A Relative Comparison among Recent Topologies of Single-Phase Non-isolated AC-DC Buck-Boost Converter based on Open-Loop Performance Analysis

Istiak Ahmed and Muhibul Haque Bhuyan

Abstract**—**In the present article, a family of power electronic single-phase, non-isolated ac-dc buck-boost converters based upon the open-loop performance analysis have been reviewed. In the literature, abundant kinds of ac-dc buck-boost converter topologies have been searched. Among them, a few important topologies are conversed here and matched with several parameters like voltage gain, efficiency, input power factor, total harmonic distortion, and the number of component counts with the variation of load resistance and duty cycles. The assessment indicates that the input switched and switched capacitor buck-boost converters maintain an impressive input power factor of 0.99 at some specific load or duty cycles. In terms of efficiency, the high-efficiency buck-boost converter can provide over 99% efficiency. The switched capacitor buck-boost converter can provide the Total Harmonic Distortion (THD) of input current less than unity.

Keywords**—**Buck-boost converter topology, total harmonic distortion, switching frequency, voltage gain.

I. Introduction

With the progress in the new technical and industrial epoch, reliability, efficiency, size, and quality of voltage translation from AC-AC, DC-DC, AC-DC, or DC-AC has become important factors. With the appropriate designs, these translators have many significant aspects in the fields of power electronics [1].

Whereas a buck converter can assist in step-down the DC signal to another lower level of DC signal [2], a buck-boost converter is a type of DC-DC converter that can do both that can help to step-up or step-down the voltage level by stepping down or up the current level respectively from its input voltage to its output voltage level at the load side. Such types of circuits contain at least two semiconductor devices, such as a diode and a transistor. However, the modern buck-boost converter circuits use another transistor instead of the diode which is used to obtain synchronous rectification. The buck-boost converter circuits also contain at least one energy-storing component like either a capacitor or an inductor, or in some cases the amalgamation of both. To diminish the ripples in the supply voltage, filter circuits are normally used both at the supply and load sides of the buck-boost converter circuits. Filter circuits are made of using either a capacitor or an inductor or both. When the filter circuit is used at the input and output terminals then they are called the supply-side and load-side filters respectively [3].

There are two distinct types of buck-boost converter circuit's modes, such as 1) continuous conduction mode in which the inductor current certainly doesn't become zero at its end and thus the inductor discharges partially before the end of the switching cycles, and 2) discontinuous conduction mode in which the inductor current become zero at its end and thus the inductor will release its energy completely when the switching cycles terminate [4-6].

There are several advantages of using the Buck-Boost converter circuit, such as it has a simple structure, it is easy to implement, it can provide greater output voltage, it can operate on short duty cycle, it can operate on small voltage with MOSFETs, etc. [4].

The single-phase AC-DC buck-boost converter circuit has many applications in the fields of power electronics. It can be used in applications, such as electronic devices used in cars, self-regulating power supplies, consumer electronics, battery-powered systems, adaptive control systems, power amplifier circuits, portable devices, etc., where the range of the battery's output voltage is significantly huge, buck-boost converters are essential [4]. It can also be used for wind energy control [7], power factor correction [8],

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residential solar PV [9], and electric vehicle battery life extension circuits [10]. It is exclusively appropriate as a front-end power supply source in variable-speed drive schemes to translate the service source potential into an adjustable dc-link voltage supply [11].

II. Topologies and Operations of the AC-DC Buck-Boost Converter

A converter is the basic element of a power electronics system. It employs power semiconductor devices and possible energy storage elements like inductors and capacitors. The task of the AC-DC converter is to translate the input AC to output DC. There has been a deep study in switched-mode power converters. They are classified as single inductor converters like Buck, Boost, and Buck-Boost converters as well as double inductor converters like Cuk [12-13], SEPIC [14], Sheppard-Taylor [15], and Zeta [16] converters, etc. The function of AC-DC Buck-Boost converters is to both step up and step down the input signal. Throughout the decades, there have been modifications to improve different aspects of the traditional AC-DC buck-boost converter. Specific converter topologies have been developed to meet desired load characteristics. In this paper, an analysis with a comparative review of three different recently developed topologies of the single-phase non-isolated AC-DC buck-boost converters is presented. In the following three subsections, various topologies and operations of different types of AC-DC buck-boost converters are discussed.

A. *High-Efficiency AC-DC Buck-Boost Converter*

A schematic circuit diagram of the high-efficiency AC-DC buck-boost converter is presented in Fig. 1. It produces an output voltage with the same polarity as the input signal. No separating device in between the source and the load sides has been employed here. The circuit comprises three inductors (L_1 to L_3), three capacitors (C_1 to C_3), six diodes (D_1 to D_6), and a switch (M_1). The inductor L_1 and the capacitor C_1 constitute the passive type input filter. The inductors L_2 and L_3 in the middle are used here as the buck-boost inductors. Capacitors C_2 and C_3 at the output terminal are called the load capacitor, and the resistor R acts as a load [17].

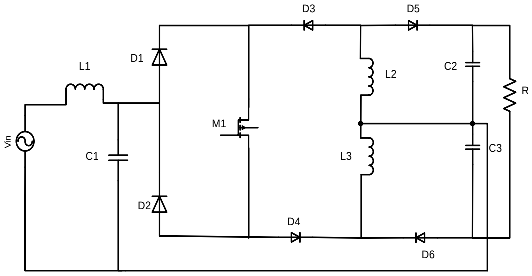

Fig. 1. High-efficiency AC-DC Buck-Boost Converter [17]

The open-loop analysis of the circuit is done using PSIM 9.1.1. MOSFET has been used as the switching device. Input voltage (V_{in}) peak is selected 300 V. The switching frequency is fixed at 10 kHz. The values of L_1, L_2, and L_3 are chosen as 5 mH, 1 mH, and 1 mH. The values of C_1, C_2, and C_3 are chosen as 1 μF, 110 μF, and 110 μF. The load resistor R is 100 Ω [17].

B. *Input Switched AC-DC Buck-Boost Converter*

The schematic circuit diagram of the input switched AC-DC buck-boost converter is presented in Fig. 2. There are three inductors and two capacitors in the circuit. As the input filter inductor, L_3 and capacitor, C_2 is used. The other two inductors operate as buck-boost inductors. The circuit has ten diodes. Capacitor, C_1 is the output capacitor and resistor R_1 is used as load [18].

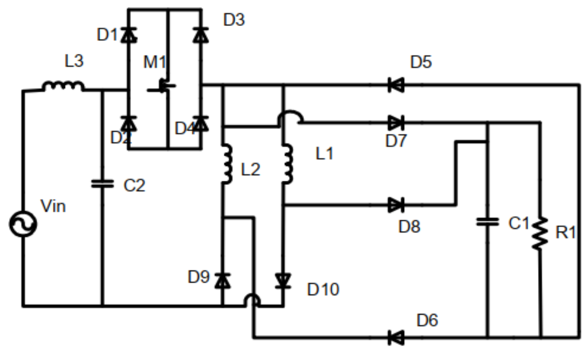

Fig. 2. Input Switched AC-DC Buck-Boost Converter [18]

The open-loop analysis of the circuit is done using PSIM 9.1.1. An IGBT is used as the switching device. Input voltage (V_{in}) peak is selected 300 V. The switching frequency is fixed at 10 kHz. The values of L_1, L_2, and L_3 are chosen as 5 mH. The values of C_1 and C_2 are chosen as 2.5 μF and 5 μF. The load resistor R_1 is 100 Ω [18].

C. *Switched Capacitor AC-DC Buck-Boost Converter*

The schematic circuit diagram of the switched-capacitor AC-DC buck-boost converter is depicted in Fig. 3. The topology of the buck-boost circuit has two stages. In the first stage, a full-wave bridge rectifier circuit is inserted using p-n junction diodes. In the second stage, a switched-capacitor DC-DC topology is used to be operated at a high frequency. The circuit has two inductors among which inductor L_1 is used as the Buck-Boost inductor. There are four capacitors in the circuit. Inductor L_{in} along with capacitor C_{in} constitutes the input filter. Capacitor C_1 is used as the output capacitor and resistor R_1 is used as the load. The circuit has a switch and a total of eight diodes [19].

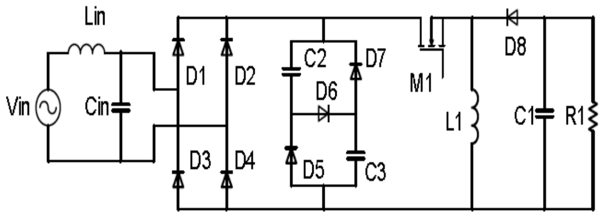

Fig. 3. Switched Capacitor AC-DC Buck-Boost Converter [19]

The open-loop analysis of the circuit is done using PSIM 9.1.1. MOSFET is used as the switching device. Input voltage (V_{in}) peak is selected 300 V. Switching frequency is set at 10 kHz. The values of L_{in} and L_1 are chosen as 40 mH and 400 μH. The values of C_{in}, C_1, C_2, and C_3 are chosen as 50 μF, 50 μF, 1 μF, and 1 μF respectively. The load resistor R_1 is 100 Ω [19].

III. Results and Discussions on the Performance Comparison of various Topologies

Based on the open-loop analysis of different topologies of the single-phase AC-DC buck-boost converter (BBC) circuits, a performance comparison is done. Table 1 provides a general comparison of three different topologies, such as high-efficiency BBC, input switched BBC and switched capacitor BBC, used in this study. For each of these topologies, the number of components, viz. switch, diode, inductor, and capacitor used in the single-phase AC-DC buck-boost converter circuits is mentioned.

TABLE I
General Comparison on different topologies of AC-DC Buck-Boost Converter (BBC)

Topology	Figure #	Ref. #	Switch/ Capacitor Count	Diode/ Inductor Count
High-efficiency BBC	1	17	1/3	6/3
Input Switched BBC	2	18	1/2	10/2
Switched Capacitor BBC	3	19	1/4	8/2

A. Performance comparison based on duty cycle variation

The open-loop performance comparison on different topologies of AC-DC Buck-Boost converter is done based on duty cycle variation. The overall efficiency, input power factor, total harmonic distortion (THD) of the input current, and the voltage gain are analyzed with the variation of the duty cycle. A load of all the converters is chosen as 100 Ω and the switching frequency of M_1 is fixed at 10 kHz. The data is provided in Table 2. For a better understanding of the comparison, a column chart and line chart are provided.

TABLE II
Performance comparison on different topologies of Single-Phase Non-Isolated AC-DC Buck-Boost Converter based on duty cycle variation

Duty Cycle	Topology	Efficiency (%)	Power Factor	THD (%)	Voltage Gain
0.1	High-efficiency BBC	97.587	0.712	40.295	0.238
	Input Switched BBC	74	0.94	3	0.64
	Switched Capacitor BBC	80	0.12	23.3	0.42
0.2	High-efficiency BBC	99.061	0.767	57.147	0.548
	Input Switched BBC	81.28	0.97	2.7	0.73
	Switched Capacitor BBC	90.88	0.39	0.8	0.84
0.3	High-efficiency BBC	99.288	0.748	61.188	0.854
	Input Switched BBC	87.34	0.97	3.15	0.79
	Switched Capacitor BBC	93.46	0.73	0.25	1.25
0.4	High-efficiency BBC	99.276	0.812	50.792	1.35
	Input Switched BBC	92.54	0.97	3.28	0.84
	Switched Capacitor BBC	94.72	0.94	0.20	1.62
0.5	High-efficiency BBC	99.158	0.901	37.724	2.08
	Input Switched BBC	97.16	0.98	2.7	0.89
	Switched Capacitor BBC	95.25	0.99	0.14	1.90
0.6	High-efficiency BBC	99.045	0.967	25.646	3.009
	Input Switched BBC	98.62	0.99	2	1.33
	Switched Capacitor BBC	95.49	0.95	0.27	2.08
0.7	High-efficiency BBC	98.719	0.969	15.753	4.147
	Input Switched BBC	98.35	0.99	1.7	2.06
	Switched Capacitor BBC	95.99	0.78	4.5	2.20
0.8	High-efficiency BBC	98.025	0.823	7.332	5.322
	Input Switched BBC	96.98	0.93	1	3.28
	Switched Capacitor BBC	95.95	0.40	3.18	1.69
0.9	High-efficiency BBC	95.292	0.342	1.535	4.02
	Input Switched BBC	86.40	0.5	0.4	3.51
	Switched Capacitor BBC	93.06	0.10	24.2	0.77

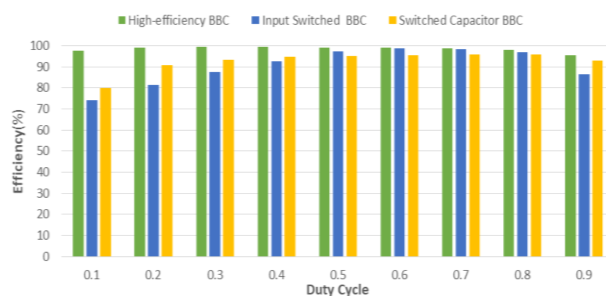

Fig. 4. Graphical comparison of efficiency between different topologies of single-phase non-isolated AC-DC buck-boost converter under duty cycle variation

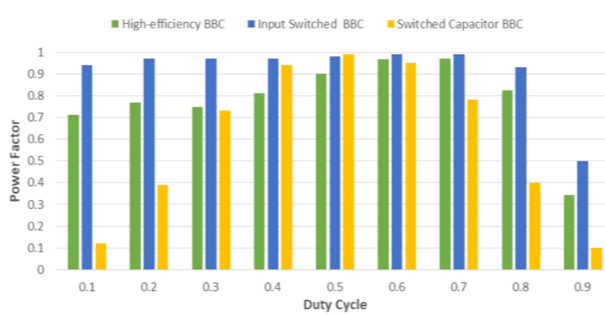

Fig. 5. Graphical comparison of power factor between different topologies of single-phase non-isolated AC-DC buck-boost converter under duty cycle variation

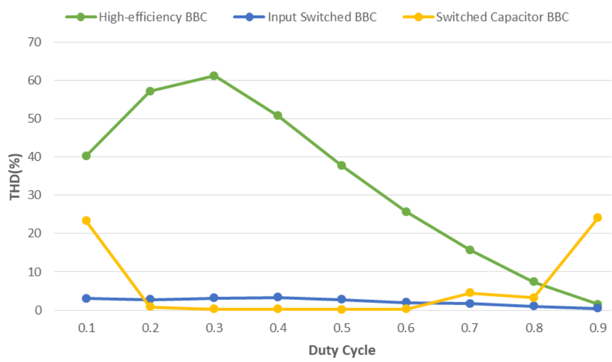

Fig. 6. Graphical comparison of THD between different topologies of single-phase non-isolated AC-DC buck-boost converter under duty cycle variation

B. Performance comparison based on load variation

The open-loop performance comparison on different topologies of AC-DC buck-boost converter is done based on load variation. The overall efficiency, input power factor, total harmonic distortion (THD) of the input current, and the voltage gain are analyzed with the variation of load. The switching frequency is fixed at 10 kHz and the duty cycle is chosen as 0.6. The data is provided in Table 3. For a better understanding of the comparison, a column chart and line chart are provided.

TABLE III
PERFORMANCE COMPARISON ON DIFFERENT TOPOLOGIES OF SINGLE-PHASE NON-ISOLATED AC-DC BUCK-BOOST CONVERTER BASED ON LOAD VARIATION

Load (Ω)	Topology	Efficiency (%)	Power Factor	THD (%)	Voltage Gain
	High-efficiency BBC	99.21	0.97	23.78	2.10
50	Input Switched BBC	98.86	0.99	1.75	1.30
	Switched Capacitor BBC	98.45	0.91	5.22	1.59
	High-efficiency BBC	99.045	0.967	25.646	3.009
100	Input Switched BBC	98.62	0.99	2	1.33
	Switched Capacitor BBC	95.49	0.95	0.27	2.08
	High-efficiency BBC	99.05	0.95	30.04	3.57
150	Input Switched BBC	98.44	0.98	4.30	1.34
	Switched Capacitor BBC	98.88	0.95	0.15	2.59
	High-efficiency BBC	98.93	0.94	35.74	4.01
200	Input Switched BBC	97.82	0.97	6.66	1.35
	Switched Capacitor BBC	98.65	0.95	0.15	3.00
	High-efficiency BBC	98.65	0.92	40.53	4.31
250	Input Switched BC	97.78	0.96	9.2	1.37
	Switched Capacitor BBC	98.40	0.95	0.15	3.36
	High-efficiency BBC	98.54	0.92	41.43	4.41
300	Input Switched BBC	97.70	0.95	11.1	1.41
	Switched Capacitor BBC	98.16	0.95	0.16	3.68
	High-efficiency BBC	98.46	0.92	40.50	4.45
350	Input Switched BBC	97.76	0.96	11.1	1.50
	Switched Capacitor BBC	97.90	0.95	0.15	3.97
	High-efficiency BBC	98.36	0.92	39.06	4.48
400	Input Switched BBC	97.72	0.97	9.52	1.59
	Switched Capacitor BBC	97.67	0.95	0.15	4.24
	High-efficiency BBC	98.45	0.92	37.17	4.51
450	Input Switched BBC	97.67	0.97	6.81	1.68
	Switched Capacitor BBC	97.43	0.95	0.16	4.49
	High-efficiency BBC	98.15	0.93	34.93	4.53
500	Input Switched BBC	97.65	0.97	4.78	1.77
	Switched Capacitor BBC	97.17	0.95	0.15	4.73

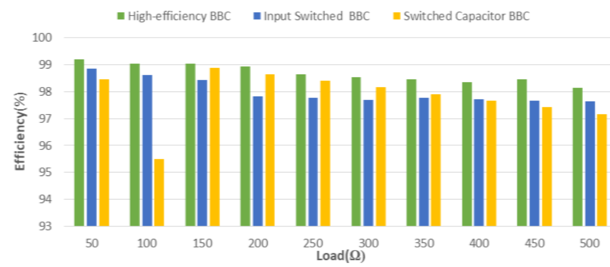

Fig. 7. Graphical comparison of Efficiency between different topologies of single-phase non-isolated AC-DC buck-boost converter under load variation

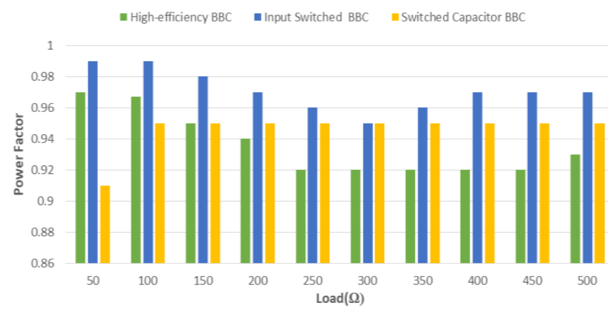

Fig. 8. Graphical comparison of Power Factor between different topologies of single-phase non-isolated AC-DC buck-boost converter under load variation

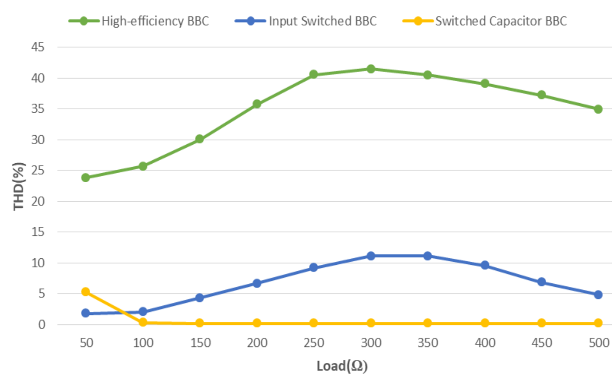

Fig. 9. Graphical comparison of THD between different topologies of single-phase non-isolated AC-DC buck-boost converter under load variation

IV. CONCLUSION

This research article represents a comprehensive open-loop analysis of three different topologies of single-phase non-isolated AC-DC buck-boost converter (BBC). Performances are compared by varying the duty cycle from 10% to 100% and load resistance from 50 Ω to 500 Ω for the different topologies. From this comparative analysis, it is realized that the high-efficiency BBC demonstrates better efficiency of over 99% than that of the other BBC upon the duty cycle or load resistance variation. The input switched and switched capacitor BBCs provide a better power factor than that of the high-efficiency BBC upon the duty cycle or load resistance changes. When the THD of the input current is considered, it has been observed that the switched capacitor BBC can provide smaller values of THD than that of the other two BBCs upon duty cycle or load variation.

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