A PQ Improved Two-Mode Control Scheme for Two-Switch Buck-Boost DC-DC Converter

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Abstract— The usage of power electronic systems has expanded to new and wide application range. In recent years, the use of Buck-Boost converters are more when compared to other type of converters. When compared with the basic converters like Cuk, Zeta, two-switch Buck-Boost converter (TSBBC) presents less voltage losses on the switches. The two-switch buck boost converter is suitable for wide input voltage applications. The two switch buck boost converter requires fewer passive components. In order to achieve high efficiency over the entire input voltage range, the TSBBC operated in buck mode at high input voltage and boost mode at low input voltage. Such operation is called two mode control scheme. The objective of this paper is to reduce the influence of the input voltage disturbance on the output voltage by implementing two-mode control scheme and obtain enhanced efficiency with low harmonic distortion. The TSBBCs have been extensively used in telecommunications, battery operated vehicles, etc. with wide input voltage range. So it is thus important to improve the efficiency of TSBBC over a high input voltage range.

Key words: TSBBC, SEPIC converters, DC-DC Converter

I. INTRODUCTION

Switch mode DC-DC converters efficiently convert an unregulated DC input voltage into a regulated DC output voltage. The two switch buck boost converter is a simplified cascade connection of buck and boost converters.[1] Compared with basic converters, which have the ability of both voltage step-up and step-down such as inverting buck-boost, Cuk, Zeta and SEPIC converters, the Two-Switch Buck-Boost Converter (TSBBC) presents lower voltage stress of the power devices, fewer passive components and positive output voltage and it has been widely used in telecommunication systems, battery-operated power supplies, fuel cell power systems, power factor correction applications, radio frequency amplifier power supplies, all of which have wide input voltage range.[5]

II. TWO-SWITCH BUCK-BOOST CONVERTER

The TSBBC is suitable for wide input voltage applications. In order to achieve high efficiency over the entire input voltage range, the TSBBC is operated in buck mode at high input voltage and boost mode at low input voltage.[3] Such operation is called the two-mode control scheme. Figure 1 shows the circuit diagram of TSBBC.[12] There are two active switches in the TSBBC, which provides the possibility of obtaining various control methods for this converter. If Q_1 and Q_2 are switched ON and OFF simultaneously, the TSBBC behaves the same as the single switch buck-boost converter. This control method is called one mode control scheme .If Q_1 and Q_2 are controlled independently; it is two mode control scheme.[6] Modes of operation can be explained in two stages, when switch Q_1 is controlled and Q_2 is off and when Q_1 is continuously on and Q_2 is controlled to regulate the output voltage.[13]

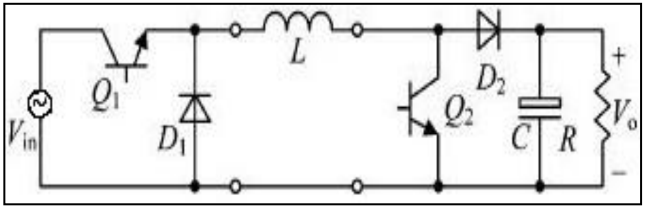

Fig. 1: Circuit Diagram of Two Switch Buck-Boost Converter

A. Buck Mode:

When the input voltage is higher than the output voltage, Q_2 is always kept OFF, and Q_1 is controlled to regulate the output voltage, and as a result, the TSBBC is equivalent to a buck converter, and is said to operate in buck mode.[24]

B. Boost Mode:

When the input voltage is lower than the output voltage, Q_1 is always kept ON, and Q_2 is controlled to regulate the output voltage, and in this case, the TSBBC is equivalent to a boost converter, and is said to operate in boost mode.

Compared to linear power supplies, switching power supplies provide much more efficiency and power density. Switching power supplies employ solid-state devices such as transistors and diodes to operate as a switch: either completely on or completely off. Energy storage elements, including capacitors and inductors, are used for energy transfer and work as a low-pass filter.[11]

The major advantages of digital control over analog control are higher immunity to environmental changes such as temperature and aging of components, increased flexibility by changing the software, more advanced control techniques and shorter design cycles. Therefore, more advanced control algorithms can be implemented on a microcontroller.

Switch-mode DC-DC converters are used to convert the unregulated DC input to a controlled DC output at a desired voltage level. Switch-mode DC-DC converters include Buck converters, Boost converters, Buck-Boost converters, Cuk converters and Full-Bridge converters, etc.

III. PI CONTROLLER

Proportional-Integral controller mode results from the combination of the proportional and the integral mode.[4] PI control is needed for non-integrating processes, meaning any process that eventually returns to the same output given the same set of inputs and disturbances. A P-controller is best suited to integrating processes. Integral action is used to remove offset and can be thought of as an adjustable V_{BIAS}.[10]

A PI controller fuses the properties of P and I controllers and the algorithm provides a balance of complexity and capability to be widely used in process control applications. It is reported that single input single-output PI controller controls 98% of control loop in paper and pulp industries. The equation which describes P controller is

$$u(t) = K_p * e(t) \tag{1.1}$$

where K_P is proportional gain, e(t) is the error and u(t) is the perturbation in output signal of PI controller from the base value corresponding to normal operating conditions.[7] It always exhibit static error with no integration property in the presence of disturbances and changes in set-point. It shows a relatively maximum overshoot and long settling time.[30]

IV. ANALYSIS OF TWO-SWITCH BUCK-BOOST CONVERTER

A conventional TSBBC uses a single inductor Figure 2. However, it has an additional MOSFET Q_2 and an additional diode D_2 compared to an inverting buck-boost converter. By turning Q_1 and Q_2 ON and OFF simultaneously, the converter operates in buck-boost mode, and the voltage conversion ratio also complies with

$$M = \frac{V_{OUT}}{V_{IN}} = \frac{D}{1-D} \tag{1.3}$$

This confirms that the two-switch buck-boost converter performs a non-inverting conversion. Q_1 and D_1 both face a voltage stress of V_{IN}, while Q_2 and D_2 both face the voltage stress of V_{OUT}.[20] Q_1, Q_2, D_1, D_2, and L_1 all face a current stress of $I_{IN} + I_{OUT}$ with inductor ripple current neglected. The relatively large number of power devices and high-current stress in buck-boost mode prevent the converter from being very efficient.[15]

A. *Operating-mode of optimization of a TSBBC*

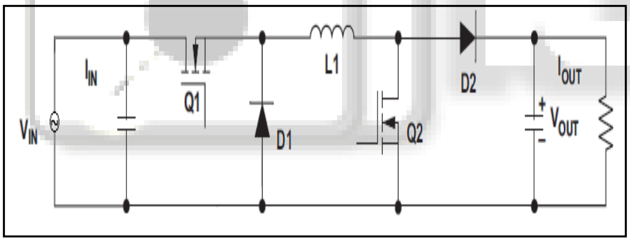

Fig. 2: TSBBC in buck-boost operation

The two-switch buck-boost converter is a cascaded combination of a buck converter followed by a boost converter. Besides the a fore mentioned buck-boost mode, wherein Q_1 and Q_2 have identical gate-control signals, the TSBBC also can operate in either buck or boost mode.[21] By operating the converter in buck mode when V_{IN} is higher than V_{OUT}, and in boost mode when V_{IN} is lower than V_{OUT}, the buck-boost function is then realized.[27]

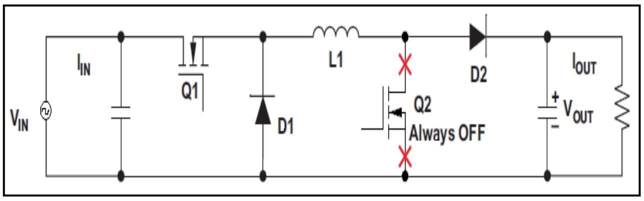

Fig. 3: Buck mode of operation

In buck mode, Q_2 is controlled to be always OFF, and output voltage is regulated by controlling Q_1 as in a typical buck converter.[25] The voltage conversion ratio is the same as that of a typical buck converter:

$$M = \frac{V_{OUT}}{V_{IN}} = D \tag{1.4}$$

where D is the duty cycle of Q_1. In buck mode, the output voltage is always lower than the input voltage since D is always less than one. Higher efficiency is possible in buck mode compared to the buck-boost mode for three reasons.[23]

1) First of all, Q_2 is always OFF in buck mode, which means there is no power dissipated in it.
2) Second Q_1, D_1, and L_1 see a lower current stress of only I_{OUT} in buck mode compared to $I_{IN} + I_{OUT}$ in buck mode compared to $I_{IN} + I_{OUT}$ in buck-boost mode, which potentially reduces power loss.
3) Third, although conduction loss of D_2 stays the same, the reverse recovery loss is eliminated in the buck mode because D_2 always conducts.[19]

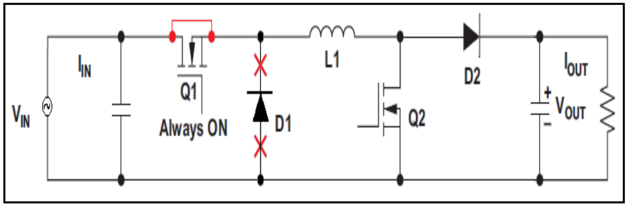

Fig. 4: Boost mode of operation

By keeping Q_1 always ON, D_1 is reverse biased and stays OFF, and the two-switch buck-boost converter then operates in boost mode. Similar to the typical boost converter, the output voltage is regulated by controlling Q_2.[16]

The equivalent circuit in boost mode is shown in Figure 4. The voltage conversion ratio is the same as that of a typical boost converter:

$$M = \frac{V_{OUT}}{V_{IN}} = \frac{1}{1-D} \tag{1.5}$$

where D is the duty cycle of Q_2. In boost mode, the output voltage is always greater than the input voltage because D is always greater than zero. Similarly, higher efficiency could be achieved in boost mode than in buck-boost mode due to fewer operating power devices and lower current stress.[17]

B. *Implementation of an efficient TSBBC*

The two-switch buck-boost converter can function in buck-boost, buck or boost modes of operation. Various combinations of operating modes can be used to accomplish both a step-up and step-down function. The buck-boost mode alone features the simplest control, but has low efficiency for both step-up and step-down conversion over the V_{IN} range.[14]

Operating Modes	Control Complexity	Efficiency (V_{IN}>V_{OUT})	Efficiency (V_{IN}<V_{OUT})
Buck-Boost	Simple	Low	Low
Buck and Buck-Boost	Moderate	High	Low
Buck-Boost and Boost	Moderate	Low	High
Buck, Buck-Boost, and Boost	Complicated	High	High

Table 1: Comparison of Operating Modes

The combination of buck, buck-boost and boost modes has the potential to achieve high efficiency over the V_{IN} range.[28] However, its control is very complicated due to multiple modes of operation and the resulting transitions between different modes. As such, the combination of buck, boost and buck-boost modes is a good trade-off between its control of complexity and its efficiency.[18]

V. DESIGN PARAMETERS

The system has been designed for AC input voltage with the following parameters shown in Table 2. The Two Switch Buck Boost converter is designed for CCM mode depending on the input voltages, output voltage and power.[2] The input voltage variation is from (250 V-450 V) for an output of 400 V, 6 kW. The design steps are given as follows:

Components	Parameters	Value in simulated model
Input Voltage Range	V_{in}	250-450V
Output Voltage	V_o	400V
Output Power	P_o	6kW
Switching frequency	f_s	50kHz
Resistance	R	26.67Ω
Capacitance	C	3mF
Inductance	L	35µH
Output Current	I_o	15A
Capacitive Filter	C_1	6µF
Inductive Filter	L_1	0.2mH

Table 2: Simulation Parameters

VI. RESULT

The operation of TSBBC for both modes has been simulated using MATLAB. THD analysis has been done for both the modes.[8] For the TSBBC operated with the two-mode control scheme, the small-signal models in buck and boost modes are built under different operation modes are given.[22]

Finally, a 250–450 V input, 400 V output and 6-kW-rated power prototype is built and tested, and the simulation results demonstrate the validity of this proposed control scheme, with which high efficiency over the whole input voltage range and improved input voltage transient response are achieved for the TSBBC.

A. Simulation Results for Buck Mode

A buck converter of 400V, 6kW is designed with an input voltage of 450V. The input current waveform in fig.5 shows that the input current is almost sinusoidal and the harmonic content of the input ac current is 22%. The rms value of input current is which is quite satisfactory.

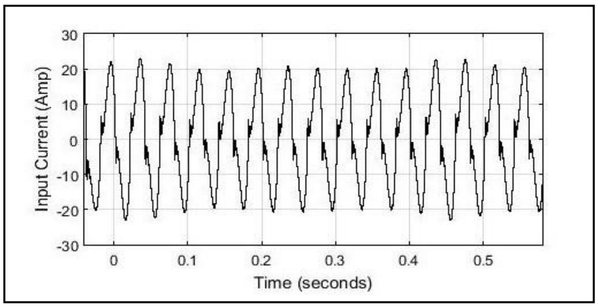

Fig. 5: Input Current Waveform

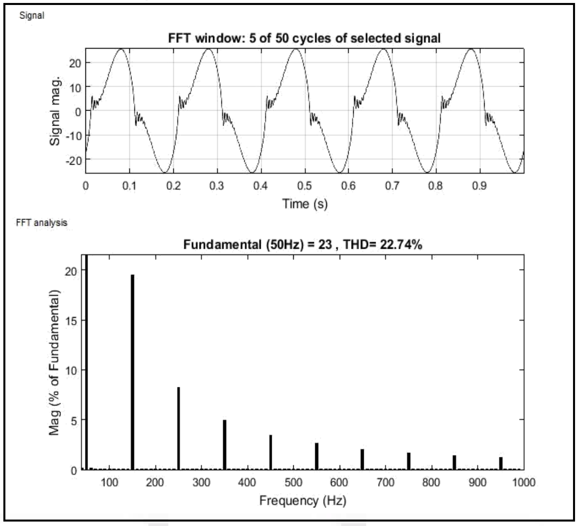

Fig. 6: FFT Signal Analysis of Input AC current at buck mode

With an input voltage of 450V, the constant dc output voltage is maintained at 400V which meets our designed system through TSBBC operating in Buck mode which is satisfactory.

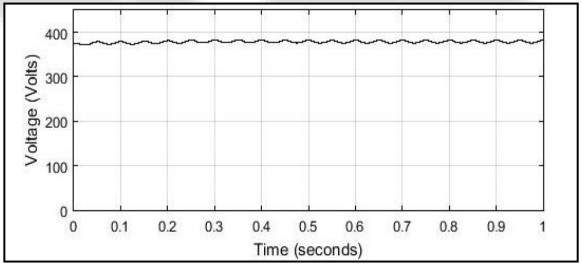

Fig. 7: Output Voltage Waveform

The output current is almost constant approx. 15Amp.

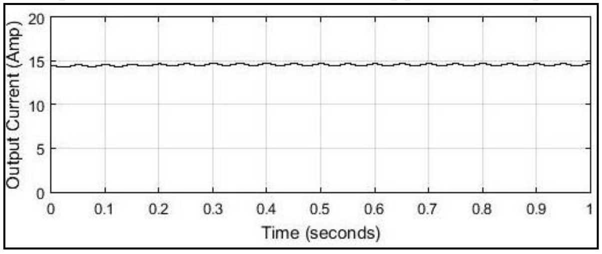

Fig. 8: Output Current Waveform

The inductive filter is selected as 0.2mH and the capacitive filter is selected as 6µF to limit the inductor current ripple under the 20% limit at rated conditions. The Total Harmonic Distortion in Boost Mode is received to be around 19%.

B. Simulation Results for Boost Mode

A boost converter of 400V, 6kW is designed with an input voltage of 250V. The input current waveform in fig.9 shows that the input current is almost sinusoidal and the harmonic content of the input ac current is 19%. The rms value of input current is which is quite satisfactory.

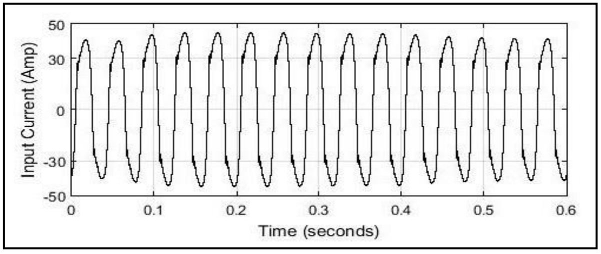

Fig. 9: Input Current Waveform

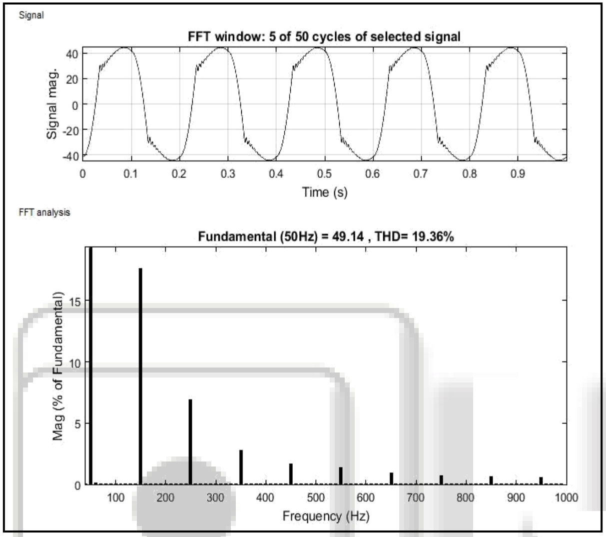

Fig. 10: FFT Signal Analysis of Input AC current at boost mode

With an input voltage of 250V, the constant dc output voltage is maintained at 400V which meets our designed system through TSBBC operating in Boost mode which is satisfactory.

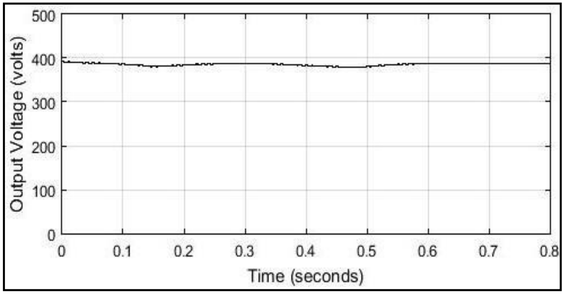

Fig. 11: Output Voltage Waveform

The output current is almost constant approx. 15Amp.

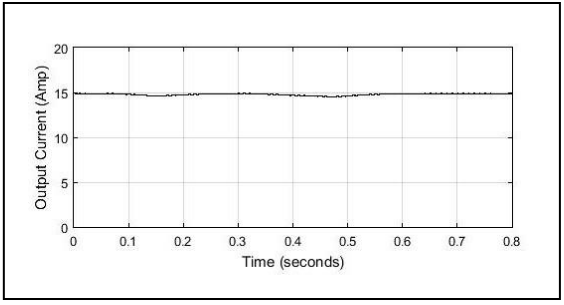

Fig. 12: Output Current Waveform

The inductive filter is selected as 0.2mH and the capacitive filter is selected as 6μF to limit the inductor current ripple under the 20% limit at rated conditions. The Total Harmonic Distortion in Boost Mode is received to be around 19%.

VII. CONCLUSION

The TSBBC operated with the two mode control scheme, the small signal models in buck and boost modes are built.[9] The switching between buck and boost modes in this proposed control scheme is nearly smooth. It is seen that the PI controller meets our demand of controlling the output voltage of ac-dc two-switch buck-boost converter in a smooth manner without much more chattering in the transient period by decreasing the rate of transition between the states of high frequency oscillation and low frequency steady state value and thereby shows a sharp decrease in rise time and settling time.[26] The implementation of PI controller also reduces the unwanted peak of output voltage during the transient period almost to zero and therefore reduces the chances of damage due to sudden rise of voltage in modern day power electronic devices having a very narrow tolerance zone to meet the requirements ultrafast performance. The Total Harmonic Distortion has been controlled within limits improving efficiency of the system.[29]

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