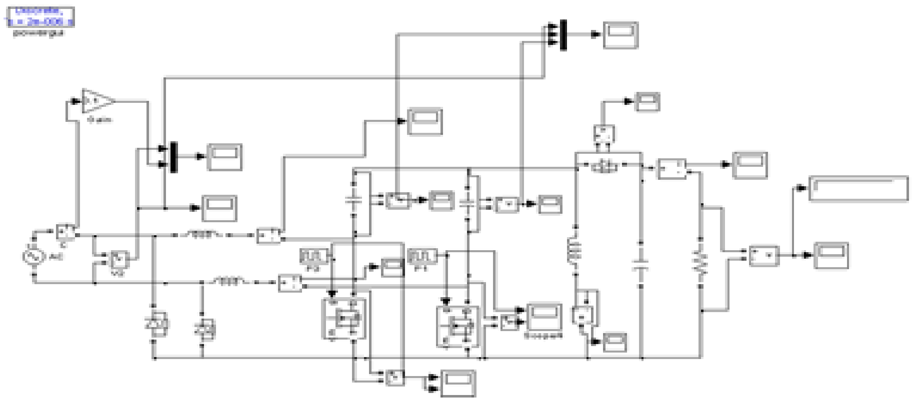

Fig. 01: Schematic of the Cuk converter.

The state space matrices for the open-loop model from the disturbance input v_g to the output v_o are the state space averaged matrices {A, B, C, D}. The state space matrices for the open-loop system from the control input d to the output v_o are the state space averaged matrices {A, B_d, C D}. Thus, the model of the ´ Cuk converter has two inputs (a control input d and a disturbance input v_g) and one output (v_o). The MATLAB model open-loop response to a unit step disturbance in v_g is shown in Fig.03. By inspection of the plotted response, it was determined that the system reached lightly damped oscillations around a steady state DC value in approximately 20 ms. The steady state value was 26 V, a value predicted from the gain equation for the ´ Cuk converter:

$$V_O = (Ds/1 - Ds)\, v_g \qquad (2)$$

With nominal duty cycle Ds = 0.667, a 1 V step input in vg produces a 2 V step in the output voltage V_O. This shows that the open-loop system does not reject disturbances on the input voltage v_g. Also, note that the output of the circuit is a lightly damped sinusoid, with an approximate frequency of 1.83 kHz (11.5 krad/s).The schematic diagram of the dc drive system is shown in Fig.04. The power circuit consists of a Cuk converter that drives a separately excited dc motor. The converter drive system is used in motoring mode only with fixed field excitation. Inner current control loop is provided in addition to the speed control loop to achieve fast transient response as well as to limit the armature current. The output of the current controller is the control voltage for the converter firing circuit. The firing pulses for the SCRs are generated with a delay angle, by cosine wave crossing method. The speed and current controllers in Fig.04 is a fuzzy logic controller.

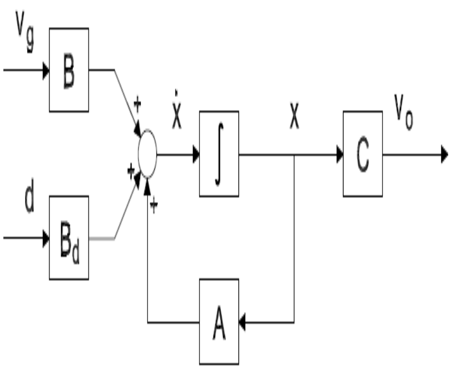

Fig. 02: State space model of Cuk converter.

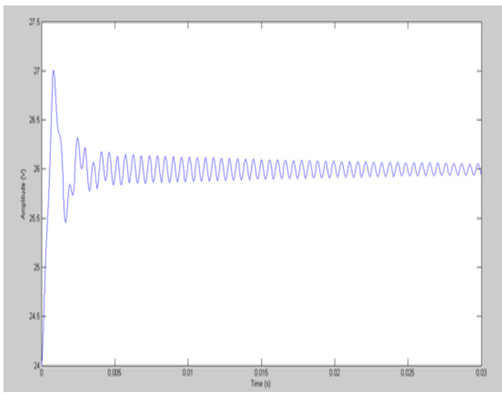

Fig. 03: Unit step disturbance in v_g

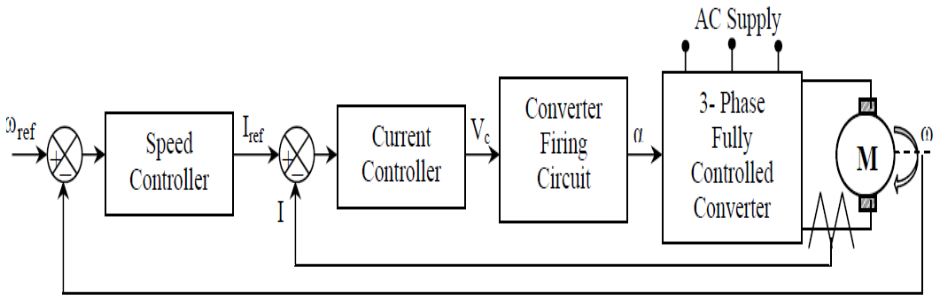

Fig. 04: Speed and current controller.

RESULTS AND DISCUSSION

1. Fuzzy Logic Control:

This paper introduces a systematic approach to construct a FLC for DC–DC convert. The fuzzy logic controller can be divided into four modules: fuzzification is the classification of input data into suitable linguistic values or sets; knowledge base includes rule base and data base. They contain knowledge of the control rules and linguistic labels; decision making is inferring control action from rule base; defuzzification is the conversion from the inferred fuzzy value to real crisp value, or control action. Fuzzy control is developed using the Matlab software- fuzzy toolbox. The fuzzy variables e, Ce and Δu are described by triangular membership functions. Five triangular membership functions are chosen for simplicity. Table 1 shows the fuzzy rule base created in the present work based on intuitive reasoning and experience. Fuzzy memberships NB, NS, Z, PS, PB are defined as negative big, negative small, zero, positive small, and positive. At every sampling interval, the reference voltage and load voltage are used to calculate the error (e) and change in error (c_e) signals that act as the input to the FLC. The stage of fuzzification, fuzzy inference and defuzzification are then performed as given below.

$$e = Vr - VL \tag{3}$$
$$C_e = e - p_e \tag{4}$$

where Vr is the reference or the desired output voltage, VL is the actual output voltage and pe is previous error. The duty ratio of the converter can be determined by the fuzzy inference. For instance, if the output voltage continues to increase gradually while the current is low during the charging process the fuzzy controller will maintain increase in voltage to reach the set point. A drop in the output voltage level triggers the fuzzy controller to increase the output voltage of the converter by modifying the modulation index (MI) of the converter. The resolution of fuzzy logic control system relies on the fuzziness of the control variables while the fuzziness of the control variables depends on the fuzziness of their membership functions.

Table 01: Fuzzy rules.
Error (e), Change in error (ce)

	NB	NS	Z	PS	PB
NB	NB	NB	NB	NM	Z
NS	NB	NM	NS	Z	PM
Z	NB	NS	Z	PS	PB
PS	NM	Z	PS	PM	PB
PB	Z	PM	PB	PB	PB

2. Simulation Results:

The Closed loop simulation using FLC is carried out using MATLAB/Simulink software. Depending on error and the change in error, the value of change of switching frequency is calculated. The Fuzzy set parameters instruction and function blocks available in MATLAB are used to update the new switching frequency of the pulse generators. The entire system is simulated with a switching frequency of 100 KHz. In order to validate the control strategies as described above, digital simulation investigation were carried out on a converter dc motor drive system whose parameters are given. In the proposed method, it is assumed that a controlled switch is implemented with power MOSFET since its inherently slow body diode. In the Fig.05a – Fig.05e, Cuk converter's duty ratio, Input voltage, inductor currents, and capacitor voltages are shown for startup transient and load transient, respectively. For Cuk converter, the startup transient takes approximately 0.9 ms. After 3 ms, the equivalent load resistance RL is reduced from 4 Ω to 2 Ω. The load transient takes approximately 1 ms. It clearly shown in figures that the power losses in the occurrence of turn on switching are maintained very low by means of the resonant operation. Output voltage and current are fed with the DC motor are shown in Fig.06.a & Fig.06.b. It can be seen from theses waveform that the current contains low harmonics and it presents a nearly sinusoidal shape. Fig.07.a - Fig.07.c shows the good performance of the whole design. One can conclude that the controller is capable of operating under load-independent operation, again, it can be seen that the output follows the reference with good accuracy and better dynamic performances.

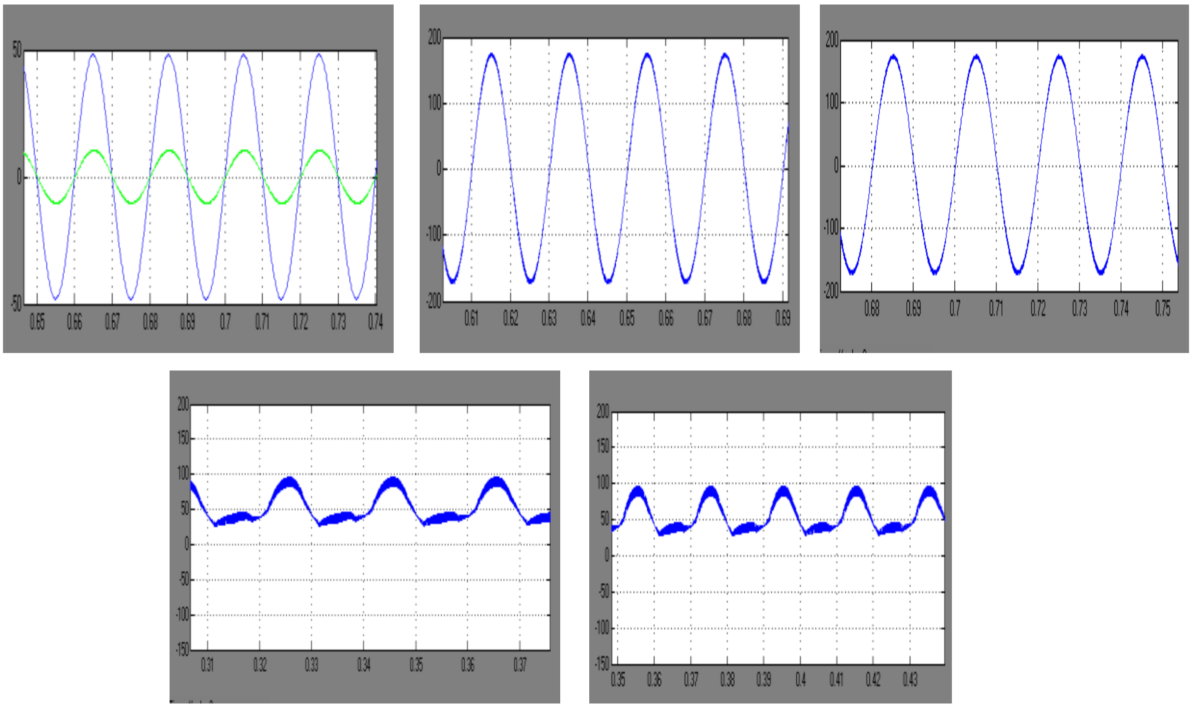

Fig. 05: a: Input AC voltage & current, b: Inductor current L1, c: Inductor current L2, d: Capacitor voltage C1, e: Capacitor voltage C2.

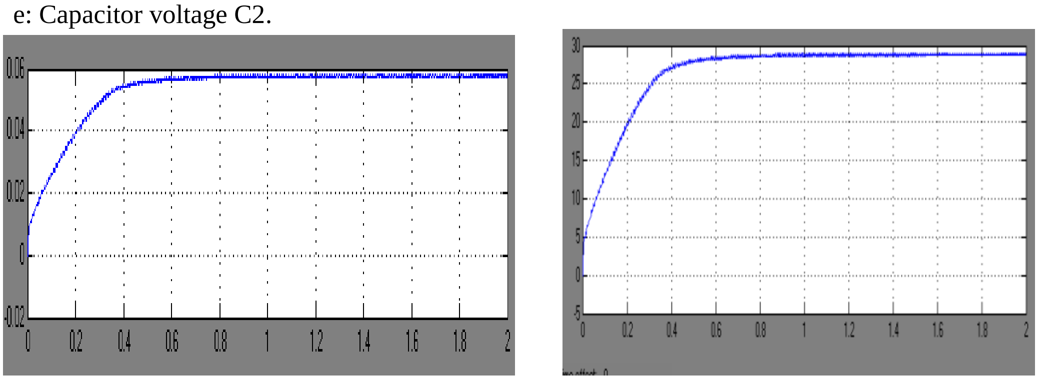

Fig.06: a: Output voltage measures 29volts, b: Output current measures 0.06amps.

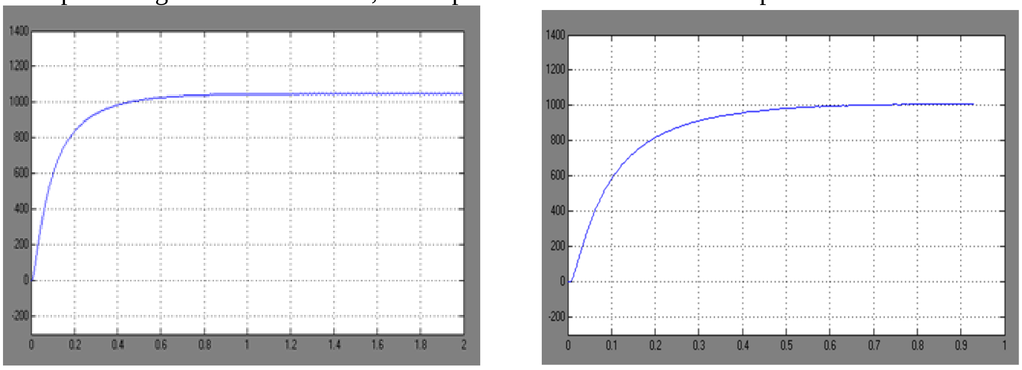

Fig. 07: a: Speed of motor under no load, b: Speed of motor under load condition.

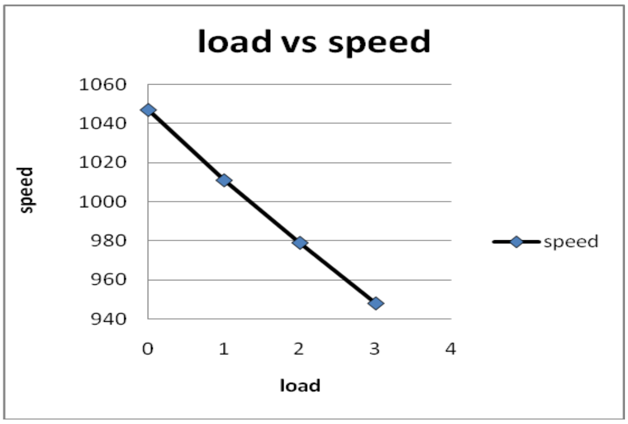

Fig. 07: c: Load Vs. Speed.

Conclusion:

The Cuk converter analysis has been module and estimating the performance at various load conditions is done. Switching frequency harmonics can be reduced by coupling the two inductors. This converter with a load shows it provides load independent operation. So, the switching power losses are minimized. It has been found from the simulated results that the closed loop controller provides better control strategies. The FLC is able to regulate the output voltage of Cuk converters to desired value despite change in load. It has been found that FLC controller is able to regulate the speed well above the rated values.

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