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Comparative Study of Reduced Ripple DC-DC Converters for Various Applications

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Abstract— High-efficiency converters play an important role in the field of renewable energy, switch mode dc regulators, electric vehicles. Compared to linear voltage regulation switching conversion is more power efficient which dissipates unwanted power as heat. Switched mode converter due to its high efficiency reduces the heat sinking needed and increases battery endurance of portable equipment. Basically, DC-DC converters are designed to move unidirectionally, from input to output whereas the switching regulator topologies can be designed to move bidirectionally. A bi-directional conversion is useful in regenerative braking of vehicles where power is supplied from wheels during braking. Selection of an appropriate converter topology is an important part of designing the systems as the converter plays a major role in determining the overall performance of the system. Based on an area of application, a suitable converter can be proposed. This paper presents different topologies of DC-DC converters used in various applications with reduced ripple by MATLAB SIMULINK software.

Keywords— MOSFET, modular multilevel, renewable energy, ripple, switching elements-inductor, diode, capacitor, soft switching, sepic converter.

I. INTRODUCTION

The recent advancement of growth of MOSFETs has made possible to improve the performance of power electronic devices. MOSFET switch consumes less DC power possess high impedance and can be operated at a higher frequency with low voltage stress [5], [6]. DC-DC converters are developed to maximize the energy harvest for photovoltaic systems and wind turbines are termed as power optimizers [6]. DC-DC converters are widely used in industrial applications such as dc motor drives, office appliances and communication equipment [7]. DC distribution system is an alternative to ac distribution systems due to its high-power quality and reliable performance. In electric car drive systems, the amplitude of the voltage of the vehicle battery terminals tends to change under different loads [9]. The main advantage of employing the advanced converters is to reduce the input current ripple without adding a large input filter [8]. To convert the dc bus voltage to different voltage levels for the load devices DC-DC converters are essential. DC-DC converters have high efficiency, high power density, high voltage gain and reduced ripple voltage [6], [7], [8]. In order to reduce the volume of power supplies, it is desired to increase the switching frequency. However, at high switching frequencies, switching losses and electromagnetic interferences increase [1]. To avoid these disadvantages soft-switching techniques are employed.

DC-DC converters are divided into two types based on how they transfer the energy. The energy can go from the input to the magnetic through the load or the energy can be stored in the magnetic to be released later to the load [5]. Based on circuit topology switched-mode power supplies classified as isolated converters and non-isolated converters.

Non-isolated converters are simplest, with the three basic types using a single inductor for energy storage [3]. In the output voltage relation D is the duty cycle of the converter, and can vary from 0 to 1. All isolated topologies include a transformer, and thus can produce an output of higher or lower voltage than the input by adjusting the turns ratio [5]. For some topologies, multiple windings can be placed on the transformer to produce multiple output voltage.

The rest of the paper is organized as follows: Section II describes various converter topologies, their advantages, limitations, and applications, Section III presents the design features of proposed converters with Simulink models, Section IV contains Simulation results and finally, conclusions are drawn on Section V.

II. TOPOLOGIES OF DC-DC CONVERTERS

A. Buck-Boost Converter

Buck-boost converter consists of a switching element MOSFET, inductor L, diode D, and a capacitor C. The difference between a buck-boost and a boost converter is the arrangement of the switching element placed before the inductor, as shown Figure 1.

The buck-boost topology can produce an output voltage that is equal to, less than, or greater than the input voltage [6]. For portable applications which require a wide range of output levels, buck-boost topology is widely used and an attractive choice when a large current is supplied. When the duty cycle is 0.5 the output voltage equals the input voltage. When the duty cycle is less than 0.5, the buck-boost converter operates in buck mode, causing the output voltage to be lower than the input voltage [6], [7], [8]. To operate the buck-boost converter in boost mode and to obtain the output voltage higher than the input voltage, the duty cycle must be greater than 0.5. The relation between buck, boost, and buck-boost dc converters are shown in Figure 2 [7].

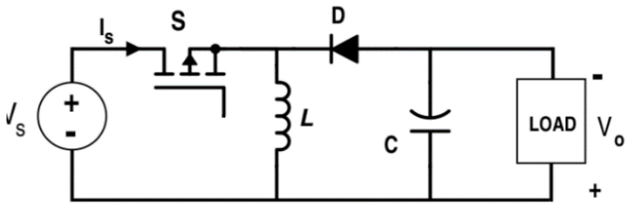

Figure 1. DC-DC Buck-Boost converter

$$V_0 = \frac{-DVs}{(1-D)} \quad (1)$$

$$D = \frac{TON}{T} \quad (2)$$

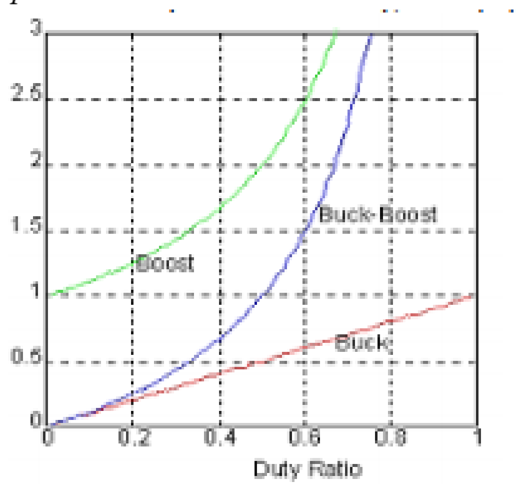

Figure 2. Comparison of the duty ratio for Buck, Boost and DC-DC Buck-Boost converter

Advantages of Buck-Boost converter:

i. Step-up and step-down of voltage is possible with the minimum component count.
ii. Both buck and boost operations are achieved simultaneously

Limitations of Buck-Boost converter:

i. Input current and charging current of the output capacitor is discontinuous and resulting in larger filter size and more EMI issues.
ii. The output is inverted which introduces complexity in the sensing and feedback circuit

Applications of Buck-Boost converter:

i. It is used in the self-regulating power supplies.
ii. Power amplifier applications.

B. Sepic Converter

The single-ended primary inductance converter (SEPIC) can either boost or buck the voltage magnitude. In this, there is no polarity inversion and wide input voltage control is possible. Basically, SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another [7]. To control the amount of energy exchanged a transistor such as a MOSFET is used.

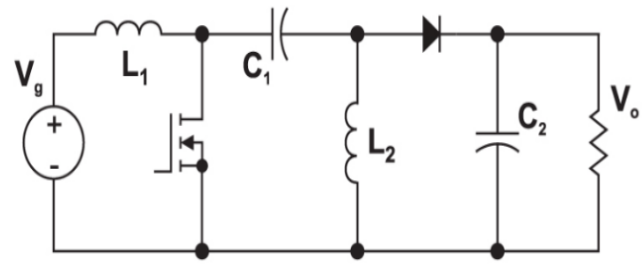

Figure 3. Sepic converter

The SEPIC converter output voltage is

$$V_0 = \frac{DVs}{(1-D)} \quad (3)$$

Advantages of Sepic converter:

i. Step-up and step-down of voltage and output voltage polarity is same as the input voltage.
ii. Reduced ripple at the output.

Limitations of Sepic converter:

i. It transfers all its energy via the series capacitor, a capacitor with high capacitance and current handling capability is required.
ii. Its control is difficult so making it only suitable for very slow varying applications.

Applications of Sepic converter:

i. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output.
ii. LED Lighting applications.
iii. NiMH chargers.

C. Single switch soft switched isolated Converter

Soft-switching techniques fall into two categories of constant switching frequency and variable frequency converters. These topologies exhibit reduced switching losses and can be operated at high switching frequencies [3]. Constant frequency soft-switching converters usually have higher component count. This usually requires additional switches which increase the converter cost and losses. This converter not only benefits from the merit of smaller transformer like the forward converter but also does not require the bulky output inductor, topology is fully soft switched and requires only one switch and a diode [1].

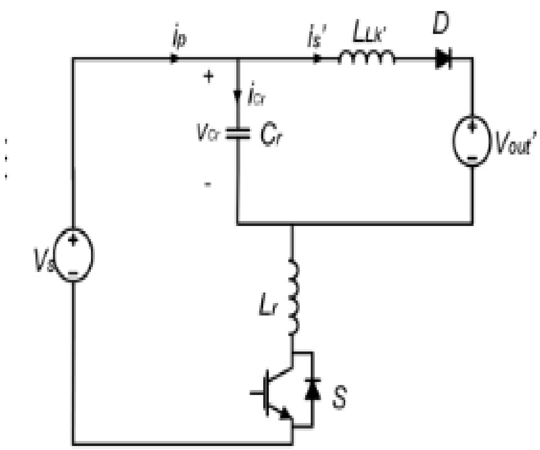

Figure 4. Single switch soft switched converter

Advantages of Single switch soft switched converter:

i. It has only one switch
ii. All semiconductor devices are soft switched

Limitations of Single switch soft switched converter:

i. Design of inductor and capacitor is difficult
ii. Control complexity is dependent on filter parameters

Applications of Single switch soft switched converter:

i. Low-cost high-frequency power supplies.
ii. Low voltage portable applications

D. Modular multilevel dc-dc Converter

It is switched capacitor DC-DC converter. To obtain a gain of K, the converter has K switching techniques. Zero Current Switching (ZCS) is used to minimize the switching losses [2], [4]. Multiphase low voltage DC-DC converters without galvanic isolation and with coupled or uncoupled inductors are proposed due to their high-power density. Multilevel architectures like the Flying Capacitor Multilevel DC/DC-Converter offer similar benefits and it will be shown that they need a smaller inductor size and provide better fault behavior for short-on-failure switches.

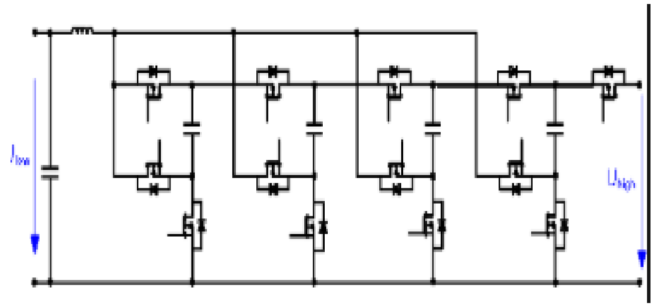

Figure 5. Modular multilevel capacitor clamped converter

Advantages of the modular multilevel dc-dc converter:

i. Low voltage stress
ii. High power capability

Limitations of the modular multilevel dc-dc converter:

i. Circuit complexity increases with the number of levels.
ii. Unbalanced stored energy in supercapacitors.

Applications of the modular multilevel dc-dc converter:

i. Used in HVDC system
ii. As a traction converter in a hybrid vehicle achieving charge balance in batteries.

III. DESIGN CONSIDERATIONS

A. Buck-Boost Converter

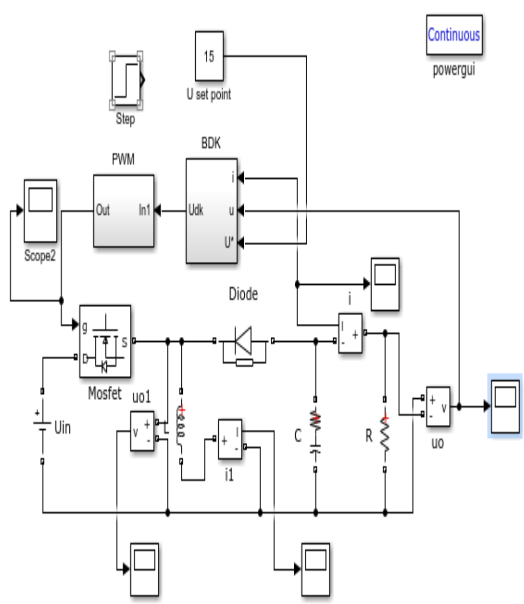

Figure 6. Simulink model of buck-boost converter

Table.1 Buck-Boost design considerations

SNo	Design Parameter	Chosen value
1	Source voltage	24V
2	MOSFET as switch	Ron=1µohm, diode internal Rd=1µohm
3	Inductance	L=100 µH
4	Capacitance	C=697 µF
5	Load Resistance	R=2.25□
6	Pulse generator	Amplitude=1V, frequency=100KHz, pulse width=50% of T

B. Sepic Converter

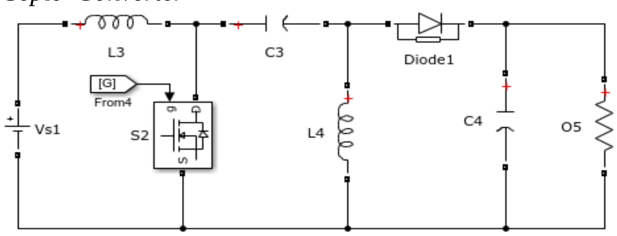

Figure 7. Simulink model of sepic converter

Table.2 Sepic converter design considerations

SNo	Design Parameter	Chosen value
1	Source voltage	20V
2	MOSFET as switch	Ron=0.1-ohm, diode internal Rd=0.01ohm
3	Series inductance	L=200 µH
4	Series Capacitance	C=200 µF
5	Shunt inductance	L=200 µH
6	Filter capacitance	C=220 µF
7	Load resistance	R=20 ohm
8	Pulse generator	Amplitude=1V, Frequency=25KHz, pulse width=40% of T

C. Single switch soft switched isolated Converter

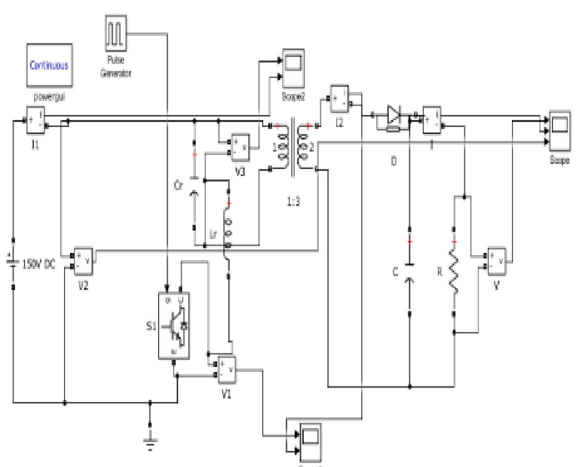

Figure 8. Simulink model of sepic converter

Table.3 Single switch soft switched converter design considerations

SNo	Design Parameter	Chosen value
1	Source voltage	150V
2	IGBT as a single switch	Ron=1m ohm
3	Isolation transformer primary inductance	L=0.1 mH
4	Isolation transformer primary Capacitance	C=0.08 µF
5	Transformer (3 winding linear transformers)	Nominal power 60kva,60 KHz, Rm=Lm=500ohm
6	Filter capacitance	C=100 µF
7	Load resistance	R=20 □
8	Pulse generator	Amplitude=1V, Frequency=60KHz, pulse width=20% of T

D. Modular multilevel dc-dc Converter

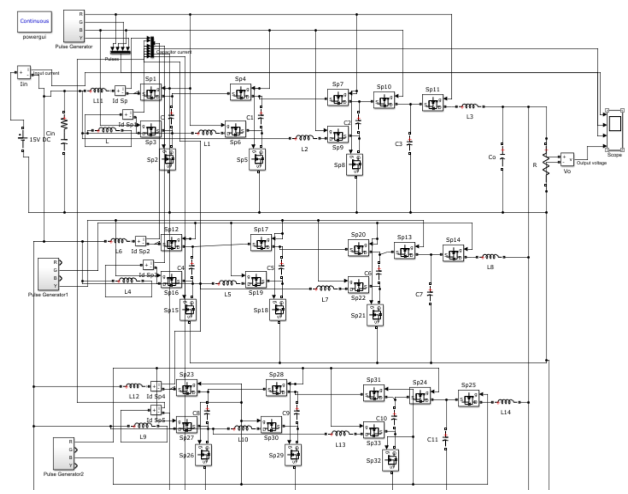

Figure 9. Simulink model of a modular multilevel dc-dc converter.

Each module is designed to consist of the following*:*

Table.4 Modular multilevel dc-dc converter design considerations

SNo	Design Parameter	Chosen value
1	Source voltage	15V
2	11 switches with MOSFET as a switch	Ron=0.35m ohm, diode internal Rd=0.01ohm
3	Series inductance	L=216 µH
4	Shunt Capacitance	C=47 µF
5	Filter inductance	L=1008µH
6	Filter capacitance	C=147 µF
7	Load resistance	R=17.2 ohm
8	4 Pulse generators	Amplitude=1V, Time=14µsec, pulse width=50% of T

IV. SIMULATION RESULTS

The simulated output of a normal buck converter is shown in Figure 10. With given source voltage of 24V, the reduced ripple output voltage is approximately 12V for a duty cycle of 0.5.

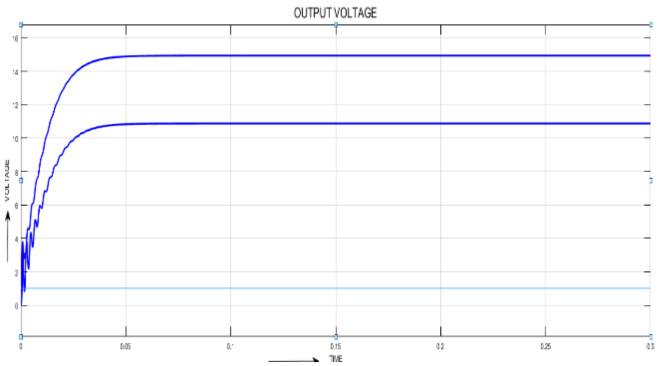

Figure 10. simulated output voltage of the normal buck converter

For a source voltage of 20V, the sepic converter output voltage of 18V is shown in Figure 11. The output is reduced ripple and with suitable modifications in design parameters, it can be used in NiMH chargers and lighting applications.

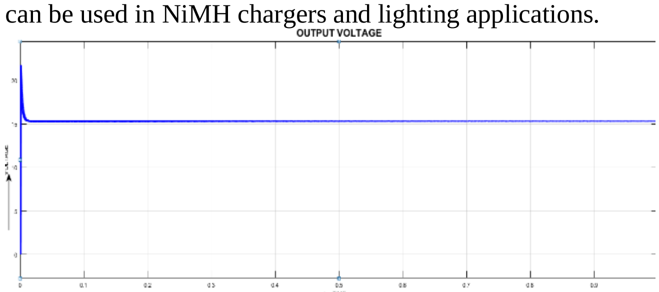

Figure 11. The simulated output voltage of the sepic converter

As a single switch, the soft-switched converter does not require output inductor the reduced ripple output is shown in Figure 12. Like other converters the inductor use is limited and the transformer core does not store energy so this is an appropriate choice for implementation of low-cost high-frequency power supplies.

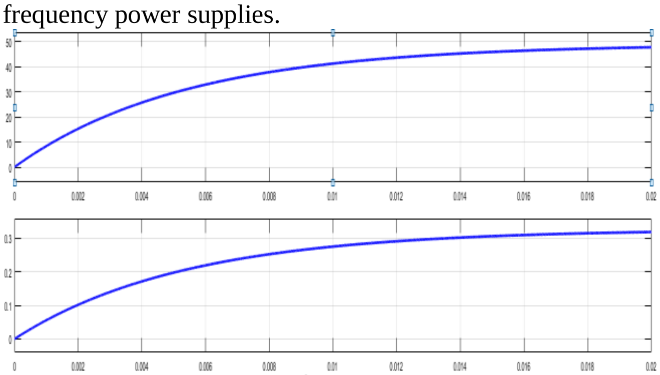

Figure 12. The simulated output of a single switch soft switched dc-dc converter.

The stabilized output voltage, input current, and capacitor current with varied gating pulses are shown in Figure 14. With modular converter low-frequency ripple due to LC current of supercapacitor can be limited. This feature enables the use of this converter as a traction converter in a hybrid vehicle for achieving charge balance in batteries.

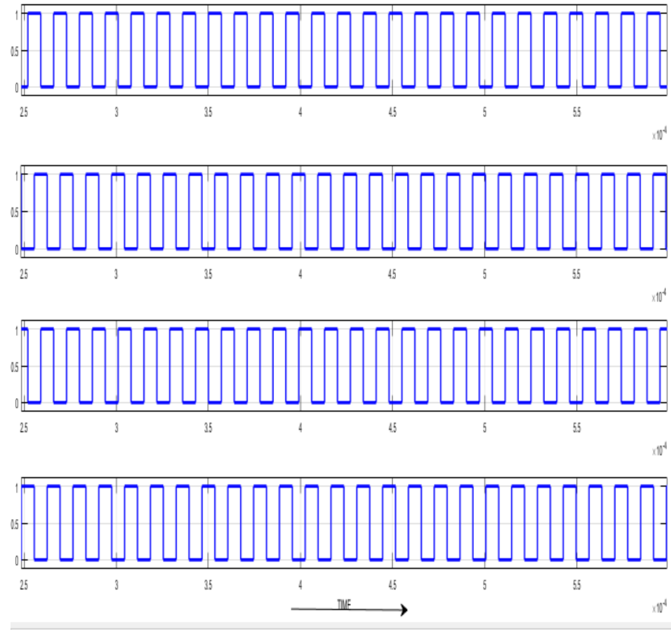

Figure 13. Gating sequence for modular multilevel dc-dc converter

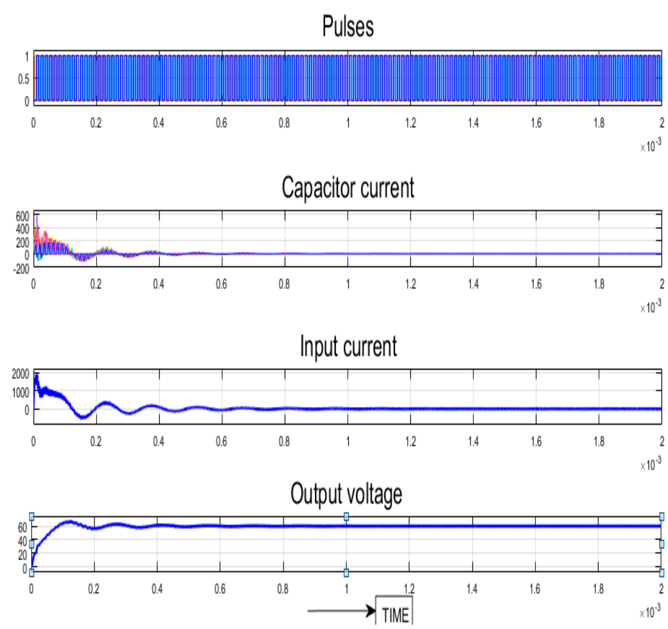

Figure 14. The simulated output of the modular multilevel dc-dc converter

V. CONCLUSION

The DC-DC converters study with various topologies contributes to the use of renewable energy in various applications especially in portable or stand-alone applications. A review on DC-DC converters shows that they can be used to produce a more efficient conversion of power. This paper also presents that the switching technique is the main element of a DC converter. Therefore, more studies on the development of new topologies for DC converters, including new switching techniques with reduced ripple are needed to create a higher efficiency and improve the existing switching technique.

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