Non inverting Buck and Boost converter: Analysis and comparative study

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Abstract—**There are many types of DC-DC converters that can be used to increase and decrease the output voltage; some of them use more than one reactive element like SIPIC, ZETA or CUK converters, the thing which increases the cost of these converters. The main idea of this article is to highlight the performance of a non-inverting buck and boost converter. In the light of this vision, this work proposes a comparison between five converters: Buck-Boost, non inverting buck-boost, Cuk, SEPIC and ZETA converters. To this end, the operating characteristics and performance of these converters are analyzed and compared.**

Keywords—Non-isolated DC–DC converters, buck and boost power converters, continuous conduction mode (CCM).

I. INTRODUCTION

In recent decades, non-isolated DC-DC power converters have become one of the most used devices in applications such as maximum power point tracker [1], Brushless DC motors [2], battery charging [3]…

The buck, boost and buck-boost are the basic converter topologies. The Buck and boost converters are widely used because of their simplicity and efficiency; the buck converter works as a step down converter whereas boost converter is used to step up the output voltage; it doesn't have over current protection [2]. The buck-boost converter can be used either to increase or decrease the voltage. But the problem is that the output voltage has opposite polarity compared to the source polarity which limits its use [2]. The cuk converter has high efficiency compared to buck-boost converter [7], but it also suffers from the problem of polarity reversal on the output voltage, and it needs additional components [2]. SEPIC is single-ended primary inductance converter, it's also an up/down converter, with no reversal of the polarity [2]. Both Cuk and Sepic converters need some additional circuits to limit current and for overload protection [2]. These limitations could be avoided by the use of zeta converter [2].

In [3], a new topology was proposed where buck, boost, and buck-boost are combined for a bidirectional multiple sources DC/DC converter. In [4], the authors discuss a bidirectional topology, which is used as a maximum power point tracker for PV stand-alone applications. In [5] a buck or boost converter tracking power converter was presented, 4 power switches were used to operate either in buck or boost modes.

In this work, the basic idea is to analyze the performance of an up/down converter, based on a non-inverting buck-boost converter, which is composed by 2 power switches, and it can operate in both buck or boost mode.

This paper is organized into 5 sections. Section II gives a brief description of the five DC-DC power converters used in this comparison and the theoretical calculation of efficiency. In section III, we analyze the simulation results. Finally, a comparison based on simulation results is addressed in section IV followed by the conclusion in Section V.

II. EXISTING STRUCTURE

A. Buck converter

Fig. 1 shows the circuit scheme of a buck converter [6], it consists of four components: a power MOSFET used as a controllable switch Q, a diode D, an inductor L, and a filter capacitor C [6]. For a lossless converter, the DC Voltage Transfer Function (Mv dc) for CCM depending on the duty ratio D, is given by [6]:

$$Mv\ dc = \frac{\text{Vout}}{\text{Vin}} = \frac{\text{Iin}}{\text{Iout}} = \text{D} \qquad (1)$$

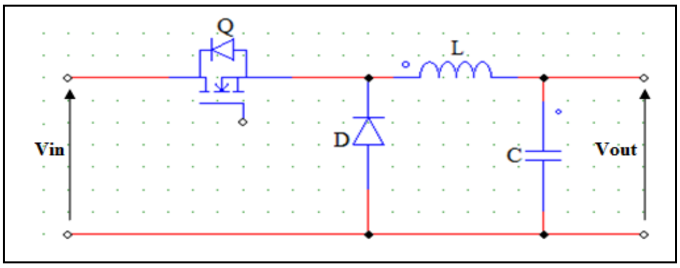

Figure 1. Circuit scheme of a buck converter.

B. Boost converter

The circuit of the PWM boost dc–dc converter [6] is shown in Fig 2. Its output voltage Vout is always higher than the input voltage Vin for steady-state operation [6]. It 'boosts' the voltage to a higher level [6]. The converter consists of an inductor L, a power MOSFET Q, a diode D, and a filter capacitor C. For a

This work was supported by the institute of research on solar energy and new energies Morocco (IRESEN)- project VERES

lossless converter, the DC Voltage Transfer Function (Mv dc) for CCM depending on the duty ratio D, is given by [6]

$$Mv\ dc = \frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{\mathrm{Iin}}{\mathrm{Iout}} = \frac{1}{1-\mathrm{D}} \qquad (2)$$

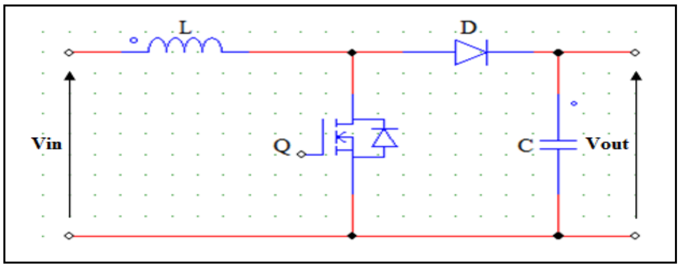

Figure 2. Circuit scheme of boost converter.

C. Buck-boost converter

The circuit of the PWM buck-boost dc–dc converter [6] is shown in Fig. 3, it consists of a power MOSFET used as a controllable switch, an inductor L, a diode, and a filter capacitor C [6]. For a lossless converter, the DC Voltage Transfer Function (Mv dc) for CCM depending on the duty ratio D, is given by [6]

$$Mv\ dc = \frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{\mathrm{Iin}}{\mathrm{Iout}} = -\frac{\mathrm{D}}{1-\mathrm{D}} \qquad (3)$$

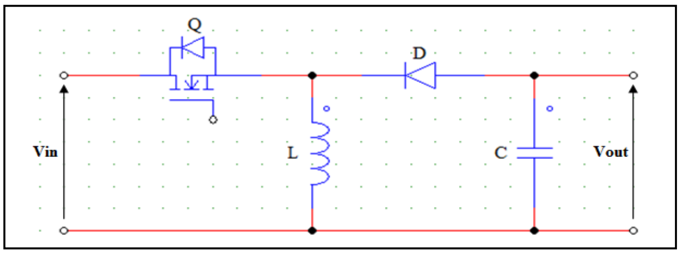

Figure 3. Circuit scheme of buck-boost converter.

D. Cuk converter

In this design (Fig. 4), the single switch Q alternately grounds the opposite ends of the capacitor, effectively switching it from the input to the output circuits [7]. C1 is charged by the input current to a positive voltage, with Q is off. With Q is on (during the charging interval of L1) [7]. Current flows from the grounded load to discharge C1 through L2, causing a negative voltage drop across the load, hence a negative output voltage [7].

The relations between output and input currents and voltages are given by [8]

$$\frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{\mathrm{Iin}}{\mathrm{Iout}} = -\frac{\mathrm{D}}{1-\mathrm{D}} \qquad (4)$$

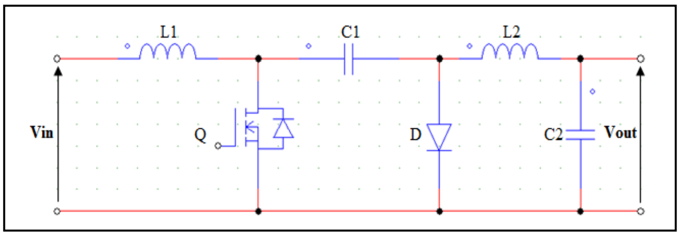

Figure 4. Circuit scheme of Cuk converter.

E. Sepic converter

Fig. 5 shows a simple circuit diagram of a SEPIC converter, consisting of an AC coupling capacitor, C1; an output capacitor, C2; coupled inductors L1 and L2; a power MOSFET, Q; and a diode, D [9].

Assuming 100% efficiency, the duty cycle, D, for a SEPIC converter operating in CCM is given by [9]

$$\mathrm{D} = \frac{\mathrm{Vout+Vd}}{\mathrm{Vin+Vout+Vd}} \qquad (5)$$

Where Vd is the forward voltage of the Schottky diode. If Vd value is zero, this can be rewritten as [2] [9]

$$\frac{Vout}{Vin} = \frac{Iin}{Iout} = \frac{D}{1-D} \qquad (6)$$

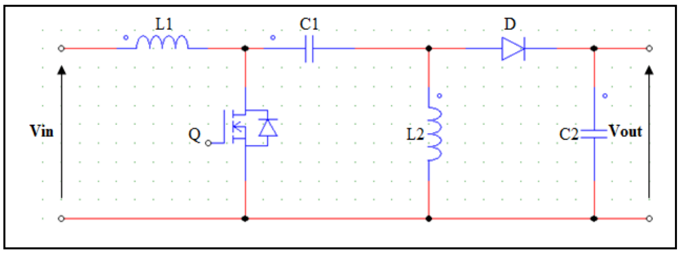

Figure 5. Sepic converter

F. Zeta converter

Fig. 6 shows a simple circuit diagram of a ZETA converter, consisting of an AC coupling capacitor, C1; an output capacitor, C2; coupled inductors L1 and L12; a power MOSFET, Q and a diode, D [10].

Assuming 100% efficiency, the duty cycle, D, for a ZETA converter operating in CCM is given by [10]

$$D = \frac{Vout}{Vin+Vout} \qquad (7)$$

This can be rewritten as [10]

$$\frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{\mathrm{Iin}}{\mathrm{Iout}} = \frac{\mathrm{D}}{1-\mathrm{D}} \qquad (8)$$

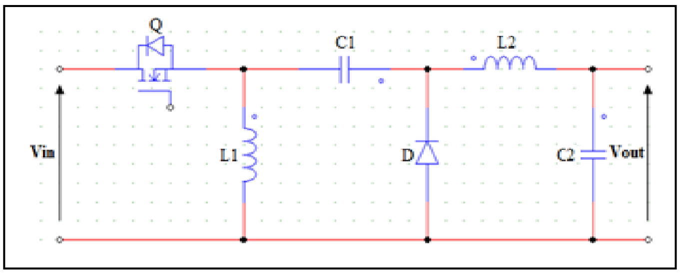

Figure 6. Circuit scheme of Zeta converter.

G. non-inverting buck-boost converter

This structure gives the possibility to have a high efficiency, and a non-inverting up/down converter, with only one inductive element. Fig. 7 shows the circuit diagram of a non-inverting buck and boost converter, this structure is composed of one inductance L, two diodes D1 and D2, two power MOSFET Q1 with a freewheel diode, Q2 without freewheel diode, and an output capacitance Cout.

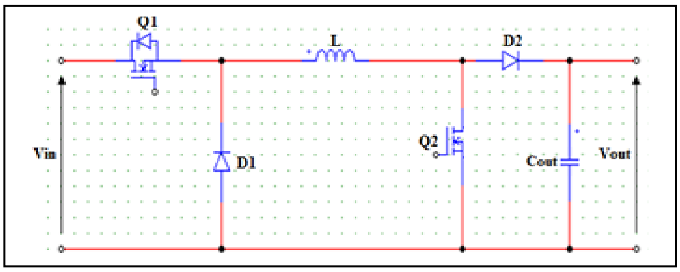

Figure 7. Circuit diagram of non-inverting buck and boost converter.

Two operating modes are possible; the equivalent circuits on these functioning modes are shown on Fig. 8 and Fig. 9.

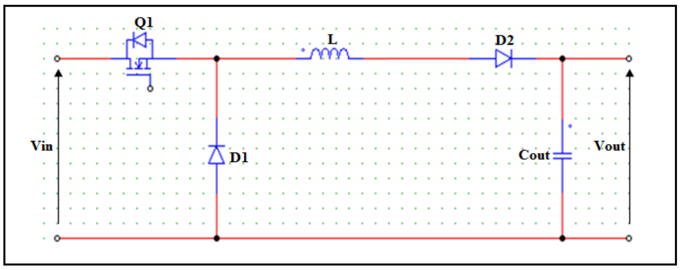

Figure 8. Buck operation mode

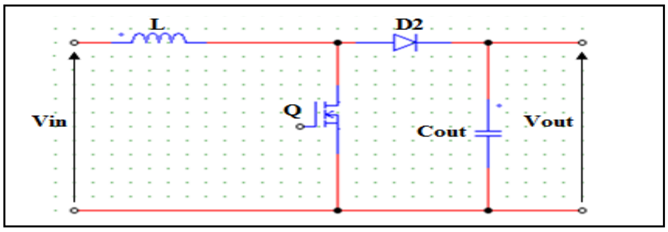

Figure 9. Boost operation mode

The buck operating mode (Fig. 8) is activated when power MOSFET Q2 is turned off, and Q1 is commanded with a pulse width modulated signal. As it can be seen from Fig. 8, the framed zone corresponds to a buck converter, without using diode D2, but for solar battery charging applications, it can be useful as a blocking diode that is necessary to prevent the reverse current flows [11][12].

The Boost operating mode (Fig. 9) is activated when power Q1 is turned on and Q1 is commanded with a pulse width modulated signal. Diode D1 is equivalent to an open switch. Therefore the circuit is equivalent to a boost converter as it can be seen on fig. 9. Concerning solar battery charging applications, no extra blocking diode is necessary when the boost topology is used [11].

III. SIMULATION RESULTS

The operations of the converters described above are tested by simulation using PowerSim software; the generated duty cycle is ensured by an open loop control block. The simulation parameters are depicted in Table 1.

TABLE I. SIMULATION PARAMETERS

Parameter	value
Vin (volts)	20
Rout (ohms)	10
Switching frequency (KHz)	40
Diode forward voltage Vd (volts)	0.6
Inductance (mH)	1
Inductance resistor (Ω)	0.01
Capacitor (uF)	100
Capacitance resistor (Ω)	0.01

Fig. 10 and Fig. 11 show the evolution of output and input voltages, for buck and boost functioning modes respectively.

These topologies are tested when the functioning mode is changed. On t=0.02s the functioning mode is changed from buck to boost operating mode, and on t=0.04s the functioning mode is returned to buck operating mode. The shape of output voltages are given on Fig. 12.

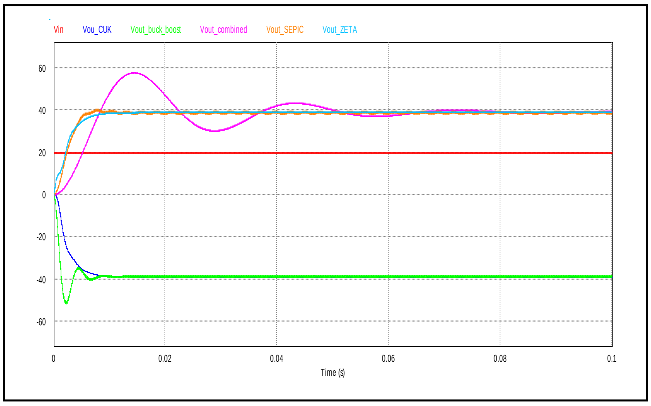

Figure 10. Buck functioning

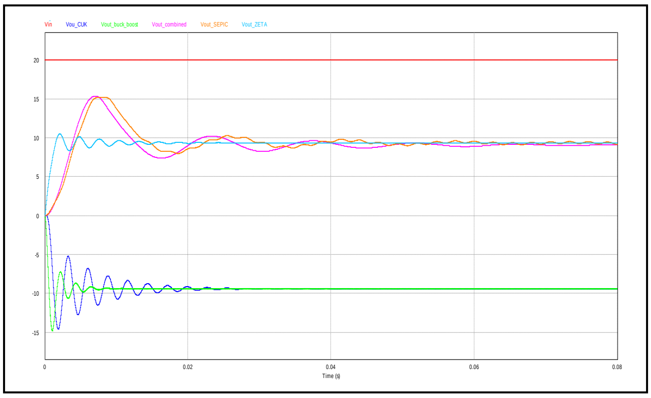

Figure 11. Boost functioning

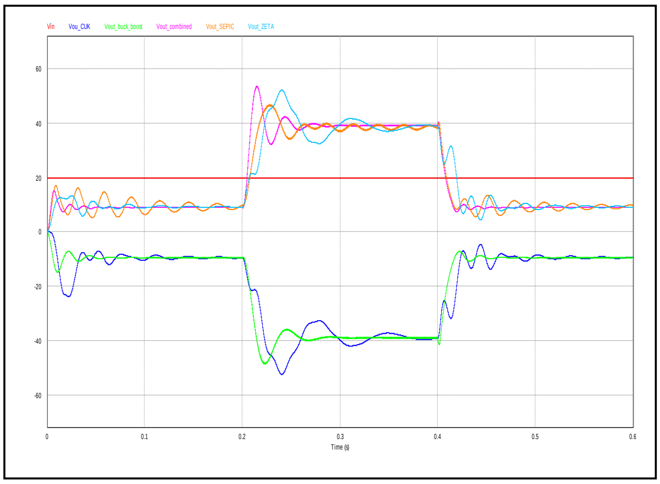

Figure 12. Input and output voltages evolution, the operating mode is changed from buck to boost to buck.

Fig. 13, Fig. 14 and Fig. 15 shows the simulation results for load variations on buck operating mode, load is varied from 30Ω→20Ω→10Ω→20Ω→30Ω.

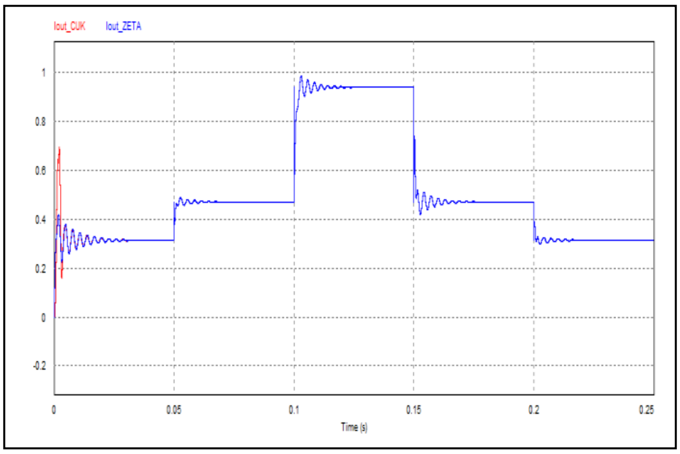

Figure 13. Output current curves for buck operating mode; load is varied from 30Ω→20Ω→10Ω→20Ω→30Ω, for Cuk and Zeta converters.

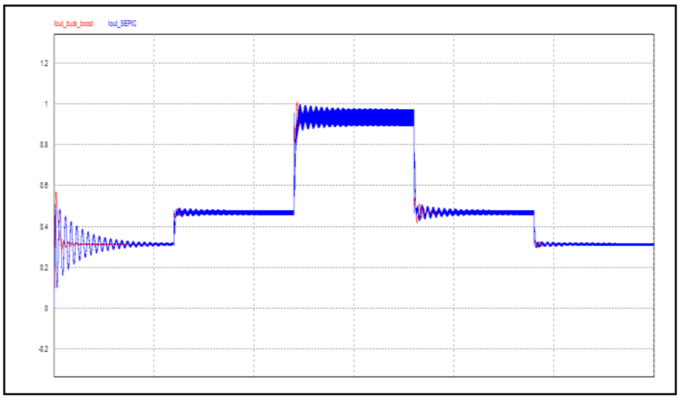

Figure 14. Output current curves for buck operating mode; load is varied from 30Ω→20Ω→10Ω→20Ω→30Ω, for Buck_Boost and SEPIC converters.

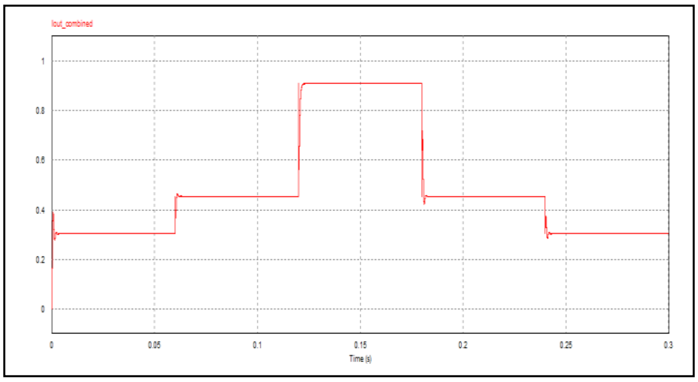

Figure 15. Current curve on buck operating mode; load is varied from 30Ω→20Ω→10Ω→20Ω→30Ω, for non-inverting buck-boost converter.

Fig. 16, Fig. 17 and Fig. 18 shows the simulation results for duty cycle variations on buck operating mode.

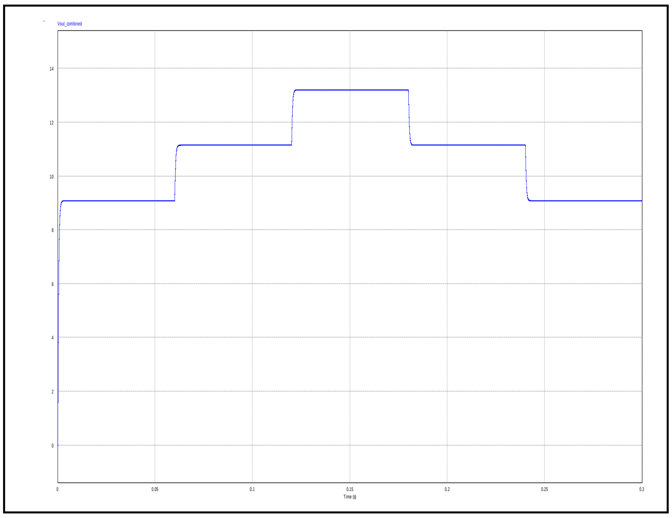

Figure 16. Output voltage curves for different duty cycle, of non-inverting buck-boost converter operating in buck mode.

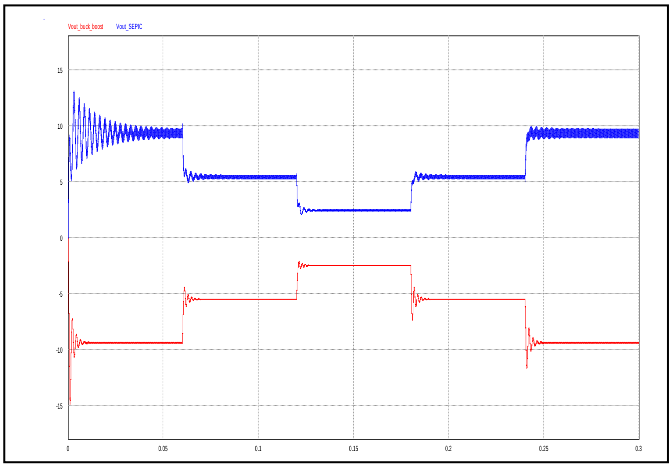

Figure 17. Output voltage curves for different duty cycle, of SEPIC and Buck-Boost converters operating in buck mode.

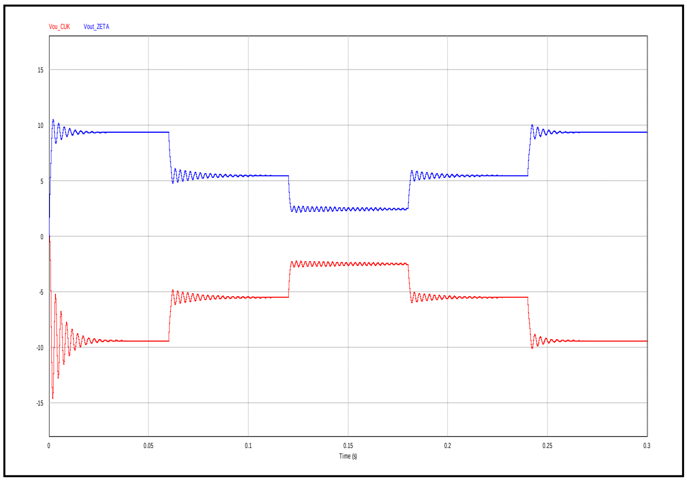

Figure 18. Output voltage curves for different duty cycle, of Cuk and Zeta converters operating in buck mode.

IV. COMPARATIVE STUDY

From simulation results depicted in the previous section, it can be seen that the non-inverting buck-boost converter presents a very small time response with no oscillations on steady state, compared to other topologies. An efficiency-based comparison, using PSIM software, is shown on table 2. The efficiency here is calculated as the ratio between the output power and the input power. Lots of parameters affect the converter efficiency, such as the internal resistance of reactive components, the polarity inversion…

Table 3 illustrates a comparison between all studied converters trough criteria such as cost and simplicity.

The non-inverting buck-boost converter presents high efficiency for the two operating modes as it is depicted from table 2. It can also be seen from table 3 that buck-boost converter is low cost and presents a simple structure compared to other converters. Cuk, SEPIC and Zeta converters need an additional coil, which increases their cost. In the non-inverting buck-boost two cheaper components are added. Hence the cost remains less expensive than Cuk, SEPIC and ZETA.

TABLE II. EFFICIENCY OF BUCK-BOOST AND PROPOSED CONVERTER BASED ON SIMULATION RESULTS, FOR THE TWO OPERATING MODES.

Operating mode / **Efficiency (%)**	**Buck**	**Boost**
non-inverting buck-boost converter	87	98
Buck-Boost	89	95
Cuk	92	97
SEPIC	93	96
Zeta	96	96

TABLE III. COMPARISON BASED ON THE COST AND SIMPLICITY OF THE STUDIED CONVERTER.

Converter	**Simplicity**	**Cost**
Buck-boost	+++	+
non-inverting buck-boost converter	++	++
Cuk	+	+++
SEPIC	+	+++
ZETA	+	+++

Fig. 19 and Fig. 20 shows the shape of output power and efficiency of studied converters, when the input voltage is changed for buck functioning mode.

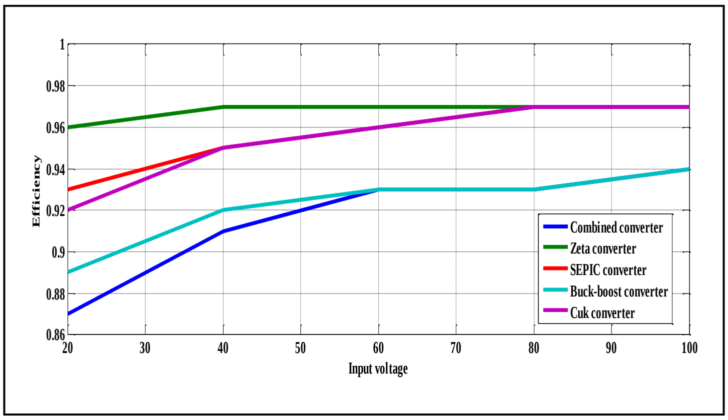

Figure 19. Efficiency Vs input voltage for buck functioning mode.

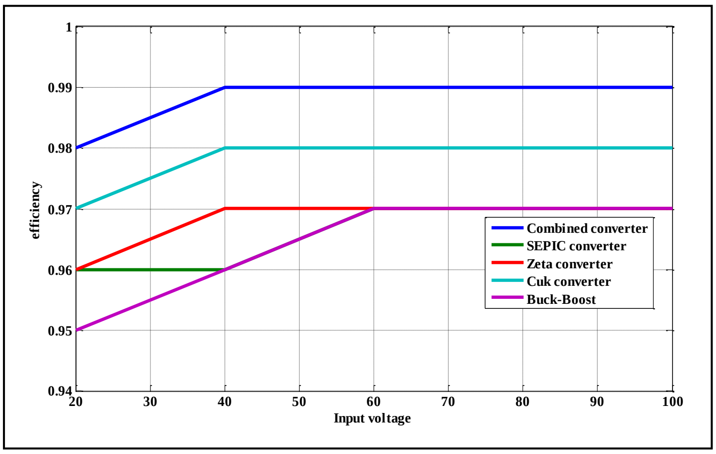

Figure 20. Efficiency Vs input voltage for boost functioning mode.

V. CONCLUSION AND FUTURE WORKS

In this paper, we have discussed five topologies of up/down converters and we have shown the usefulness and performance of the non-inverting buck-boost converter. According to the above simulation results, it can be seen that non-inverting buck-boost converter ensures higher efficiency and avoids the polarity inversion problems occurring with other traditional buck-boost and Cuk converters. Moreover, the non-inverting buck-boost topology proves to have low cost and simple design which makes the sizing easier than other up/down converters.

Our priority for further work is to prove the validity of this comparison through experimental tests, and then to synthesize a proper controller which able to guarantee good performances for steady state and dynamic modes especially for electric vehicles applications.

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