Transient Response Improvement of Cuk Converter using SMC & FLC

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Abstract- This paper presents a control scheme for a DC-DC Cuk converter. The proposed Sliding Mode controller and Fuzzy Logic controller is designed to produce regulated variable DC output voltage. The response of the system is then compared with PID controller to find the greater degree of robustness to plant uncertainties and insensitive to disturbances acting on the system. The voltage is regulated by changing the duty cycle of the converter. Cuk converter has some advantages compared to other type of converters such as low input and low output current ripple, Improved system efficiency, low switching losses, fast transient responses. A comparison of the effects of the PID controller, the SM control and Fuzzy Logic controller on the DC-DC Cuk converter response in steady state, under line variations, load variations is performed. Dynamic transient response of the system using the proposed controller is then analyzed and verified using MATLAB- Simulink.

Keywords- Cuk converter, PID controller, Sliding mode controller, Fuzzy Logic controller.

I. INTRODUCTION

DC-to-DC converters are circuits which convert sources of direct current (DC) from one voltage level to another by changing the duty cycle of the main switches in the circuits. These converters are widely used in regulated switched mode dc power supplies and in dc motor drive applications. The input to these converters is often an unregulated dc voltage, which is obtained by rectifying the line voltage and it will therefore fluctuate due to variations of the line voltages. Switched mode dc-dc converters are used to convert this unregulated dc input into a controlled dc output at a desired voltage level[1],[2],[3],[4]. With the peculiar properties , the Sliding mode control technique has been applied to the cuk converters and obtained highly performed switching regulators with first order response and large ability to suppress disturbances[5]. Cuk converter, is superior to other converters on its non-pulsating input and output currents, either step-up and step-down voltage gain[6]. Among the most popular controller is the fuzzy logic controller. A FLC does not require precise mathematical model. This tool is very strong considering that it has excellent immunity to external disturbances. However, fuzzy logic controller requires substantial computational power due to complex and heuristic decision making processes[7]. Therefore, the motivation of this thesis is to improve the performance of a dc-dc cuk converter through controller improvements.

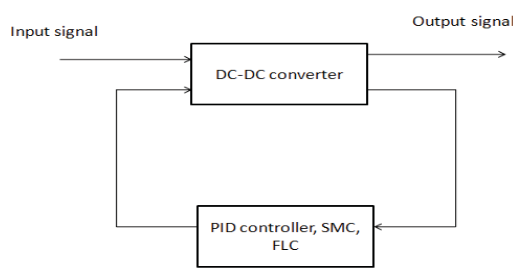


Figure1.1 :Basic block diagram

The input signal is given to the DC-DC converter, the output of the converter is send as feedback to a controller. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly. By tuning the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. In SMC, the purpose of the switching control law is to drive the non-linear plants state trajectory onto a pre-specified surface in the state space. This surface defines the rule for proper switching. SMC uses a sliding surface which ensure the output voltage to go to desired value once the system get onto the sliding surface. In Fuzzy Logic controller it grabs plant output compares it with the desired input and then decides what the plant input. The inputs and outputs are crisp. The fuzzification block converts the crisp inputs to fuzzy sets and defuzzification block returns these fuzzy conclusions back into the crisp outputs.

II. CUK CONVERTER ANALYSIS

A. When switch S is 'on', 0 < t < DT

In the state when switch S is on, the converter circuit takes the form shown in Figure 2.1. There are two separate meshes. In the left hand mesh the input inductor L1 stores energy from the source over S during the time interval. The energy storage capacitor C1 is now in the right hand mesh and it transfers stored energy, over S, to the load R, and energy storing elements L2 and C2. Due to the inappropriate voltage polarity of the charge on the capacitor C1, diode D1 is reverse biased and therefore off.

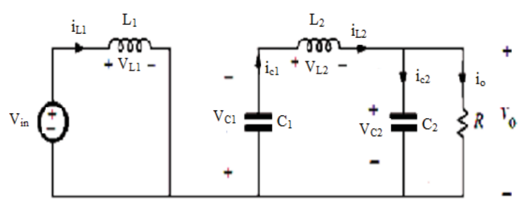


Figure 2.1: Cuk converter equivalent circuit when S is on

$$\frac{di_{L2}}{dt} = (V_{C1} - V_0)/L_2$$

Current passing through S is the sum of input and output inductor currents:

$$I_S = I_{L1} + I_{L2} \qquad (1)$$

B. When switch S is 'off', DT < t < T

The circuit is divided into two separate meshes as seen in Figure 2.2. When S is off, the energy storage capacitor C1 in the left hand mesh is charged through L1 and D1 in this time interval. Diode D1 common to both meshes is forward biased in this time interval. L2 and C2 in the right hand mesh transfer their stored energies, left from the previous time interval during the steady-state operation, to the load R over D1 again.

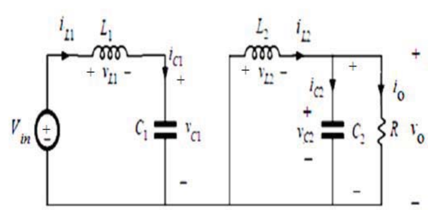


Fig 2.2: Cuk converter equivalent circuit when S is off

$$\frac{di_{L1}}{dt} = (V_{in} - V_{C1})/L_1$$

Current passing through D1 is the sum of input and output inductor currents:

$$i_{D1} = i_{L1} + i_{L2} \quad (2)$$

In steady state, the transfer function can be determined by average current through capacitor in one period is zero. Therefore, by solving the linear equation during turn-on and turn-off, the average output voltage is derived as follows;

$$[\,[ic1_{closed}]DT + [ic1_{open}](1 - D)T = 0$$

$$(i_{L1}/i_{L2}) = D/(1 - D) \quad (3)$$

$$(i_{L1}/i_{L2}) = -V_o/V_{in} \quad (4)$$

The relationship of output-input voltage function yields the transfer function as follows

$$V_o = -V_{in}D/(1 - D) \quad (5)$$

III. SIMULATION CONTROLLER OF SMC

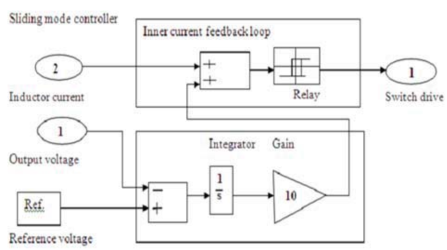


Figure 3.1: Block diagram of SMC

The output voltage is compared with reference voltage and the difference is given to integrator. The integrator which amplifies the output through a gain and the result is added from an inductor current loop and it is given to a hysteresis relay. The output is then compared with reference pulse generator and the generated control pulse is given to the switch for proper regulation of the system.

A. Sliding mode controlled cuk switching regulator

If 0<k<1

if $M/L_1 \geq 1$

$V_{c1} = MV_g/L_1 - V_0^* \leq 0$

$\frac{M(V_{c1} - V_g)}{L_1} - V_0^* \geq 0$

if $M/L_1 \leq 1$

$$V_{C1} - MV_g/L_1 - V_0^* \geq 0$$

$$\frac{M(V_{C1}-V_g)}{L_1} - V_0^* \leq 0$$

$$\sigma = k_1(V_0 - V_0^*) + k_2 R C_2 \frac{dV_0}{dt} = 0$$

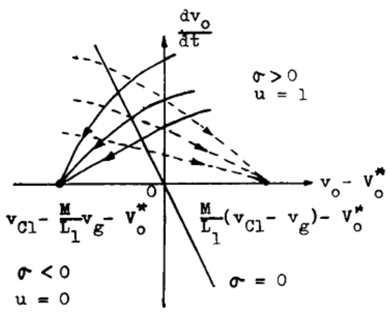


Figure 3.2: The phase plane descriptions when 0<k<1

IV.SIMULATION CONTROLLER OF FUZZY LOGIC SYSTEM

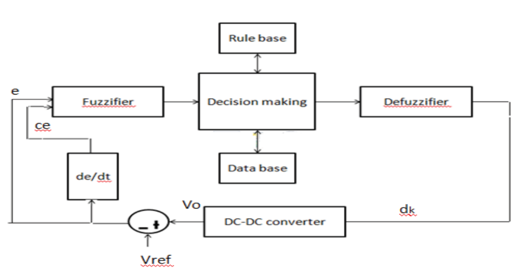


Fig 4.1: Block diagram of Cuk converter using FLC

The difference between system output voltage and reference voltage is considered as error. The error (e) and change of error (de/dt) are used as input variables to the Fuzzifier. The Fuzzification block converts the crisp input to fuzzy sets and the rule table is created to determine which output ranges are used. The output change in duty cycle is then defuzzified and the output control signal is given to the switch to control the system.

$e(t)=r(t)-y(t)$
$\Delta e(t) = e(t)-e(t-1)$

The control signal

$u(t)=u(t-1)+\nabla u(t)$

V.SIMULATION AND RESULTS

A. Simulation model of cuk converter using pid controller

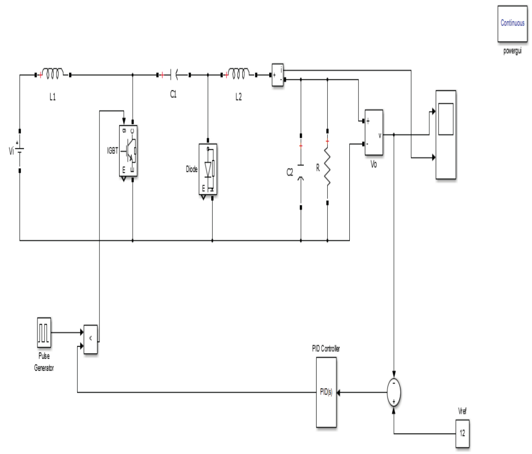


Figure 5.1: Simulink model of Cuk converter with pid controller

B. Output waveform of Cuk converter with PID controller

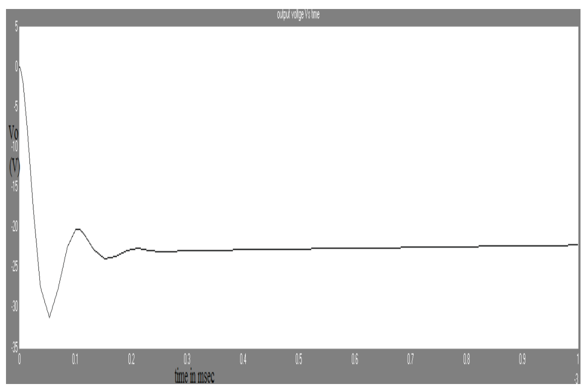
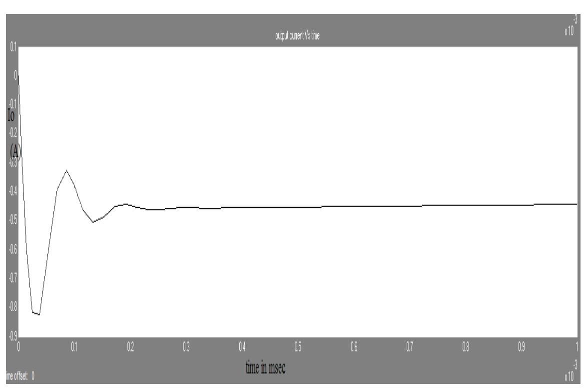


Figure 5.2 : Output voltage Vs Time



C. Output waveform of Cuk converter with SMC controller

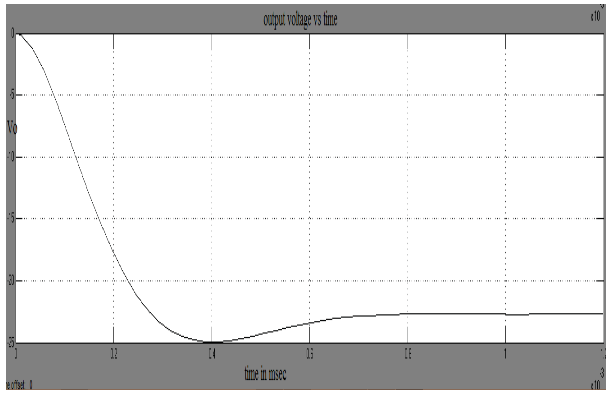


Fig 5.4: output voltage vs time

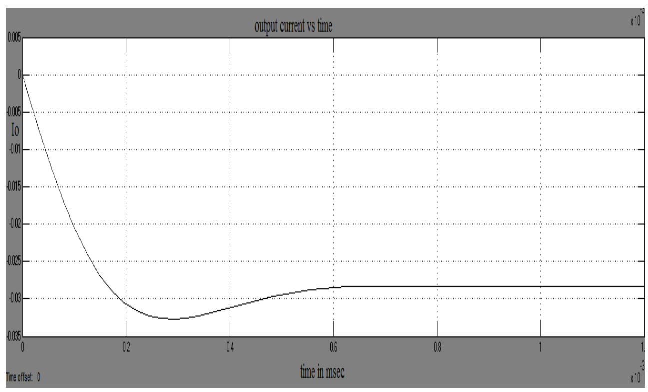


Fig 5.5: output current vs time

D. Output waveform of Cuk converter with Fuzzy Logic controller

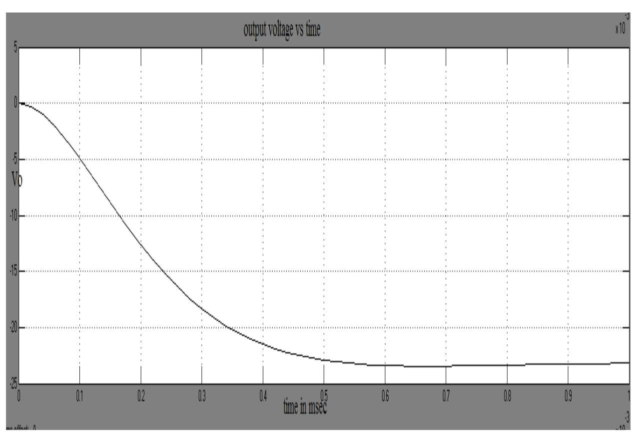


Figure 5.6: output voltage vs time

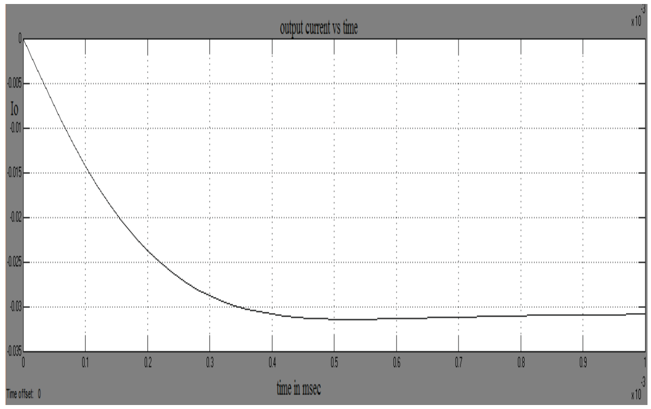


Figure 5.7: output current vs time

TABLE 1

COMPARISON OF SYSTEM RESPONSE BETWEEN PID, SMC AND FLC

CONTROLLER	VOLTAGE PROFILE	SETTLING TIME	CURRENT PROFILE
FLC	24.4 V	0.0006 msec	0.031 A
SMC	24.4 V	0.0008 msec	0.028 A
PID controller	24 V	0.008 msec	0.028 A

VI. CONCLUSION

A comparison between the Transient response of Cuk converter using PID, SMC and FL controllers are highlighted. Performance analysis for controlling of DC-DC Cuk converter is evaluated in simulation under the internal losses and input voltage variation. Sliding mode controller and PID controller have some overshoot voltage but voltage drop is more using PID controller.SM controller has maximum settling time as compared to PID controller. FLC has no overshoot and has a smoother output compared to SMC and PID controller and also has maximum settling time. The transient response improvement of the system is verified using MATLAB-Simulink and the comparison of system response using PID controller, SM controller and FL controller is shown. Using FL controller the transient performance and steady state performance is improved compared to other two controllers.

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