Simulation and Implementation of Dual-Stage Design Buck and Boost Converters for Low Power Applications

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Abstract

Due to tremendous increase in the multi-functionality of a modern battery operated portable electronic devices namely smart phones, laptops, tablets etc.., life of a battery is an important issue. In order to extend the life of a battery, an effective voltage regulator is necessary. For this reason, the task of dual stage design of buck and boost converters are examined. At first and foremost, discussion is made on the benefits of supplanting the customary one-stage buck and boost converters by an incorporated dual-stage buck and boost converters. The outline parts of a dual-stage 6V-to-1V and 3.6V-to-12V converters are indicated as an illustration to elucidate the benefits of the proposed configuration more than one-stage approach. MATLAB/SIMULINK model is made for the total system to ensure its operation and performance. The results demonstrate that, using dual-stage design methodology, one can achieve greater efficiency and can reduce the ripple content in addition to the benefits of size and cost reduction.

1. Introduction

The modern portable electronic devices which are in use today such as smart phones, laptops, tablets etc.., are advancing in technology. More and more functionalities are getting added up; more applications are being installed to help a user to get a desired work done in short time. With increase in application there is increase in energy consumption. Therefore it is necessary to have a better energy management with better design and technology. Most recent researches and efforts in the design of DC-DC converters using high switching frequency have been made to achieve greater efficiency in addition to the benefits of size and cost reduction. But due to use of high frequency which is in the range of MHz has reverse impact on the circuit i.e. using of high switching frequency increases the switching losses and generates the high harmonic contents.

In order to overcome the above problems, a dual-stage design has introduced with a frequency in KHz range. By adopting dual-stage design methodology, even ripple content can be reduced completely by stage wise.
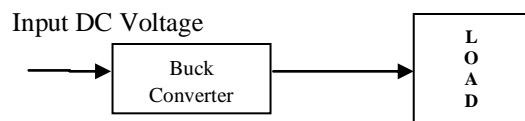
2. Existing Systems

Input DC Voltage

Fig: 1. A) A Simple Block Diagram Representation of Existing System Buck Converter Topology
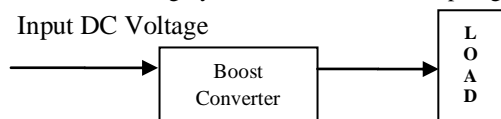
Input DC Voltage

Fig: 1. B) A Simple Block Diagram Representation of Existing System Boost Converter Topology

The simple block diagram representations of a conventional buck and boost converter topologies are shown above in Fig. A) and Fig B) respectively. The conventional buck or boost converters consist of single stage to perform their operation to provide the necessary output voltage which is supplied to the load. Depending on the duty cycle, the input and output voltages, the values for the components such as inductor, capacitor is to be calculated. For these DC-DC converters, if the range of the input/output voltage becomes more and more wide, then the converter efficiency gets affected by the issues of narrow duty-cycle. So, keeping all the above mentioned demerits of these existed converter topologies in a view, one can find a solution to overcome these problems by adopting the dual-stage design DC-DC converters.

3. Benefits of Adopting Dual-Stage Design Buck and Boost Converters Over Customary One-Stage Buck And Boost Converters

➢ Limitations of wide input/output voltage on single stage buck and boost converter
• The converter efficiency suffers a lot due to narrow duty-cycle issues as the input/output range of buck converter becomes wide. To overcome this problem, a lot of efforts have been made by using autotransformer versions buck converter
• Using autotransformer versions of buck converter is not an efficient way from the size and cost point of view. Because employing autotransformer versions of a dc-dc converter requires huge space
• In addition to the defined problem, the switching frequency is limited by the leakage inductance
• It states that, the idea of using dual-stage design approach can improves the efficiency significantly. To implement the power switches for wide input/output buck dc-dc converters require high rating metal oxide semiconductor devices and even higher rating metal oxide semiconductor devices are larger in size

- Also higher rating complementary metal-oxide semiconductor and bipolar complementary metal-oxide semiconductor processes require complicated set of masking during their fabrication and processing
- From the previous problems stated above, breaking the buck conversion process into multiple stages not only gives the solution for achieving greater efficiency but also allows the use of low rating devices

4. Proposed Dual-Stage Design Architectures

A. Dual Stage Design Buck Converter

The Fig. 1 depicts a simple block diagram representation of dual-stage design buck converter.

An input DC voltage of 6V is applied to the first stage which converts it to 3V. The output of first stage converter is then applied to the second stage converter which converts it to1V output DC voltage which is then applied to the load.

For each stage the conversion ratio is 0.5. Due to maintenance of constant conversion ratio enables to choose same low rating devices which makes the design simpler and effective. Breaking the converter into multiple stages result in better efficiency and one can reduce the ripple content stage wise.

B. Specifications

- Input DC Voltage : 6V
- Output DC Voltage : 1V
- Switching Frequency : 200KHZ
- Duty Cycle : 50%
- Efficiency : $\geq 90\%$
- Ripple : $\leq 1\%$
- Output Capacitor of each stage : 1μF

C. Dual Stage Design Boost Converter

The Fig. 2depicts a simple block diagram representation of dual-stage design boost converter.

An input DC voltage of 3.6V is applied to the first stage which consists of charge pump doubler that doubles the applied input voltage. In this case the input voltage is 3.6V so the output of the charge pump doubler or a first stage is 7.2V. The output of first stage converter is then applied to the second stage converter which converts it to 12V output DC voltage which is then applied to the load.

D. Operation of Single Stage Voltage Divider Circuit

Fig 3 depicts the circuit diagram of single stage voltage divider. The operation is as follows

- **Mode 1: Charging Phase:**
S_1 and S_2 are ON which connects the flying capacitor C_F in series with theinput voltage and the capacitor C_o. During this phase, the two capacitors charge from the input source. This phase is called the charging phase.
- **Mode 2: Discharging Phase:**
At the second phase, S_3 and S_4 are ON which connects the flying capacitor CF in parallel with the output capacitor C_o. This phase is called the discharging phase and the load is supplied by the required current through this phase.
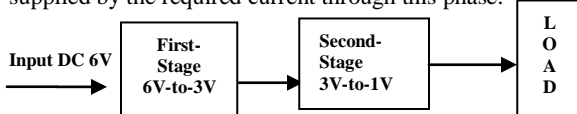
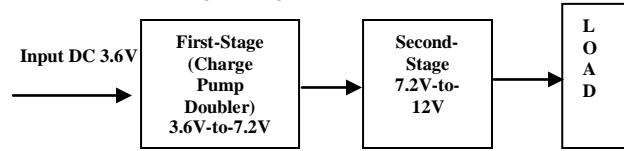Fig: 2. A Simple Block Diagram Representation of Dual-Stage Design Buck converter

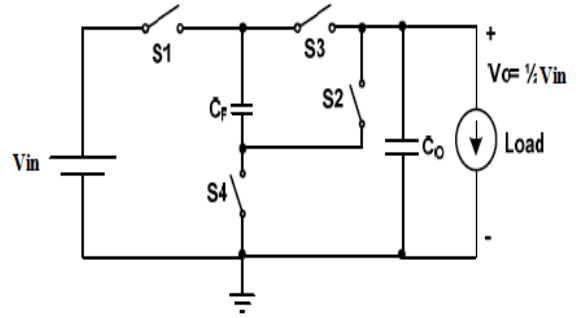Fig: 3. A Simple Block Diagram Representation of Dual-Stage Design Boost converter

Fig: 4. Single-Stage Voltage Divider Circuit

5. Calculation of Component Values for the Proposed Converters

Referring to Fig. 2,
Initially, the input dc voltageV_{in}= 3.6V
Output of the first stage due to charge pump doubler = 7.2V
So, now Input dc voltage V_{in}= 7.2V
Constant parameters:

- V_{in} = 7.2v
- V_{out}= 12V
- R_{out} = 10 Ω
- Switching frequency f_s= 200KHz to 1Mhz

Now, calculating the duty cycle by using the formula:
$D = V_{out} - V_{in}/ V_{out}$
$D = 12 - 7.2 / 12$
$D = 0.4$
Now calculating the inductor current I_L as
$I_L = V_{out}/ R_{out} (1-D)$
$I_L = 12 / 10(1-0.4)$
$I_L = 2A$
Calculating the output current I_{out}
$I_{out}= V_{out}/ R_{out}$
$I_{out} = 12/10$
$I_{out} = 1.2A$
Also, ripple current ΔI_L can be calculated as:
$\Delta I_L = I_{out} * V_{out}* 0.2 / V_{in}$ (Because 20% of load current)
$\Delta I_L= 0.4A$
Now calculating the inductor L and capacitor C as:
$L = V_{in} D / \Delta I_L f_s$
$L = 7.2$ μH
Also $C = I_{out}\Delta I_L / 0.1 * 10^6$(Because 10% of load voltage)
$C = 4.8$ μF

6. MATLAB Simulation Models and Results

Fig. 4 and Fig. 5 depict simulation models of dual-stage design buck and boost converter respectively. Simulation models are designed by using IGBTs and other simple elements which make the design efficient and results

in effective model, better operation performance in addition to the benefits of cost and size point of view. Fig. 6 to Fig. 8 shows the Simulation results of Dual-Stage design Buck and Boost Converters.
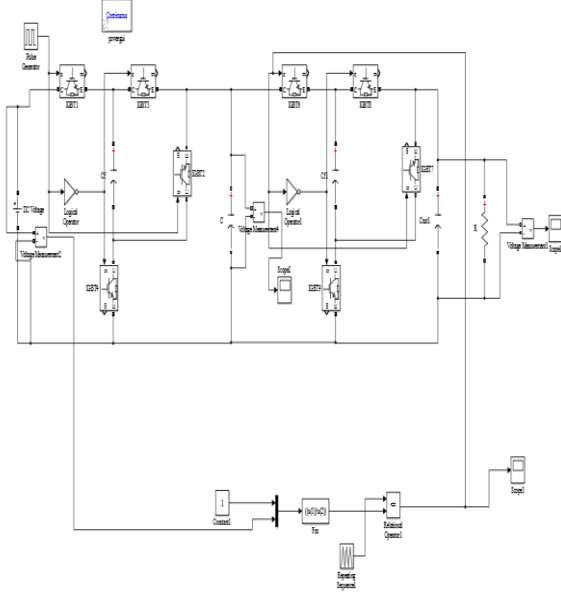

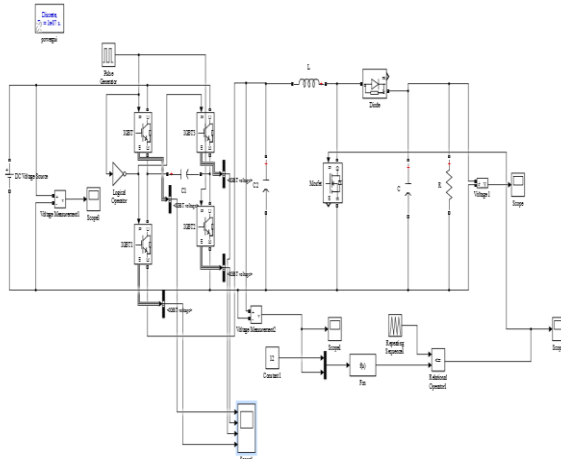**Fig: 5.** Simulation Model of Dual Stage Design Buck Converter

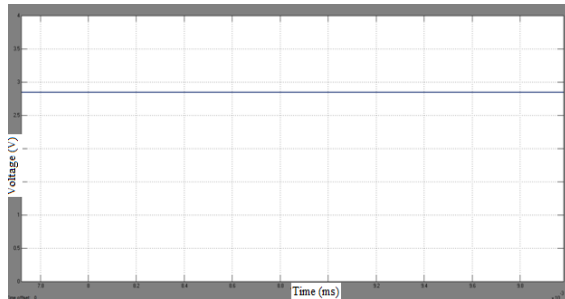**Fig: 6.** Simulation Model of Dual Stage Design Boost Converter

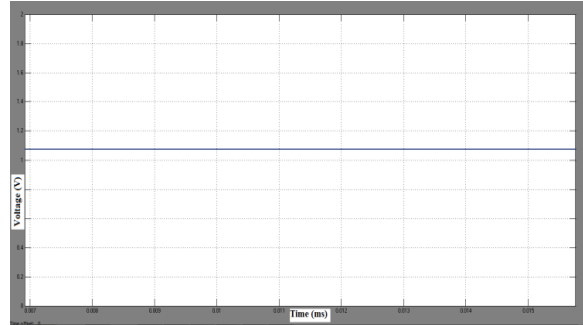**Fig: 7.** Simulation Result of Dual-Stage Design Buck Converter (First-Stage)

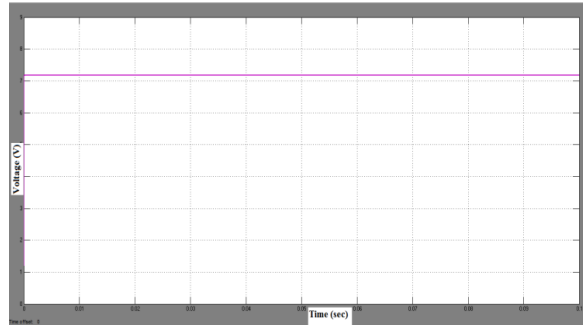**Fig: 8.** Simulation Result of Dual-Stage Design Buck Converter (Second-Stage)

Fig: 9. Simulation Result of Dual-Stage Design Boost Converter (First-Stage/Charge pump Doubler)
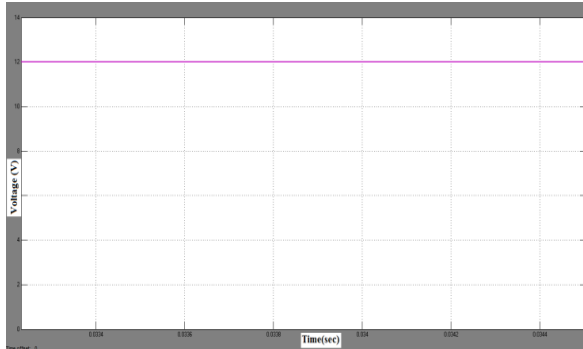

Fig: 10. Simulation Result of Dual-Stage Design Boost Converter (Second-Stage)

7. Conclusion

The operation of a Dual-Stage Design Buck and Boost Converter models are studied by using MATLAB simulator and the comparison between customary one-stage DC-DC and proposed Dual-Stage Design DC-DC converters in terms of benefits are discussed. Dual-Stage Design Buck and Boost Converter is implemented. The experimental results and study shows that, dual-stage design DC-DC converters are more efficient, simple in design in addition to the size and cost point of view.

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