Digital Combination of Buck and Boost Converters to Control a Positive Buck–Boost Converter and Improve the Output Transients

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ABSTRACT

This project is concern to achieve a high efficiency control strategy for improving the transients in the output voltage of a dc-dc positive buck-boost converter is presented in this paper. The sophisticated control technique can regulate an output voltage for an input voltage, which is higher, lower, or the same as the output voltage. There are several existing solutions to these problems, but all have their disadvantages. The technique introduced here is unique of its kind from the point of view of ripple content in the output voltage and the reliability of the control strategy. The best approach involves a tradeoff among cost, efficiency, and output noise or ripple. The main objective of this work is to have a positive buck-boost regulator that automatically transits from one mode to the other. The method introduced in this paper is a combination of buck, boost, and buck-boost modes. Basic analytical studies have been made and are presented.In the proposed method, instead of instantaneous transition from buck to boost mode, intermediate combination modes consisting of several buck modes followed by several boost modes are utilized to distribute the voltage transients. This is unique of its kind from the point of view of improving the efficiency and ripple content in the Output voltage Theoretical considerations are presented. Simulation results are shown to prove the proposed theory.

Keywords: buck boost converter, svm

I INTRODUCTION

A very common power-handling problem, especially for portable applications, powered by batteries such as cellular phones, personal digital assistants (PDAs), wireless and digital subscriber line (DSL) modems, and digital cameras, is the need to provide a regulated non-inverting output voltage from a variable input battery voltage. 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.

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.

This paper describes a new method for minimizing the transients in the output of a DC-DC converter required for small powered portable electronic applications. The transient problem has been the most serious problem for power supplies needing the output voltage in the mid-range of the input voltage. The maximum transient arises when the input voltage becomes almost equal to the output voltage. Selecting the best approach involves a tradeoff among cost, efficiency, and output noise or ripple. There are various techniques used to solve the problem of transients. However, most of the methods have drawbacks such as comparatively higher transients or lower efficiency because of the longer switching operations. This paper describes few methods already been used to solve the transient problem and points out the demerits of those methods. In addition, a new combination method, which combines buck and boost modes during the transition mode, is described in this paper to minimize the transients at the output of the converters when the input voltage is near to the output voltage. Mathematical equations have been put forward to support the proposed idea for the transient minimization. Simulation results have been added to make a comparative analysis of transient response of this method with respect to the other methods

II DC-to-DC converter

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different than that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage, and possibly even negative voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

Most DC to DC converters also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the input voltage.

There are three kinds of switching mode DC-DC converters, buck, boost and buck-boost. The buck mode is used to reduce output voltage, whilst the boost mode can increase the output voltage. In the buck-boost mode, the output voltage can be maintained either higher or lower than the source but in the opposite.

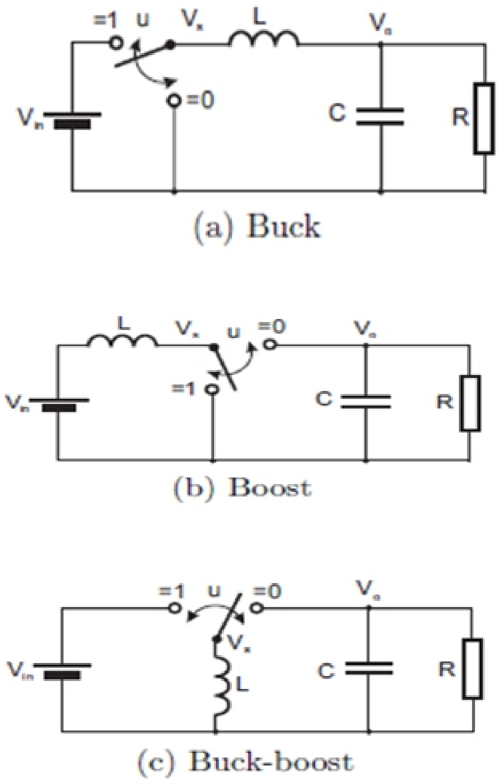

Fig.2.1. Buck, Boost, Buck-Boost Converter Equivalent Circuit Diagram.

These converters consist of the same components, an inductor, L, a capacitor, C and a switch, which has two states u = 1and u = 0. All converters connect to a DC power source with a voltage (unregulated), Vin and provide a regulated voltage, Vo to the load resistor, R by controlling the state of the switch. In some situations, the load also could be inductive, for example a DC motor, or approximately, a current load, for example in a cascade configuration. For simplicity, here, only current and resistive loads are to be considered.

2.1.1. Working Principles

The working principles of the DC-DC converters can be explained as follows. In the buck mode, when the switch is on position 1, the DC source supplies power to the circuit which results an output voltage across the resistor. When the switch changes its position to 0, the energy stored in the inductor and capacitor will discharge through the resistor. Appropriately controlling the switching position can maintain the output voltage at a desired level lower than the source. In the boost mode, when the switch is on position 1, the circuit is separated into two parts: on the left, the source is charging the inductor; meanwhile the capacitor on the right maintains the output voltage using previously stored energy. When the switch changes its position to 0, both the DC source and energy stored in the inductor will supply power to the circuit on the right, hence boost the output voltage. Again, the output voltage can be maintain at desired level by controlling the switching sequence.

Finally, for the buck-boost mode, switch positions 1 and 0 represents charging and discharging modes of the inductor. Appropriately controlling the switching sequence can result in output voltage higher or lower than the DC source.

2.1.2 Chopper

A chopper is a static device that converts fixed d.c input voltage to a variable d.c output voltage directly. A chopper is a high speed ON/OFF semi-conductor switch. It connects the source to load and disconnects the load from source at a fast speed. In this manner a chopped load voltage is obtained.

A chopper may be thought of d.c equivalent of an a.c transformer having continuously variable turns ratio. Like a transformer, a chopper can be used to step down or step up the fixed d.c input voltage. If the averaged output voltage is less than the supply voltage then it is a step down chopper and is known as a buck chopper. If the averaged output voltage is greater than the supply voltage then it is a step up chopper and is known as a boost chopper.

2.1.3 Operation of Boost Chopper

The fig. 4 illustrates an elementary form of a step up chopper , called as Boost chopper.

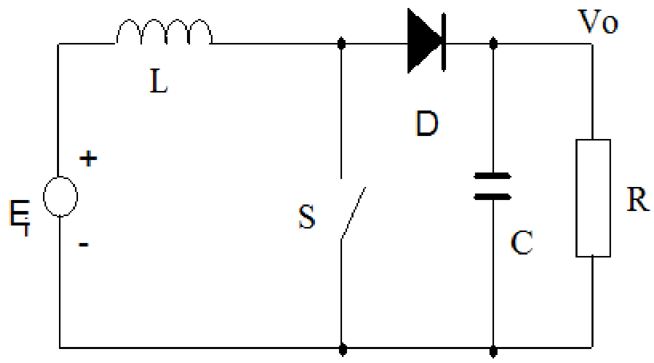

Fig. 2.2. Boost chopper circuit

In this chopper, a large inductor L, in series with source voltage Vs is essential as shown in Fig. 4. When the chopper is ON, i.e.., during the period Ton the inductor stores energy as there is closed current path and the load voltage Vo is zero. During the interval Toff as the inductor current cannot die out instantaneously, this current is forced through the diode and load. As a result, voltage across the load is given as,

$$V_o = V_s + L(di/dt),$$

which exceeds the source voltage Vs indicating a step up chopper.

The expression for the output voltage of a boost chopper can be given as,

$$V_o = V_s \cdot T/(T - T_{on}) = 1/(1-\alpha) \cdot V_s$$
$$\text{Where } T = T_{on} + T_{off}$$

When the chopper (switch) is ON, i.e.., during the period Ton, chopper is ON and load voltage is equal to source voltage 'Vs'. During the interval Toff, the load current flows through the free-wheeling diode. As a result load terminals are short-circuited by free-wheeling diode and load voltage is therefore, zero during Toff. In this manner a chopped d.c voltage is produced at the load terminals.

The average load voltage 'Vo', is given by,

$$Vo=Ton/(Ton+Toff)*Vs$$
$$=(Ton/T)*Vs$$
$$=\alpha*Vs$$

Where Ton=ON time
Toff=OFF time
α =(Ton/T)=duty cycle

Thus, the load voltage can be controlled by varying the duty cycle 'α', which implies that if the input voltage 'Vs' is constant and the duty ratio 'α' is varied as desired, the output of Buck converter will be as that of 'α'

i.e.., $\dot{v}o = \alpha vs$
where 'α' represents the duty ratio

2.1.4 Advantages of Buck Over Boost

The advantages of Buck Converter are as mentioned below,

1. In Boost converter, the output voltage is very sensitive to changes in duty cycle and it might be difficult to stabilize the regulator but this is not the case in Buck regulator.

2. The Buck regulator configuration is very simple and has high efficiency greater than 90%.

3. In Boost converter, the averaged output current is less than the averaged inductor current by a factor of (α) and a much higher R.M.S current would flow through the filter capacitor, resulting in the use of large filter capacitor and a large inductor than those of a Buck converter.

4. Voltage gain of a Buck converter is greater than Boost converter. The voltage gain of Buck converter is α where as gain of Boost converter is 1/(1- α)

Because of the aforementioned advantages of Buck converter over the Boost converter, we are using Buck rather than Boost. In order to obtain, a sine wave as the output of the inverter using d.c to d.c topology, the output waveform of the Buck converter circuit should be in the form of a fully rectified sine wave. To obtain this the duty ratio 'α', is varied slowly relative to the switching frequency in the form of a fully rectified sine wave, which is obtained from a bridge rectifier (a.c to d.c converter).

Then, obviously the output voltage 'vo', will be in the form of a fully rectified sine waveform.

By passing this through a bridge circuit which is synchronized with the fully rectified sine wave form 'α', the output 'vo' is "unfolded" into a sinusoidal waveform vac.

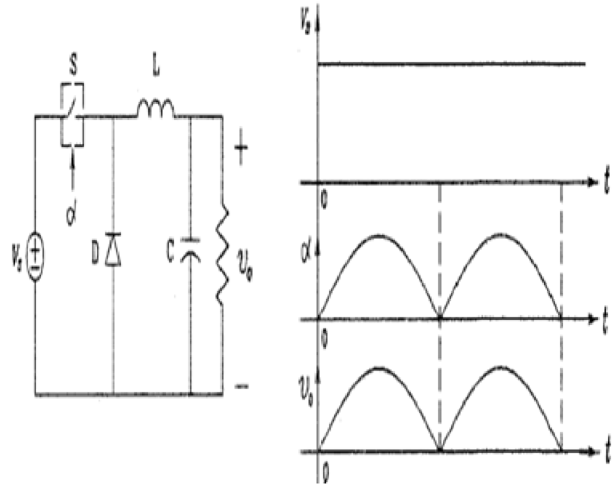

Fig. 2.3. Buck converter with duty ratio varying in the form of a fully rectified sine wave

By passing this through a bridge circuit which is synchronized with the fully rectified sine wave form 'α', the output 'Vo' is "unfolded" into a sinusoidal waveform v_{ac}, as shown in Fig. 2(b).

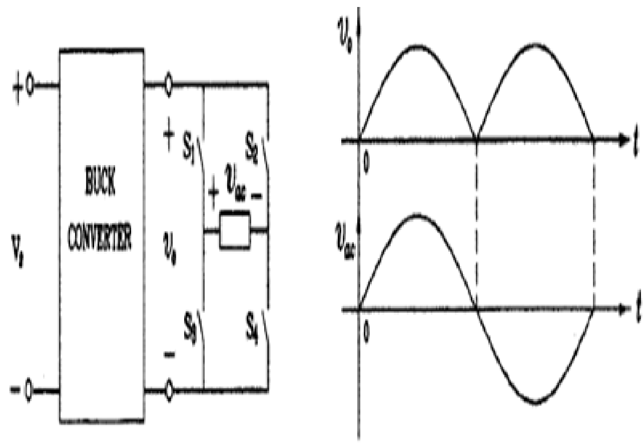

Fig. 2.4. A bridge synchronizer following a Buck converter to obtain a sine wave

Advantages of using a dc to dc topology.

Compared to the bridge type inverter the inverter using a d.c to d.c converter configuration has several advantages,

1.Only one switch operates at high frequency and, as a result switching losses will be significantly less. The conduction loss will be slightly higher because of one extra switch, but however, the overall losses will be less, thereby increasing the efficiency.

2.The output filtering capacitors in the d.c to d.c converters can be a d.c type capacitor. E.g., an electrolytic capacitor which is smaller and less expensive than the a.c type capacitor for the same capacity required in the bridge configuration, however the inverter using bridge configuration must use an a.c type capacitor as a filter.

3.The bridge circuit in the inverter using d.c to d.c converter topology shown in Fig (2b). operates at low frequency, e.g. 60Hz.

Hence it has the safe delay interval. In contrast, conventional bridge type inverter works at high frequency and the delay interval between the upper device and the bottom device in each leg must be very short, increasing the risk of short circuit.

4.More important is that, with a d.c to d.c converter topology, the advanced control techniques such as current mode control, direct duty ratio control, digital data sampling control, sliding mode control developed from the investigations of d.c to d.c converters can be directly applied to the d.c to a.c switch mode inverter.

2.1.5 Necessity for control of PWM and dc to dc converters

Power conversion is usually achieved by appropriate configuration of the d.c to d.c converter circuit components and proper operation of the semiconductor switches. Any d.c to d.c converter will be designed for specific line (input voltage) and load (output) conditions. In other words, the circuit will be operated at steady state condition.

But in practice this may not be possible and there is always a possibility of some disturbances which cause the circuit operation to deviate from the nominal values considerably. These disturbances may be due to the changes in the source, load, circuit parameters, and perturbation in switching time and events such as start up and shut down etc.

This deviation of the circuit operation from the desired nominal behavior is known as the dynamic behavior of the circuit. If the above mentioned disturbances have negligible effect on the circuit operation, no action will be required by the designer to correct this situation.

But in most cases the departure from nominal conditions will affect the circuit operations to large extent and therefore, the designers will be required to design a proper controller or compensator to overcome this situation of the circuit operation.

The control circuit in switch mode power supply (SMPS) circuits has several main functions. During steady state operations, the control circuit maintains the output voltage constant, if there is any change either in the input voltage or load. During transient operations, the control circuit protects all the components used in the converter by limiting external stress on them.

In pulse width modulation (PWM) converters the control circuit regulates the output by fixing the switching frequency and varying the on time of the switch, while on the other hand in resonant switched mode power supplies the control circuit regulates the output by varying the switching frequency and fixing the on or off time of the switch.

Several control techniques are available for conventional switched mode power supplies which work on PWM method, some of the most common techniques will be discussed here in the later section.

III Positive Buck-Boost Converter
3.1 Circuit Topology

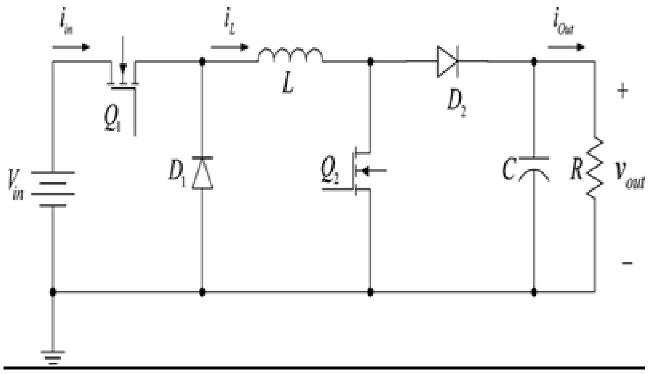

Fig.3.1. Circuit Topology of a Positive Buck-Boost Converter

3.2 Operation of a positive Buck-Boost Converter:

The circuit topology of a positive buck–boost converter is shown in Figure. In buck–boost operating mode, always, two switches, Q1 and Q2 , and two diodes,D1 andD2 , are switching in the circuit. A positive buck–boost converter can operate as a buck converter by controlling switch Q1 and diode D1 , when Q2 is OFF and D2 is conducting. It can also work as a boost converter by controlling switch Q2 and diode D2 , while Q1 is ON and D1 is not conducting. When the voltage of the battery is more than the output reference voltage, converter operates as a buck converter. As soon as the voltage of the battery drops to a value less than the output reference voltage, the converter should switch to boost mode. The added advantage of the converter is that the output of such a converter is always positive.

Table 3.1. presents the values of α_1, β_1 , and γ_1 for the conventional method of transition from buck to buck–boost and the values of α_2, β_2 , and γ_2 from buck–boost to the boost operating conditions.

Table-3.1Transition model control parameters (α, β, and γ) for the Conventional method of transition from a buck to boost Operating topology

Buck to Buck-boost transition	$\alpha_1 = \beta_1 = \gamma_1 = 1$
Buck-boost to Boost transition	$\alpha_2 = \beta_2 = \gamma_2 = 1$

Table-3.2 Parameters of Positive Buck–Boost Converter

Variable	Parameter	Value
L	Magnetizing inductance	100 μH
C	Output filter capacitance	330 μF
V_{in}	Input voltage	3.6V-6V
V_{ref}	Output voltage	5 V
f	Switching frequency	100 kHz
R	Output resistance	20 Ω

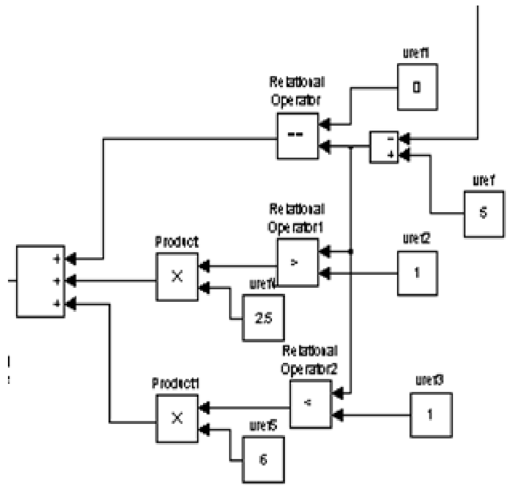

Fig.3.2. Closed loop control strategy for the proposed method

IV Operation of Positive Buck–Boost Converter

The circuit topology of a positive buck–boost converter . In buck–boost operating mode, always, two switches, Q1 and Q2 , and two diodes,D1 andD2 , are switching in the circuit. A positive buck–boost converter can operate as a buck converter by controlling switch Q1 and diode D1 , when Q2 is OFF and D2 is conducting. It can also work as a boost converter by controlling switch Q2 and diode D2 , while Q1 is ON and D1 is not conducting. When the voltage of the battery is more than the output reference voltage, converter operates as a buck converter. As soon as the voltage of the battery drops to a value less than the output reference voltage, the converter should switch to boost mode. The added advantage of the converter is that the output of such a converter is always positive Table presents the values of α1, β1 , and γ1 for the conventional method of transition from buck to buck–boost and the values of α2, β2 , and γ2 from buck–boost to the boost operating conditions .The overall system level closed loop control strategy of the proposed method . The control logic for. deciding the modes of operation is based on the idea of Fig. Here, both the input and the output voltages are sensed and the proper duty ratios are applied to the switches Q1 and Q2 based on proper duty setting and the desired mode of operation.

V Computer Simulation

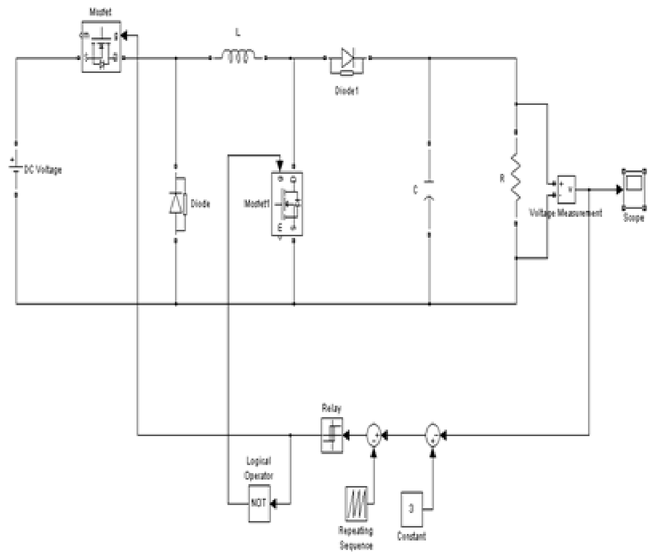

Fig.5.1. Simulation Model for Positive Buck-Boost Converter.

Result:

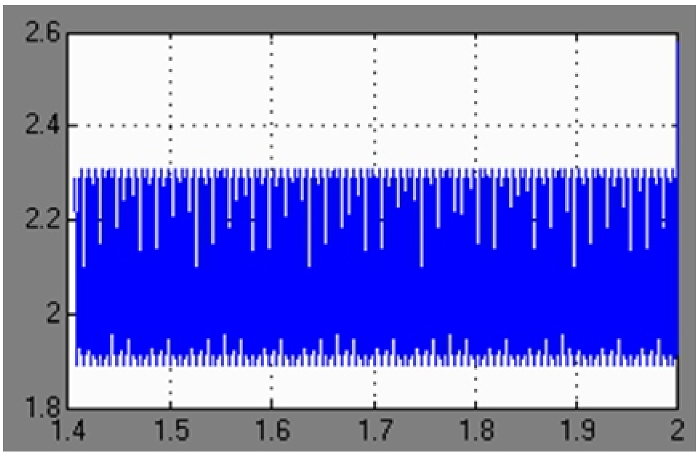

Fig.5.2. Simulation result of positive buck-boost converter for 3v.

Simulation Results of the combination method

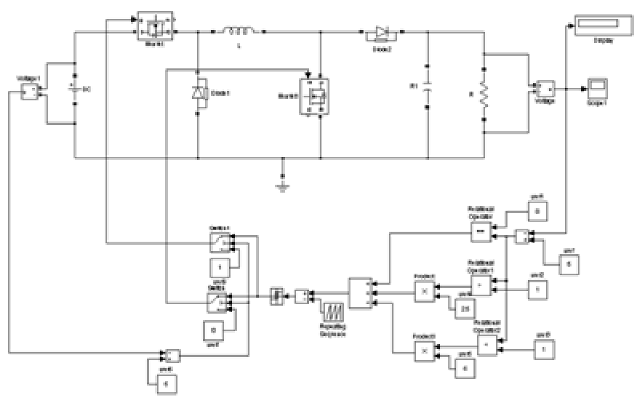

Fig.5.3. Simulation diagram of the proposed method

Result:

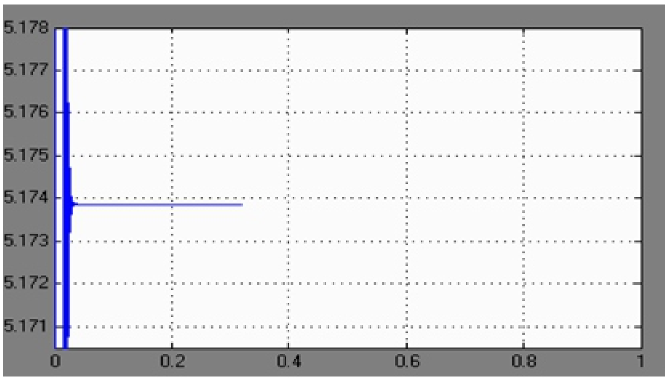

Fig.5.4. Output Result for Combination Mode of Buck-Boost Converter.

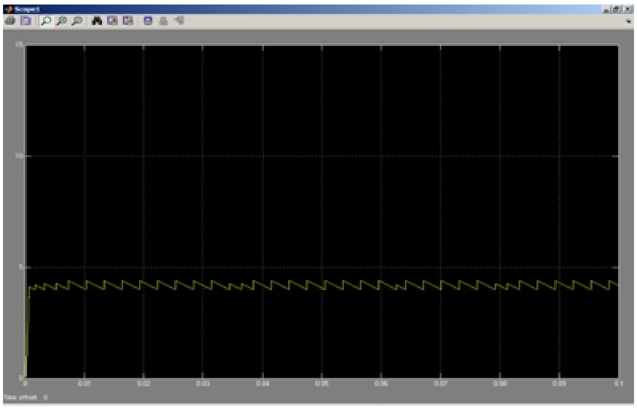

Fig.5.6. Simulation results when input is set to 3V

In this particular section when 3v input is given we get 5v as output .for this input voltage the circuit is working in Boost Mode. The lower voltage is increased by combining the input voltage with the charge of the capacitor so that the output voltage is the sum of the input voltage and the charge of the capacitor. Duty cycle of boost(D boost) = 1- V in/V out according to this duty cycle formula we can tell that the circuit is working in boost mode .Duty cycle of bucko and Duty cycle of boost is 1.the circuit is efficient such that it is able to reach the requirement .

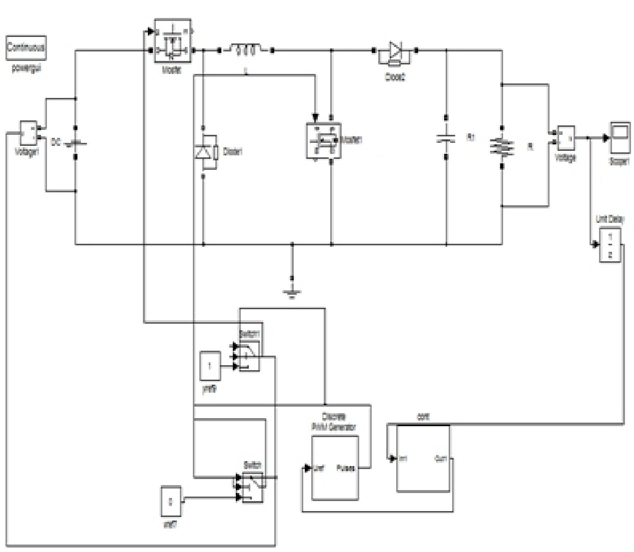

Fig.5.7. When Input voltage is set to 5V in Simulation diagram

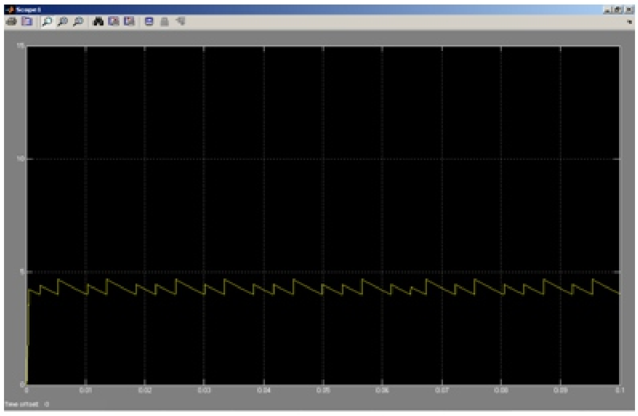

Fig.5.8. Simulation results when input is set to 5V

In this particular section when 5v input is given we get 5v as output .for this input voltage the circuit is working in Boost Mode and Buck Mode. The variation of voltage is increased by combining the input voltage with the charge of the capacitor so that the output voltage is the sum of the input voltage and the charge of the capacitor in Boost mode. Duty cycle of boost(D boost) = 1- V in/V out according to this duty cycle formula we can tell that the circuit is working in boost mode .Duty cycle of bucko and Duty cycle of boost is 1.the circuit is efficient such that it is able to reach the requirement .

The variation of voltage is decreased by turning off the switch when required and achieved the output required voltage Buck mode. Duty cycle of buck and boost (D boost-bust) = V out/V out+ V in Duty cycle of buck max is 1 and Duty cycle of boost min is 0.

In this particular section when 7v input is given we get 5v as output .for this input voltage the circuit is working in Buck Mode. The Higher voltage is decreased controlling the on time and off time of the switch such that required output voltage is achieved that is 5v.

Duty cycle of buck(D buck) = V out/Vin according to this duty cycle formula we can tell that the circuit is working in buck mode . Duty cycle of bucko.5 and Duty cycle of boost is 1.the circuit is efficient such that it is able to reach the required voltage that is 5v.

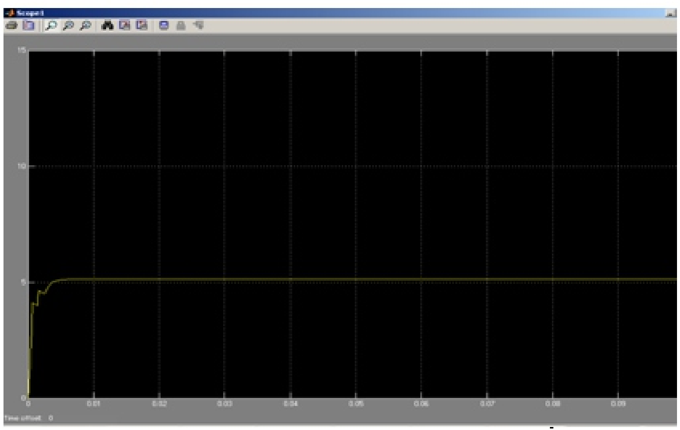

Fig.5.10. Simulation results when input is set to 7V

VI Conclusion

By applying the parameter values from Table II for the calculation of buck and boost samples and using (6), just beforevin ≈ vout , the rounded ratio of α1 and β1 is 3:1. Similarly, just after vin ≈ vout , the ratio of α2 and β2 is found to be 1:2. Thus, we choose α1 = 3or three buck cycles and β1 = 1or one boost cycle for the time period in combination mode A and α2 = 1 or one buck cycle and β2 = 2 or two boost cycles for the time-period in combination mode B. This ratio is presented in termsof block diagram in Fig. 15 for solving the addressed problem.

By applying this combination method of control and simulating the converter, the results 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 4%; however, canceling the buck–boost operating mode in between significantly improves the efficiency of the converter.

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