Real-Time Buck Boost Converter with Improved Transient Response for battery Power Applications

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Abstract— **The need for regulated, non inverting, constant output voltage from a variable input is on the rise. In this paper, a novel intermediate digital combination mode control is introduced along with real time buck boost converter. So that the cost, efficiency, reduction in the ripple content and output voltage can be enhanced. In conventional control method of buck boost converter, a direct transition from buck to boost mode, produces unwanted spikes in the output voltage. Therefore, designing buck boost converter with improved transient response considerably reduces the spikes, which appear in the conventional output. While this method eliminates the direct buck boost mode operation, it introduces an intermediate combination mode consisting of several buck modes, followed by several boost modes. The introduction of intermediate combination mode results in improved efficiency and reduction in ripple content of the output voltage.**

Keywords— Digital combination, Lead-acid battery, Real time buck–boost converter, transients, efficiency, Regulation

1. INTRODUCTION

PROVIDING a regulated non inverting output voltage from a variable input battery voltage source is a very common power-handling problem, especially for portable applications (powered by batteries) like cellular phones, personal digital assistants (PDAs), DSL modems (digital subscriber line), and digital cameras. The battery voltage, when charged or discharged, can be greater than, equal to, or less than the output voltage. But for such small-scale applications, it is very important to regulate the output voltage of the converter with high precision and performance. Thus, a tradeoff among cost, efficiency, and output transients should be considered [1]–[3]. A common power-handling issue for space-restrained applications powered by batteries is the regulation of the output voltage in the midrange of a variable input battery voltage. Some of the common examples are 3.3 V output with a 3–4.2 V Li cell input, 5 V output with a 3.6–6 V four-cell alkaline input, or a 12 V output with an 8–15 V lead–acid battery input [4]–[7].

For an input voltage range that is above and below the out-put voltage, the use of a buck or a boost converter can be ruled out unless cascaded. Cascaded combination of converters results in cascaded losses and costs; therefore, this approach is seldom used. In such a range of power demand, the transition of dc voltage from one level to another is generally accomplished by means of dc/dc power converter circuits [8]–[10].

Output ripple, efficiency, space, and the cost etc are the important points of concern for such low-voltage-range power supplies. The above mentioned topologies are generally not implemented for such power supplies due to their lower efficiency, higher size, and cost factors. The most difficult problem is the spikes in the output voltage, which causes the converter to reduce efficiency during the transition from buck mode to the boost mode. Cost, size, switching speed, efficiency, and flexibility all need to be considered in designing such power supplies [11]–[15].

This paper presents a novel method to fulfill the requirements of energy-efficient power supplies for battery-powered portable applications. The two main important factors, the efficiency and the voltage regulation, which are derived numerically from the experimental results, are shown, and their comparison with the conventional methods is tabulated. The novel method improves the transition problem and tries to reduce the transients happening during the transition from the buck mode to the boost mode.

The paper is organized as follows. Section 2 discusses the operation of the converter in different modes. Existing topologies and solutions to deal with this problem are addressed in Section 3. The proposed new method of transient improvement is presented in Section 4. Section 5 addresses the simulation results applying the conventional and proposed methods of control. Experimental results are presented in Section 6 to verify the simulations that are carried out for different control techniques. Conclusions are drawn based on each method in Section 7.

2. MODE OF OPERATION FOR NOVEL CONVERTER

Fig.1 shows an example for a battery-powered application. The input voltage of the battery when fully charged is 15 V and when it discharged from 15 V to 8 V, this supply needs to continuously provide a steady output of 12 V. 16].

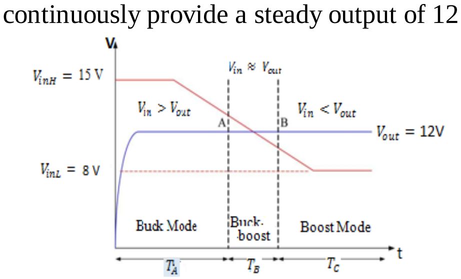


Fig. 1. Input–output curve variation for the power supply.

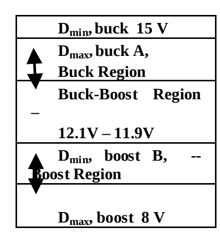


Fig. 2. Duty ratio for buck and boost modes

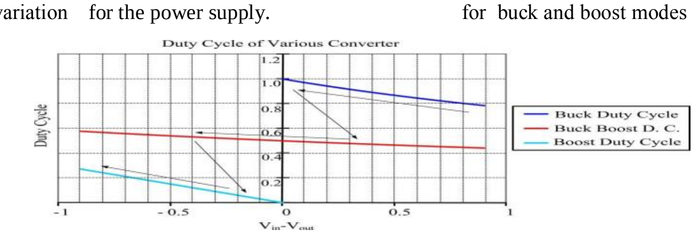


Fig. 3. Variations of duty cycle of buck, buck–boost, and boost converter Vs / V_o

A. Analytical Studies

In buck topology, when V_{in} is equal to V_{out} , the duty cycle(**DC**) will approach to 1, $DC_{buck} = V_{out} / V_{in}$. In the boost operating topology, when V_{in} approaches V_{out} , the duty cycle moves toward zero, $DC_{boost} = 1 - (V_{in} / V_{out})$. In the buck–boost operating condition, since $DC_{buck\text{-}boost} = V_{out} / V_{in} + V_{out}$, therefore, for V_{in} equal to V_{out}, duty cycle becomes 0.5. In other words, when V_{in} decreases toward V_{out}, the duty cycle should follow the pattern of 1 for buck to 0.5 for buck-boost and then zero in the boost operating topology. This is demonstrated in Fig.3.

3. PRESENT MODEL OF BUCK BOOST CONVERTER

A. Demerits of Using an Ordinary Buck–Boost Converter

The biggest problem associated with a ordinary buck–boost converter is that the output of such converter is inverted. of course, it can be inverted, but it requires a transformer, which adds to the cost and space and sacrifices the efficiency of the converter [3].

B. Drawbacks of Using SEPIC Converter

A very popular buck–boost topology that requires more components but produces a non inverting output is the single ended primary inductance converter (SEPIC). It has limited efficiency and requires either a transformer or two inductors. Thereby, increase the size and the cost. Use of these components would add to the losses, thereby degrades the efficiency of the converter [8]-[9].

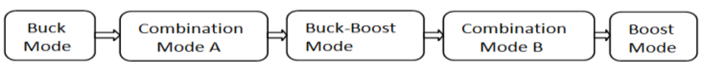


Fig. 4. Combined method based control logic for deciding modes of operation.

4. NOVEL METHOD

The Novel method is to add interface modes, which are a combination of buck and boost operating topologies. As shown in Fig. 5, when the input voltage is considerably higher than V_1, the converter operates in purely buck mode. However, during the time period, where the input voltage is between V_1 and V_2, threshold voltage, the combination mode A comes into operation, followed by the buck–boost mode for the voltage range V_2 and V_3. In the voltage range V_3 and V_4, the converter operates in the combination mode B. Finally, for the input voltages below V_4, the converter operates purely in the boost operating mode. By adding the combination modes A and B during the time periods "T_1" and "T_3" just before and after the stage, where $v_{in} \approx v_{out}$, the transient at the output of the converter can be improved significantly shown in Fig 5. Operation of the converter in buck– boost mode decreases the efficiency of the converter. In order to improve its efficiency, buck–boost mode should be eliminated. This is another major contribution of this paper. In that case, time periods T_2 will be eliminated and the operation mode will change from buck to the boost through intermediate combination modes, therefore, obtain smoother output waveform. This is the concept of digital combination of power converters (DCPCs), which is applied to a non inverting buck–boost converter in this paper.

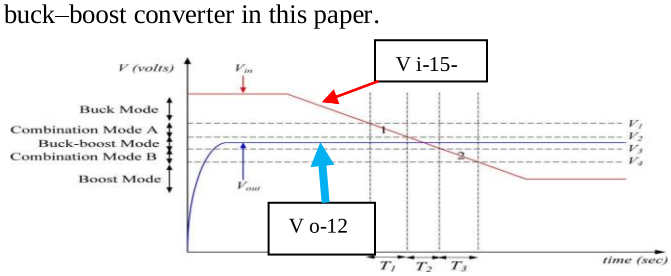


Fig.5. Voltage curves for combined-method-based control.

A. Function of Real Time Buck–Boost Converter

The circuit diagram of a real time buck–boost converter is shown in Fig.6. In buck–boost operating mode, always, two switches, S_1 and S_2, and two diodes, D_1 and D_2, are switching in the circuit. The added advantage of the converter is that the output of such a converter is always positive [11]–[15].

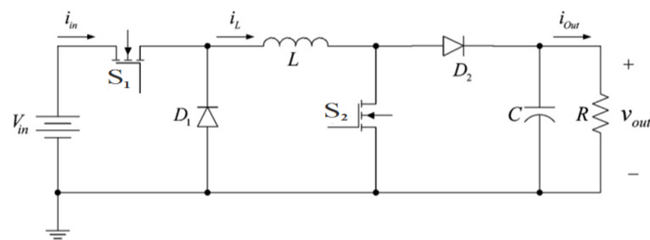


Fig. 6. Circuit diagram of a Real Time Buck–Boost Converter.

The overall system level of closed loop control strategy of the proposed method is shown in fig.7. The control logic for deciding the modes of operation is based on the idea of fig.6. Here both the input and the output voltages are sensed and the proper duty ratios are applied to switches S_1 and S_2 based on proper duty setting and desired mode of operation.

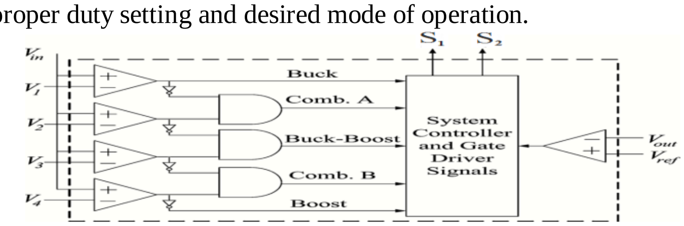


Fig.. 7. Closed loop control strategy for the p proposed method

B. Function of Combined Method

Consider X and Y are the buck and boost samples of switching cycles. The operation with X_i and Y_i switching cycles in transition mode will be repeated for Z_i times. In period combination mode A, combining X_1 buck samples and Y_1 boost samples, the output voltage variation can be expressed as
Now, for the output voltage variation to be minimum or zero,

$$\frac{X_1}{Y_1} = \frac{-(1-d_{boost})^2 \left(\frac{v_{out}}{2L}\right) d_{boost} T - I_{0,boost} + \frac{1}{R} v_{out}}{(1-d_{buck}) \left(\frac{v_{out}}{2L}\right) T + I_{0,buck} - \frac{1}{R} v_{out}} \quad \text{-- (1)}$$

TABLE I
PARAMETERS OF R-T BUCK BOOST CONVERTER

VARIABLE	PARAMETER	VALUE
V_{in}	**Input voltage**	**8V – 15V**
V_{ref}	**Output voltage**	**12V**
L	**Magnetizing inductance**	**110μH**
C	**Output C (filter)**	**400μF**
R	**Output resistance**	**30Ω**
F	**Switching frequency**	**100KHz**

Similarly for the combination mode B, the ratio of boost and buck pulses can be defined in terms of circuit parameters. By implementing the proposed combination modes, since transients get almost evenly distributed due to the application of these combination modes, the output voltage transients will significantly improved.

5. SIMULATION RESULT OF BUCK –BOOST -MAT LAB 7

The simulation results have been obtained for the converter based on the parameters shown in table I.

1. Conventional Method of Solving the transition problem.

Simulations are carried out on the real time buck-boost converter using the conventional methods. Fig.8 to Fig.11 presents the input, output voltage waveform, buck and boost pulses for a direct transition from buck to boost mode. There is about 12%-14% ripple in the output voltage during direct transition from buck to boost.

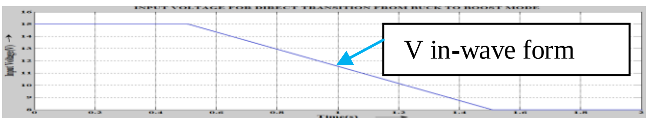


Fig.8.**Input** voltage for direct transition from buck to boost mode.

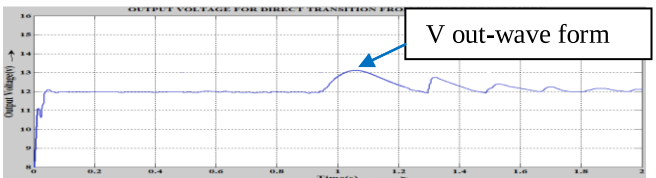


Fig. 9.**Output** voltage for direct transition from buck to boost mode.

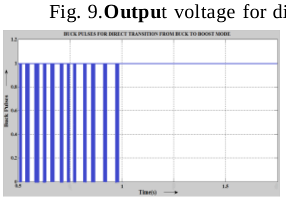


Fig. 10.Buck pulses for direct Fig. Transition from buck to boost

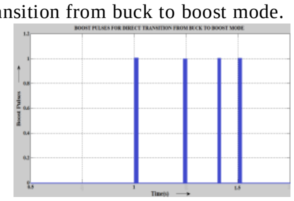


Fig 11.Boost pulses for direct transition from buck to boost mode.

Fig.12 to Fig.15 shows the input voltage, output voltage, and buck and boost pulses for a transition from buck to boost with an Intermediate buck-boost mode. The simulation results indicate that the presence of spikes in the output voltages during transitions through different modes is about 7% of output.

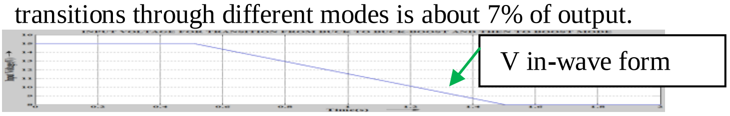


Fig.12 Input voltage for transition from buck to buck–boost and then to boost mode.

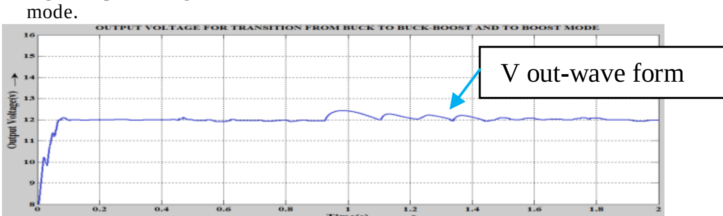


Fig. 13. Output voltage for transition from buck to buck–boost and then to boost mode.

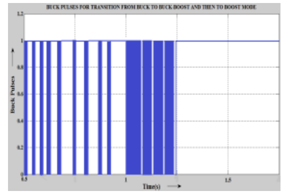


Fig. 14. Buck pulses for transition from buck to buck–boost and then to boost mode.

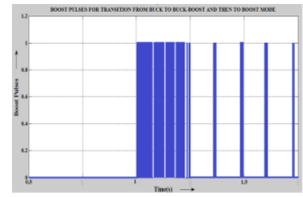


Fig. 15. Boost pulses for transition from buck to buck–boost and then to boost mode.

2. Results of novel method

Applying the parameter values from Table I for the calculation of buck and boost samples and using eqn(1), just before $V_{in}=V_{out}$ the rounded ratio of X_1 and Y_1 is 3:1. Similarly, just after $V_{in}=V_{out}$ the ratio of X_2 and Y_2 is found to be 1:2. Thus we choose $X_1=3$ or three buck cycles and $Y_1=1$ or one boost cycle for the time period in combination A and $X_2=1$ or one buck cycle and $Y_2 = 2$ or two boost cycles for the time period in combination mode B.

A) Novel Combination Method With Buck–Boost Mode in the Middle*:* The simulations were carried out on the converter using the exact combination method along with the buck–boost in the middle. This method improves the ripple content in the output voltage of the converter when the input voltage becomes almost equal to the output voltage and during other transition modes. The waveforms are shown in Fig.16 to Fig.19. It is seen that the peak transient happening during the transition is about 5%.

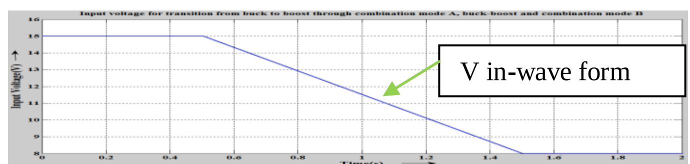


Fig. 16. Input voltage for the transition from buck to boost through combination mode A, buck–boost, and combination mode B

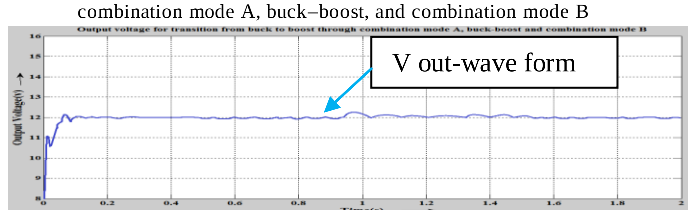


Fig. 17. Output voltage for the transition from buck to boost through combination mode A, buck–boost, and combination mode B

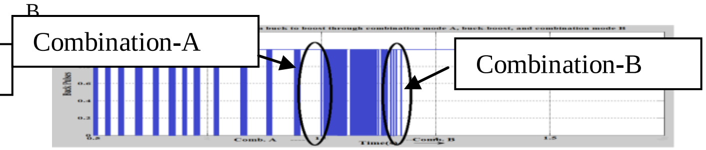


Fig.18. Buck pulses for the transition from buck to boost through combination mode A, buck–boost, and combination mode B

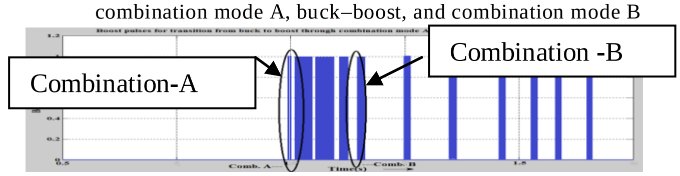


Fig.19. Boost pulses for the transition from buck to boost through combination mode A, buck–boost, and combination mode B

B) Without Buck–Boost Mode in the Middle:

The buck– boost mode, in the middle, was neglected to save the efficiency of the converter, since during this mode of operation, both the switches are operated simultaneously.

By applying this combination method of control and simulating the converter, the results shown in Figs.20 to 23 are obtained. The simulation results show that output voltage transients during transition from combination mode A to combination mode B are somehow similar to transients available in transition from combination mode A to buck–boost mode. This voltage variation in this method is about 5%; however, canceling the buck–boost operating mode in between significantly improves the efficiency of the converter. This is also proved through the measurements in Section 6.

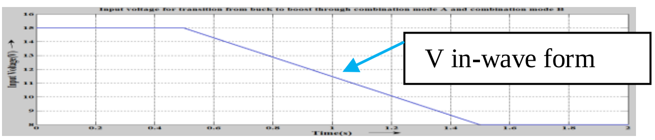


Fig.20. Input voltage during transition from buck to combined mode A and then to combined mode B and boost.

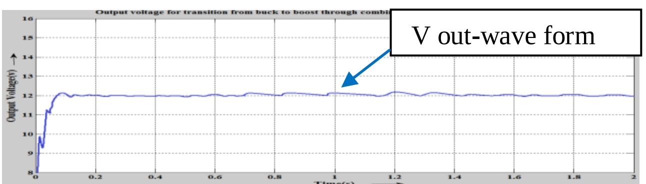


Fig.21. Output voltage during transition from buck to combined mode A and then to combined mode B and boost without buck–boost mode.

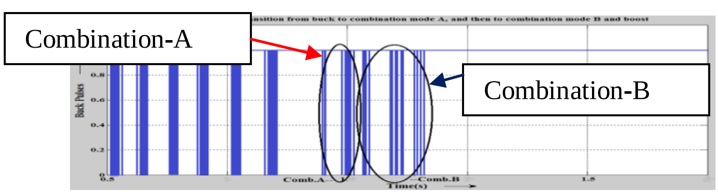


Fig.22. Buck pulses during transition from buck to combined mode A and then to combined mode B and boost.

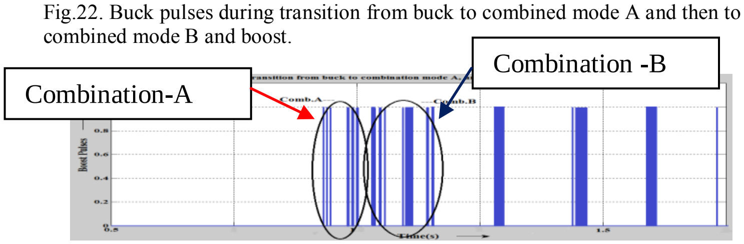


Fig.23. Boost pulses during transition from buck to combined mode A and then to combined mode B and boost.

6. HARDWARE RESULTS

The hardware of a positive buck–boost converter is designed based on the parameters listed in Table I. Then the converter operates at 100 kHz switching frequency. Two n-type MOSFET switches and two Schottky barrier diodes are used for real time buck–boost converter configuration.

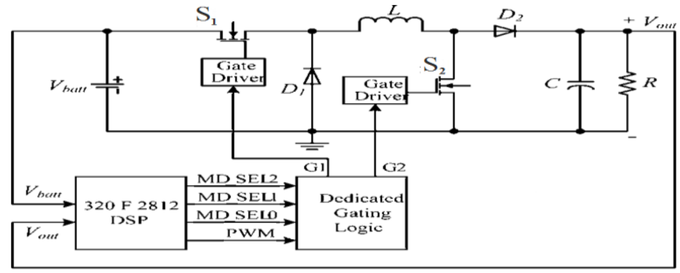
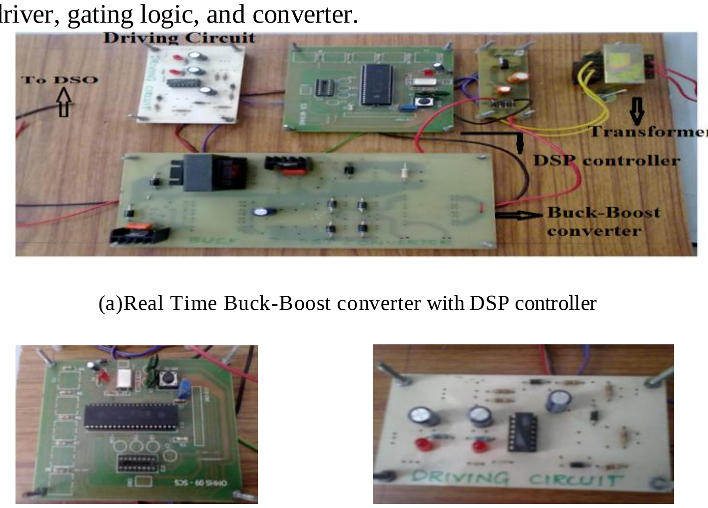


Fig. 24. Hardware circuit configuration

The MOSFET switches and diodes are IRF540 and 1N5817, respectively. Controller has been implemented using a Texas Instrument digital signal processor (DSP) (320F2812). The output voltage reference is set to 12 V, and input voltage varies from 15 to 8 V.

The operating modes are dependent on mode selection signals, applied from DSP. The overall configuration of converter and controller is shown in Fig. 24. G1 and G2 are buck pulse and boost pulse, sequentially. MD_SEL0, MD_SEL1, and MD_SEL2 determine operation modes: Fig. 25 presents the experimental setup that is composed of DSP controller, gate driver, gating logic, and converter.



(a)Real Time Buck-Boost converter with DSP controller

(b) DSP Processor

(c) Driving Circuits

Fig.25. Experimental setup composed of (a) converter, (b) DSP controller, and (c) driving circuits.

Fig. 26 demonstrates the output voltage of the converter, buck pulses, and boost pulses during a direct transition from buck mode to boost mode. Output voltage has a considerable variation during the transition from buck to boost.

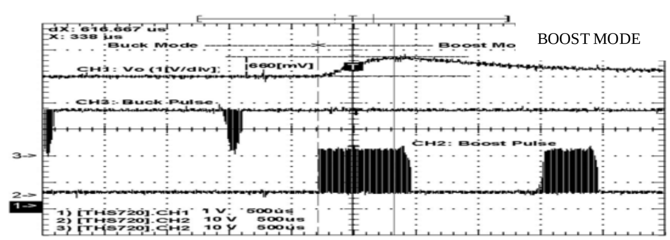


Fig.26. Output voltage, buck, and boost pulses in a direct transition from buck to boost mode.

Figs.27 present the output voltage of the converter, buck pulses, boost pulses, and buck–boost pulses for an indirect transition from buck to boost. In this case, transition from buck to boost is carried out through a transition from buck to buck–boost mode, followed by a transition from buck–boost to boost mode.

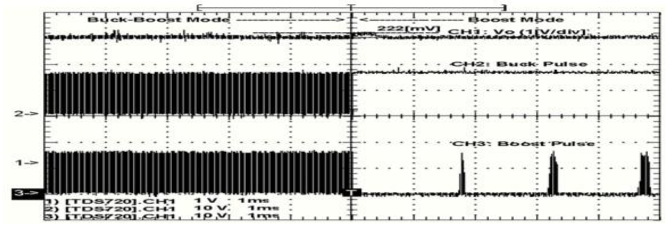


Fig.27. Output voltage, buck, and buck–boost pulses in transition from buck to buck–boost mode.

Fig. 28 presents the input and output voltages of the converter in a whole range of operation. Input voltage decreases from 15 to 8 V. Output voltage is tightly regulated at 12 V. In this experiment, transition from buck to boost is a combination of four different operating modes. The ripple during direct transition from buck to boost mode is about 15% (Fig. 28). The voltage ripple is defined as the peak– peak ripple as a percentage of the output voltage of the converter.

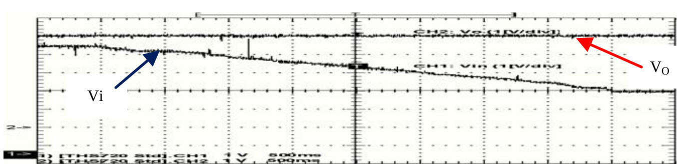


Fig.28. Input and output voltages for the transition from buck to boost mode through proposed method.

In order to improve the efficiency of the converter in addition to improving the output voltage transients, dynamic behavior of the system for a direct transition from combination mode A to combination mode B is investigated shown in fig. 29 .

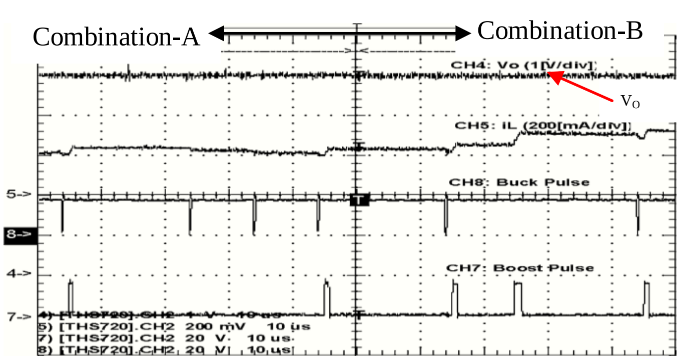


Fig.29. Output voltage, buck pulses, and boost pulses in transition from combination mode A to combination mode B.

Adding Buck–boost mode improves the voltage transient to about 6% in transition from buck to buck–boost (Fig. 27) and decreases the ripple transient from buck–boost to boost to about 10% (Fig. 30); however, staying in buck–boost mode for a long time sacrifices the efficiency of the converter. Adding combination modes A and B between buck and boost modes significantly improves the voltage transients, as shown in Figs. 28, and 29.

Table II summarizes the output voltage ripple during transients from different modes of operation. Fig.30 to Fig.32 presents the efficiency of the converter versus the input voltage variations for various transition modes for different loads. Fig.30 presents the efficiency of the converter in the transition from buck to buck–boost and then boost mode.

TABLE II

SUMMARY OF THE OUTPUT VOLTAGE TRANSIENTS DURING TRANSITION DIFFERENT MODES OF OPERATION

Transition	Output voltage ripple (%)
Direct buck to boost	**14%**
Buck to buck-boost	**7%**
Buck-boost to boost	**11%**
Buck to combination mode A	**6%**
Combination mode A to buck-boost	**5%**
Buck-boost to combination mode B	**4%**
Combination mode B to boost	**4%**
Combination mode A to combination mode B	**5%**

Efficiency of the converter in the region where input voltage is approximately equal to output voltage plus diode voltage drop descends to 68% due to the operation of the converter in buck–boost mode. Similarly, transition from buck to combination mode A and then buck–boost mode sacrifices the efficiency when input voltage is about 12.2 V. Eliminating the buck–boost mode in Fig.33 improves the efficiency by about 16% and 19%, respectively, in the cases of R = 16.7 Ω and R = 25.2 Ω.

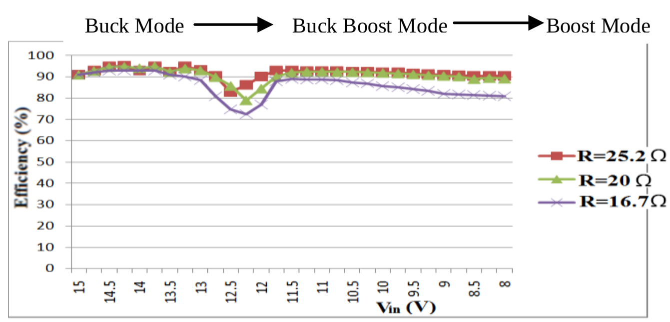


Fig. 31. Efficiency plot versus the input voltage variations for transition from buck to buck–boost and then boost mode.

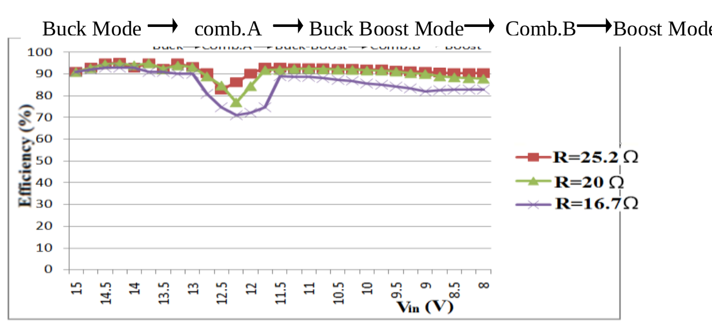


Fig. 32. Efficiency plot versus the input voltage variations for (a) transition from buck to boost through buck–boost and combination modes.

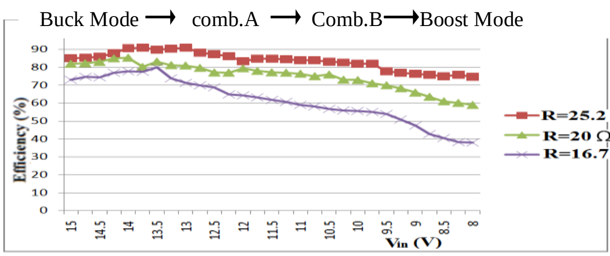


Fig. 33. Efficiency plot versus the input voltage variations for transition from buck to boost without buck–boost mode

The simulation results closely coincide with the experimental results, with the adoption of same values for all the parameters in the simulation circuits and hardware.

7. CONCLUSION

In this paper a dc/dc real time buck–boost switching converter has been illustrated with a highly enabling control strategy of pulse width modulation. The proposed control scheme can regulate the output voltage for an input voltage, Based on the charge status of the battery supply. The novel method introduced in this paper is unique in improving the efficiency at the same time reduced the ripple content of the output voltage for a real time buck–boost converter whenever smooth transition is needed from the buck mode to the boost mode. And the concept of DCPC is introduced, which improves the transition ripple by distributing the voltage transients. In this method, the capability of skipping over higher loss interface stages such as buck–boost mode in the case of a real time buck–boost converter significantly improves the efficiency from 16% and 19% and ripple content has been reduced from 14 % to 4% of the circuit topology. The presented Matlab simulation outputs and experimental results validate the proposed novel method and its merits. The novel theory has been utilized to improve the output voltage transients in transition from buck to boost mode. This is an efficient technology to improve the voltage transients in any application that require transition between different converter topologies.

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