Efficient and Novel Voltage Control for DC-DC CUK Converter under load variation

Syed Mujtaba Mahdi Mudassir, Faheem Ahmed Khan, and Shaziya Sultana

***Abstract*— A control system is a set of mechanical or electronic devices that regulates other devices or systems by way of control loops. Typically, control systems are computerized. The mode of operation in a Control System where controlling variables is a function of the system and the structure is changed knowingly according to set of rules, which are already declared: for example a sensor based system, is called as sliding control mode where the feedback control system response is limited and revolves around surface in the space to a point of equilibrium.**

In this mode of schemes, a switching variable dictates which form of control is to be used at a given instant, depending on the position of the state from the surface. First a set of points for which the switching function is null is used called as sliding surface. Sliding Mode Control (SMC) is a very robust technique which can handle sudden and large changes in dynamics of the system which can be applied to many areas like controlling of motor, aircraft and spacecraft, process control and power systems. SMC is one of the best tool in the industry to design controllers for the systems which has variable values, and provides robust properties against matched uncertainties, However,this use of SMC can only be achieved after the occurrence of the sliding mode. Before the occurrence of the switching function as null i.e. during the reaching phase, the system is affected by even matched ones. Several first order SMC applications for linear and nonlinear systems can be found in the literature [1]. Hence to eliminate the reaching phase and to make sure the ruggedness of the system throughout the entire closed-loop system response Integral Sliding Modes are used. In this paper a design procedure for sliding mode controllers for better control of voltage is applied, and then the ideas implemented are extended to all integral sliding modes in order to ensure optimum operation of entire system response[2]. Necessary conditions for the existence of sliding modes are also given. The closed-loop system is also proved to be exponentially stable. Simulation and experimental tests using the prototype of controlled DC-DC CUK converter were performed to validate the proposed control approach.

***Index Terms*— DC-DC converter, CUK converter, closed loop, sliding mode control, load variation, Efficient control, reaching phase.**

I. Introduction

In this paper a very popular converter called as CUK converter is used which has low input and output ripple. By controlling the duty cycle, it can be operated as a boost or buck regulator. The ĆUK converter designed for variable loads can be operated in both continuous and discontinuous current modes and has many advantages like easier load control, elimination of the reaching phase and ensuring ruggedness of the system.Fig 1 shows different DC-DC Converter topologies.

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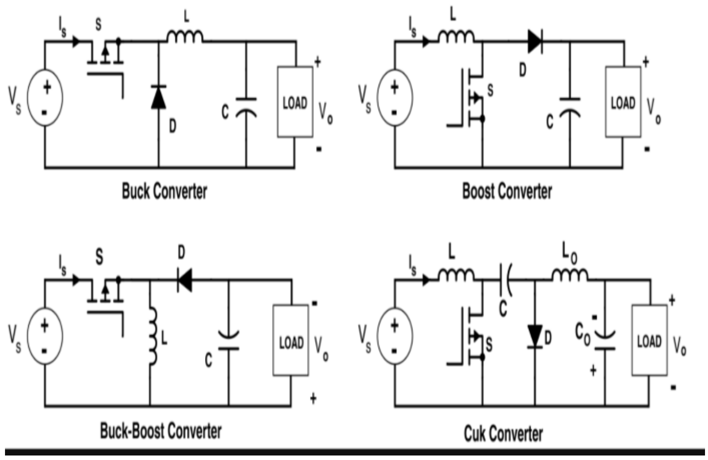

Fig1. Different DC-DC control Strategies

The ĆUK converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude, with an opposite polarity. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor.

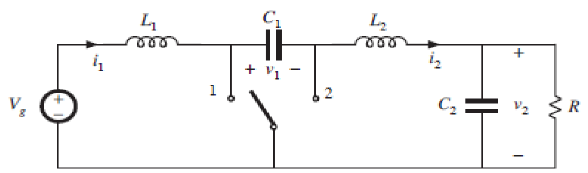

Fig 2. CUK converter with ideal switch

Fig 2 shows an ideal switch CUK Converter which transforms a DC voltage at the input to a DC voltage at the output with reversed polarity. Compared to the Buck, Boost and Buck-Boost converters the CUK converter uses an additional inductor and capacitor to store energy.CUK converter is an inverting converter, so the output voltage of the converter will be in the reverse with respect to the input voltage. CUK converter is used for the voltage regulation for the dc application systems. CUK converter is used in hybrid solar-wind energy system as a regulator where input voltage depends on speed of wind and sun, in order to make the output voltage as a constant source CUK converter is used [6]. Thus by using the Activate tool the CUK Converter topology is implemented.

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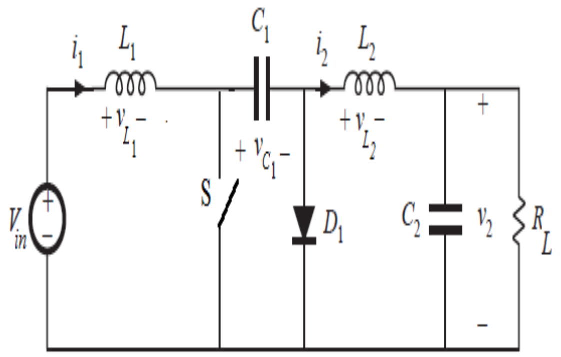

Fig 3. CUK Converter

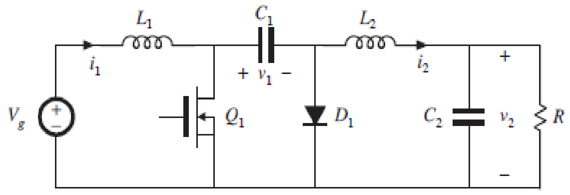

Fig 4. Cuk Converter using MOSFET

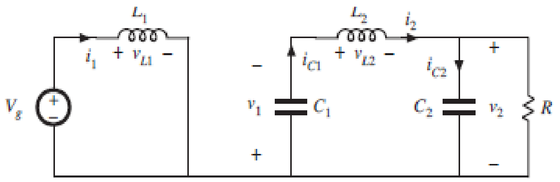

Fig 5. MOSFET in ON mode

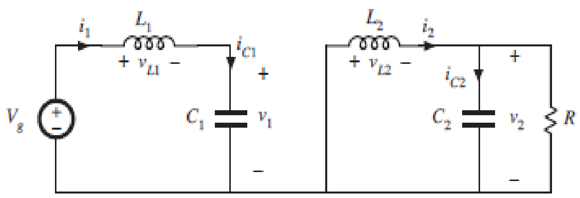

Fig 6. MOSFET in OFF mode

A. *Operation of CUK Converter*

Fig 3 shows the basic CUK Converter .There are two modes of operation of CUK Converter

1) *Continuous mode Operation (CMO)*

CUK converter is basically an extension of buck/boost converter and was invented by CUK. The output here is opposite in polarity of input voltage and can either step up or step down the input voltage. With the aid of one additional capacitor and inductor this converter is famous for its extremely low ripple in the input and output current. Figure5 shows the schematic of this converter. Here C_1acts as a primary source of transferring power from input to output side. When the power electronic switch is off then the diode is forward biased and allows the current to pass through the inductors L_l, capacitor C_l and inductor L_2. The circulation of current in this CMO charges the capacitor C_l . But since the capacitor receives energy both from the source voltage and the inductor therefore as soon as the voltage across capacitor exceeds the input voltage the current through Ll start decreasing and at this stage the energy stored in L2 is

2) *Discontinous mode Operation(DCMO)*

From the operating point analysis, the voltage conversion ratio of the CUK converter operating in DCMO can be calculated. But such a relation depends on the system parameters due to its DCMO condition, therefore to present voltage conversion , the following parameters have been taken as an example : L1 = L2 = 200 µH, C1 = 50 µF, C2 = 23.5 µF, R = 100 Ω and T = 20 µs. Figure11 shows the steady state voltage conversion for the given parameters, where a nearly linear behavior is observed. Similarly, the analysis of the steady state duty cycle of 20 % is shown in fig 9of the first topology, the second topology of duty cycle of 50 % is depicted in figure10,The analysis of the steady state duty cycle of 80 % is shown in fig 11 of the third topology

For the same parameters, where it is observed the steady state Mosfet duty D1 = D that ensures a DCM operation (D3 > 0) of the Cuk converter.

B. *Software Implementation:*

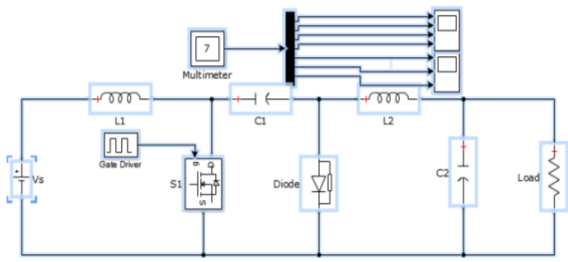

Fig 7. Simulation Diagram of CUK Converter

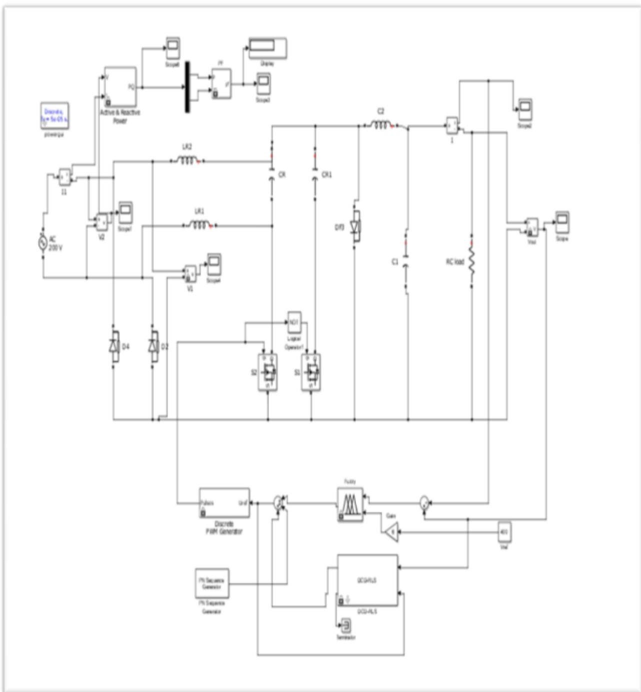

Fig 8. Simulink model of the proposed converter

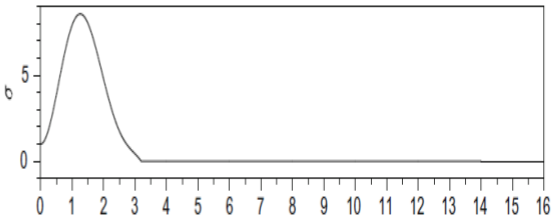

Fig 8 a) For smooth Disturbances

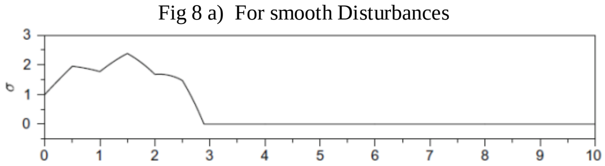

Fig 9. For 20% Duty Cycle

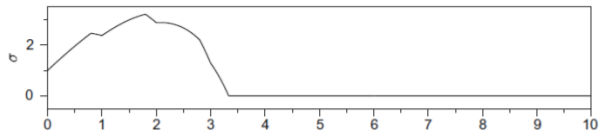

Fig 10. For 50% Duty Cycle

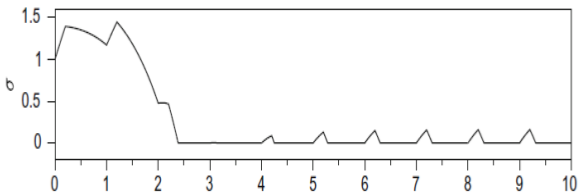

Fig 11. For 80 % Duty Cycle

C. Hardware Implementation

- The properties of integral sliding modes can be summarized as follows:
- There is no reaching phase and a sliding mode is enforced throughout the entire system response;
- During sliding, the order of the motion is the same as the original system;
- By a suitable choice of sliding surface, the effect of unmatched uncertainty can be ameliorated;
- During the sliding mode, the system motion is invariant to matched uncertainties;

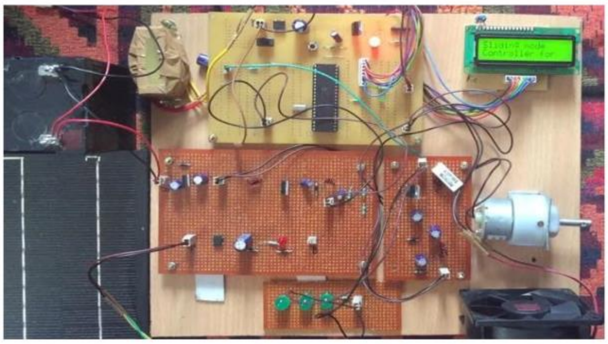

Fig 11. sliding mode Operation

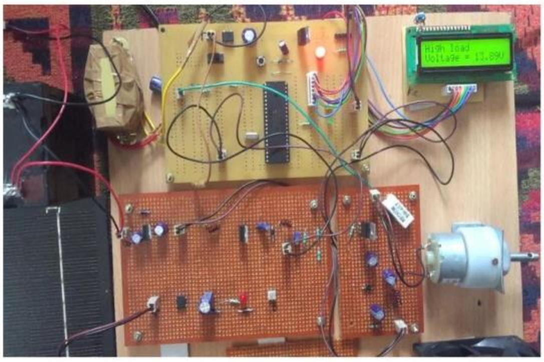

Fig 12 . High Load

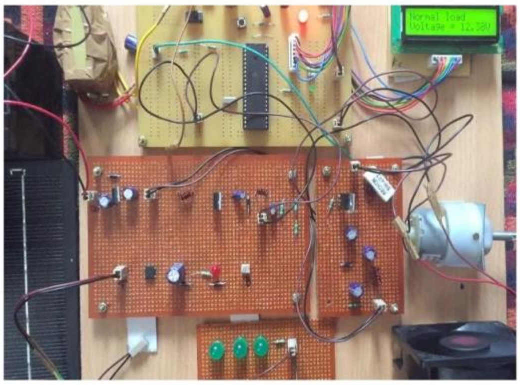

Fig 13. Normal Load Operation

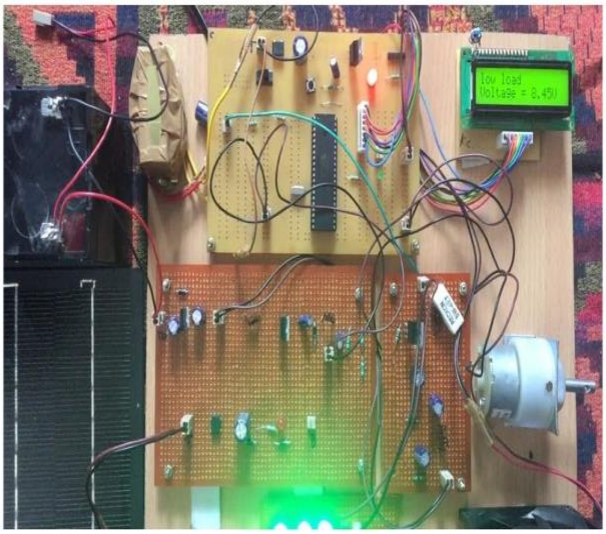

Fig 14. Low Load Operation

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II. PARAMETERS AND COMPONENTS OF CUK CONVERTER PROTOTYPE

Table 1

Parameters	**Symbols**	**Value**
Input voltage	$v_i(t)$	50 V
Desired output voltage	v_{do}	60 V
Switching frequency	f_s	50 kHz
First capacitance	C_1	2.5 μF
Second capacitance	C_2	280 μF
First inductance	L_1	1 mF
Second inductance	L_2	1 mF
Components	**Symbols**	**Part number**
Switch	S_1	IXTX200N10L2
Gate Driver	G_1	SKHI 22B R
Diode	D_1	E20U60DN

The dc component of a converter waveform is given by its average value or the integral over one switching period, divided by the switching period [34]. Solution of a dc-dc converter to find its dc, or steady state, voltages and currents therefore involves averaging the waveforms.

The linear ripple approximation greatly simplifies the analysis. In a well designed converter, the switching ripples in the inductor currents and capacitor voltages are small compared to the respective dc components, and can be neglected [28]

The principle of inductor volt-second balance allows determination of the dc voltage components in any switching converter. In steady-state, the average voltage applied to an inductor must be zero.

Table 2

Controller	**Simulation**	**Experiment**
The equivalent control	1.5369 V	5.3369 V
SMC control	0.2753 V	0.6391 V

The above table shows the results of simulation for the equivalent control as well as for sliding mode control (SMC).The simulation result shows a better control if sliding mode controller is applied. The experimental results for both the controller.When we employ sliding mode control for the cuk converter the voltage control was very goog as compared to the conventional way of controlling.

III. OUTPUT WAVE FORMS

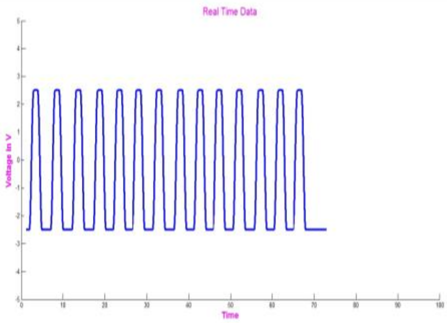

Fig 15 .Waveform for High Load

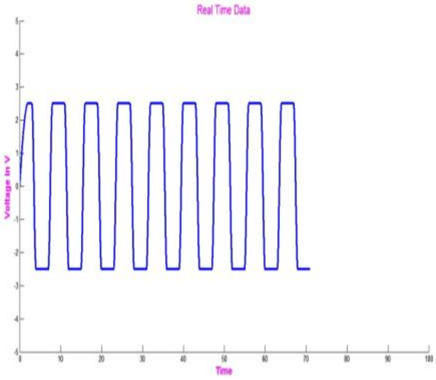

Fig 16.Waveform for Low Load

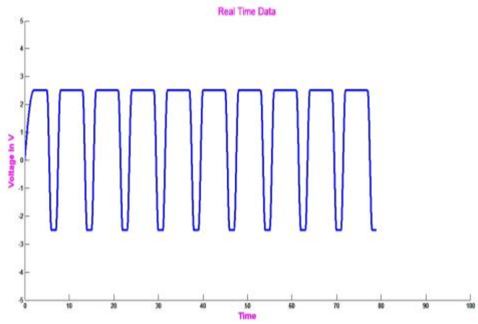

Fig 17.Waveform for Normal Load

IV. HARDWARE RESULTS:

Fig 13 shows normal load operation of CUK converter, The output voltage of the converter is regulated by having control over the duty ratio of the MOSFET . The CUK converter described in this chapter operates in continuous conduction mode with an operating frequency and duty ratio of 20, 50 & 80 %.The design data for this converter is specified in Table-2.

Figure 8a) shows smooth operation of the converter. Hardware results for low, normal and high loads are shown in figures no 12, 13 & 14.

A CUK converter is a basically a buck boost converter but the difference is that the output voltage is either more or less than the input Voltage. Sliding mode operation hardware results are also shown in figure 11.It consists of four energy storing elements two inductors (L) and capacitors (C), a switch and a diode. The capacitor is used to transfer energy and two inductors L1 and L2 are connected to convert input voltage source (Vi) and output voltage source (Vc) into current sources. Here (33) a non-isolated CUK converter is considered operating on step up mode. For the purpose of optimizing the converter dynamics, while ensuring correct operation in any working condition, robust multivariable controllers could be used. (12).The operation is based on capacitive energy transfer who is more efficient than inductive energy transfer. Though the current in the input and output sides are continuous and ripple free, there is very little chance of the ripple current falling to zero. It can be applied where very low input and output noise are essential.

Software Results:

The proposed DC-DC CUK converter was designed and simulated in MATLAB working platform. The modes of operation of proposed converter were analyzed by the operating condition of auxiliary and main circuit. From the eight operating mode circuits, the output currents were calculated. For evaluating the output performance, the proposed CUK converter output was tested with the designed hardware system. From the testing results, the output power of the synchronous converter, the converter efficiency and the efficiency deviation were analyzed. The analyses showed that the proposed CUK converter was better when compared to conventional CUK converter.

In the proposed CUK converter, the conduction losses and switching losses are reduced. The conduction losses are reduced by replacing the diode with MOSFET and the switching losses are reduced by providing an auxiliary circuit. The proposed converter system is operated based on the soft switching techniques. These switching techniques are to provide smooth transition of voltage and current. Fig 15 shows simulation result with load at high. So, the conversion efficiency of the load is improved meeting the dynamic energy requirement is in an efficient way. Fig 16 shows simulation result with load at low. It has a significant advantage over other inverting topologies since they enable low voltage ripple on both the input and the output sides of the converter. Fig 17 shows Waveform for Normal Load operation. Then, the different operation mode of proposed CUK converter is analyzed at different operating conditions of auxiliary and main circuits.

The Table 1 shows the results of output voltage and current produced by the proposed CUK converter design compared with existing CUK converter.

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