Performance Analysis of PWM based Sliding Mode Control

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Abstract – *The dc-dc converters exhibits a non-linear behavior. Thus the linear control approach seems to be non-effective. The Sliding Mode Control (SMC) is a non-linear approach that could yield a better control in these converter. The performance of SMC in different converters is analyzed here. The analysis is done on basic converters buck, boost, Cuk and a modified converter. The analysis is done by simulating the circuit in MATLAB/SIMULINK software.*

Key Words: DC-DC converter, Gain, MATLAB, Renewable Energy, Sliding Mode Control.

1. INTRODUCTION

The world is encountering serious environmental threats these days. As a part of civilisation and industrialisation we could witness over exploitation of non-renewable resources. They are getting depleted day by day and are in verge of extinction. There is an alarming need to somehow replace these energy resources with renewable ones. There are a number of renewable resources which are available around. That includes solar, wind, tidal, hydro, oceanic and geo-thermal. But these sources are having disadvantage of very low efficiency. Required measures need to be taken to overcome this problem. The renewable sources produces a less output. So as to increase the output, dc-dc converters are required. They could step-up the output to required levels. The Internal Combustion (IC) engines have started to get replaced by Electric Vehicles. These are vehicles that use electric motors for propulsion rather than IC engines.

Power electronics is an important part of renewable energy integration [1]. There are many advancements in converter topology to improve the gain. The basic converters are buck, boost, buck-boost and Cuk [2]. The designs are based on output current and voltage ripples. There are modifications in converter circuitries so as to obtain high conversion ratio to be used in renewable energy applications [3].The switching cycle determines the output gain of converters. The switching is controlled by different control methods [4]. There exists different control methods like PI control, fuzzy logic control, one cycle control, sliding mode control, voltage mode and current mode control. SMC is a non-linear control method that can offer good dynamic response, robustness and stability. The system produces chattering problem [5]. Modified approaches are introduced to eliminate chattering. The non-linear system has got stabilization problems [6]. The contraction property and sliding surfaces is the basis to provide incremental stability. The SMC is modified to be based on pulse width modulation [7]. This is used here for all the converters simulation purpose so as to analyse the performance.

2. COMPARISON

The converters are compared by applying PWM based Sliding Mode Control for their switching. The dc-dc converters are those electronic circuitries that can change the voltage and current levels. The change in voltage or current levels implies that either to increase or decrease the voltage or current value given at input. These circuitries are basically made of power switches, input supply, load and passive components like inductor and capacitor. The more number of passive components affects the working efficiency of converter. The converter performance is defined by its gain or voltage conversion ratio.

Depending on the output voltage levels they are basically classified as buck, boost, buck-boost and Cuk converters. The switching is defined by duty cycle which indicates the portion of total time period in which the switch is in conducting mode. The buck converter, as the name suggests, converts the input voltage to a lower output. Similarly, for boost converter, a stepped up output is obtained. The buck-boost is a combination of buck and boost circuits in which the converter can perform both buck and boost function depending on duty cycle (threshold is usually 50%). The Cuk converter is also a combination of buck and boost. Unlike buck-boost, the boost output act as input to buck portion. A modified Cuk converter is also analysed here which is a combination of conventional Cuk and Boost. The boost is followed by Cuk circuit and it is controlled by single switch. The gain is also improved of about ten times that of a conventional Cuk converter.

The operation of converter is defined by two modes that is when switch is on and when it is off. Thus the converters possess two modes of operation. The converter switching is controlled by SMC. It is modified to work based on PWM technique. The conditions to be met are hitting, existing and stability conditions. Additionally, invariance condition need to be evaluated as modification such that system disturbance is also considered.

The SMC law is mathematically defined generally as,

$$S(x) = \sum_{i=1}^{N} C_i x_i$$

where N is system's order and x is state variables. Always C_1 is taken as 1. Here we go for a second order system and thus the SMC equation is given by,

$$S(x) = x_1(t) + C_1 . x_2(t)$$

The sliding function is S=0. The coefficient C_1 value limit is obtained by giving 0 and 1 for control input. By considering the on-off state equations for converter and applying volt-sec balance equations on them, the gain is obtained.

The voltage conversion ratios of converters are given by;

Buck converter: D

Boost converter: $\frac{1}{1-D}$

For both Buck-boost and Cuk converter: $\frac{D}{1-D}$

Modified Cuk converter: $\frac{D}{(1-D)^2}$

3. SIMULATION

The PWM based SMC is applied to buck, boost, Cuk and modified Cuk converters. The evaluation is done basically on buck converter then generalizing it to other converters. The effect is evaluated by MATLAB/SIMULINK software. The minimum disturbance amplitude required is 0.02 for buck converter and 0.04 for other converters. The ripple content and voltage stresses are also evaluated. The simulation diagrams and waveforms are shown in following figures. The SMC simulation block is shown in Fig-5.

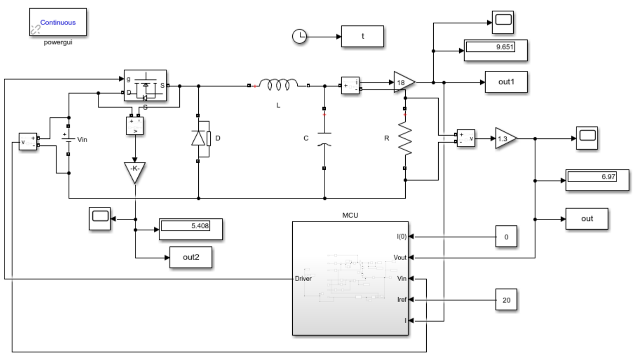


Fig -1: Buck converter

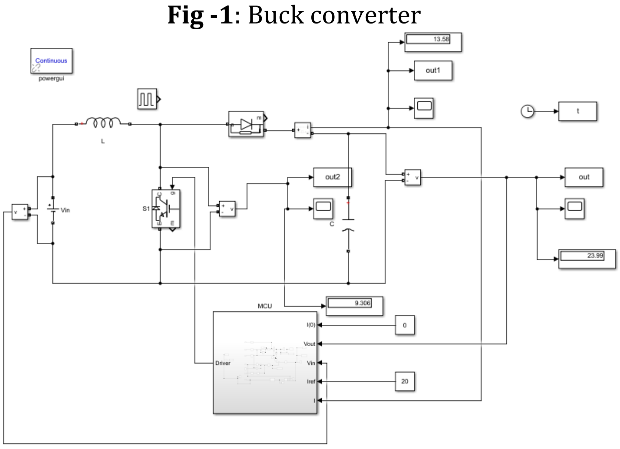


Fig -2: Boost converter

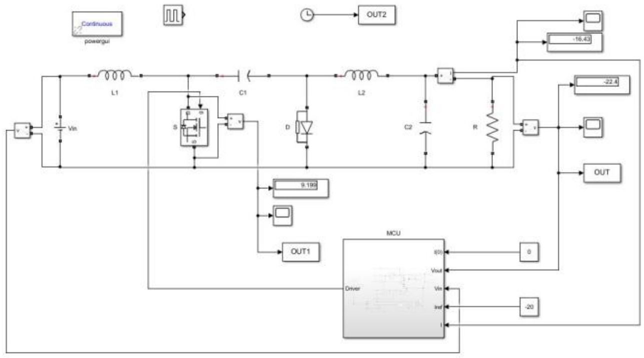


Fig -3: Cuk converter

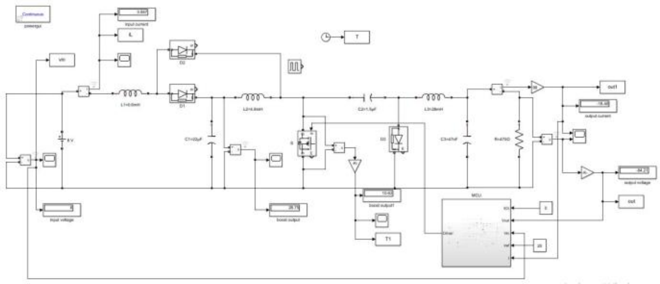


Fig -4: Modified Cuk converter

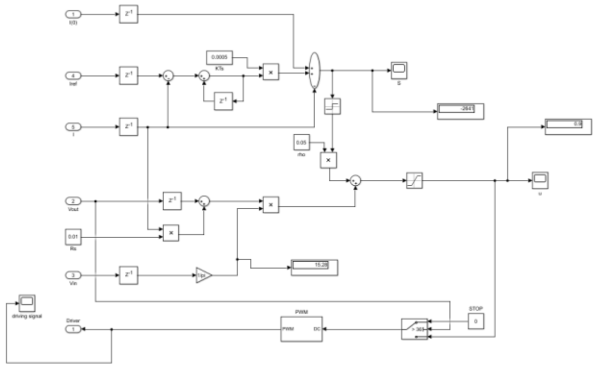
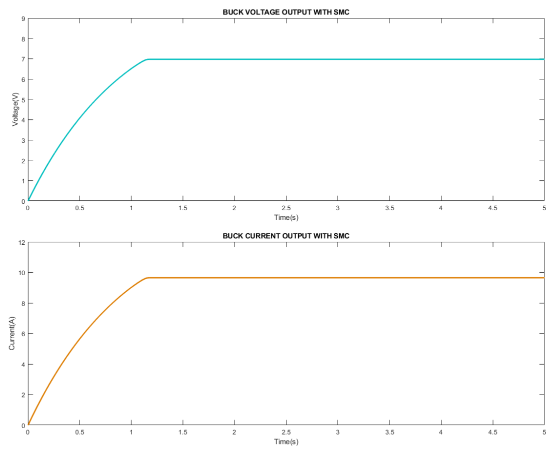


Fig -5: SMC control block



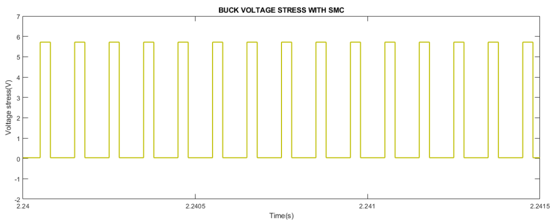


Fig -6: Waveforms (Buck)

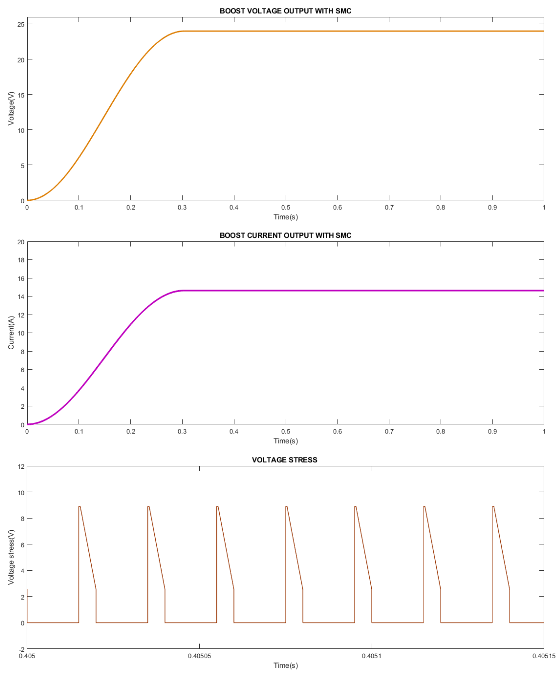


Fig -7: Waveforms (Boost)

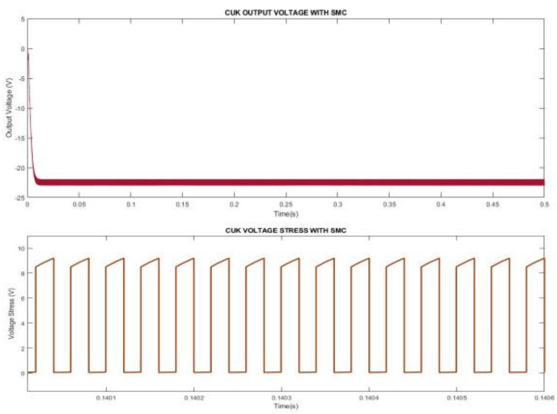
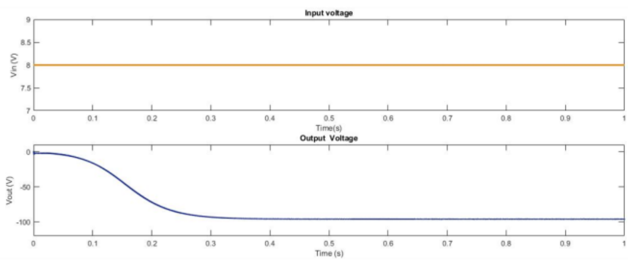


Fig -8: Waveforms (Cuk)



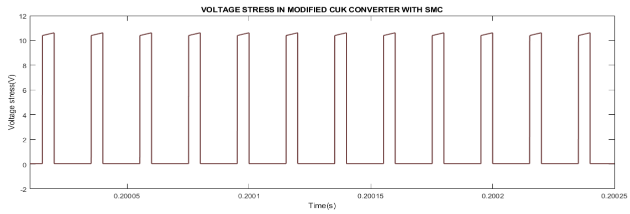


Fig -9: Waveforms (Modified Cuk)

The simulation is carried out and response is analyzed. The results obtained are tabulated as in Table-1.

Table -1: Comparison of converters

FEATURES	BUCK	BOOST	CUK	MODIFIED CUK
OUTPUT	6.5V, 9A	24V, 14A	-23V, -16A	-85V, -18A
GAIN	D	$\frac{1}{1-D}$	$\frac{D}{1-D}$	$\frac{D}{(1-D)^2}$
VOLTAGE RIPPLE (%)	8	10.5	10	9.1
CURRENT RIPPLE (%)	0.78	1.2	1.21	1
VOLTAGE STRESS	5.4	9.3	9.1	10
MIN. ρ	0.02	0.04	0.04	0.04

A maximum of 9 A is obtained from buck converter even though reference of 20 A is given. The converter cannot produce a higher current than 9 A without changing input voltage. The boost and Cuk topologies shows an increased current output with the use of SMC. The modified topology could produce an output near to reference. There is slight decrease in voltage output when sliding mode is applied. The converters are exhibiting a less output current ripple in SMC. The buck converter losses its sliding mode operation when ρ reduce below 0.02 and for boost, Cuk, modified Cuk converters it is 0.04. In all the 4 converters there is a burst in energy such that the charging time can be minimized. The charging time is reduced to a great extent. It can be seen that the SMC has improved the system performance to great extend which shows the advantage of SMC. The proposed control scheme can be adopted in burst energy mode applications. The huge inrush of energy can be stored using ESS than Lithium-ion battery.

4. CONCLUSIONS

The work deals with performance analysis of converters with application of sliding mode control scheme. Here, a modified technique is used where the SMC is based on PWM technique. The modification make use of invariance condition. The control scheme is applied to buck, boost, Cuk and a modified Cuk converter. The performance analysis is done with help of simulation. The waveforms are observed and studied and formed conclusions. The SMC is found to be a best method to control current by maintaining a constant current profile and producing enough voltage output near to required value. It is ideal to be used in renewable energy applications as it is reliable and robust. It is non-linear control technique which has got wide power electronic applications. The sliding mode is burst energy mode in which there is a huge production of energy. The modifications in SMC can open new possible applications.

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