Performance of Positive Buck-Boost Converter with Mode Select Circuit and Feed-Forward Techniques Using Fuzzy Logic Controller

I. INTRODUCTION

The modern trend technology uses portable devices and the development of semiconductor manufacturing technology; Conversion efficiency, power consumption, and the size of devices have become the most important design criteria of switching power converters. For portable applications better conveniences extension of battery life and improves the conversion efficiency of power converters. It is essential to develop accurate switching power converters, which can reduce more wasted power energy. The proposed topology can achieve faster transient responses when the supply voltages are changed for the converter by making use of the feed forward network. With mode select circuit the conduction & switching losses are reduced the positive buck–boost converter operate in buck, buck–boost, or boost converter. By adding feed-forward techniques, the proposed converter can improve transient response when the supply voltages are changed. Hence Positive buck-boost converters with mode select circuit & feed forward techniques using fuzzy logic converter is designed And the modeling & experimental results were verified in MATLAB/ Simulink.

Abstract—This project is a highly efficient & novel control strategy for improving the transient in the output voltage of a dc–dc positive buck-boost converter which is required for low portable devices. The portable devices development of semiconductor manufacturing technology, conversion efficiency, power consumption, and the size of devices have become the most important design criteria of switching power converters. For portable applications better conveniences extension of battery life and improves the conversion efficiency of power converters. It is essential to develop accurate switching power converters, which can reduce more wasted power energy. The proposed topology can achieve faster transient responses when the supply voltages are changed for the converter by making use of the feed forward network. With mode select circuit the conduction & switching losses are reduced the positive buck–boost converter operate in buck, buck–boost, or boost converter. By adding feed-forward techniques, the proposed converter can improve transient response when the supply voltages are changed. Hence Positive buck-boost converters with mode select circuit & feed forward techniques using fuzzy logic converter is designed. And the modeling & experimental results were verified in MATLAB/ Simulink.

Keywords— Positive buck–boost converter, Feed-forward techniques, mode select, Fuzzy logic control.

I. INTRODUCTION

The modern trend technology uses portable devices and the development of semiconductor manufacturing technology; Conversion efficiency, power consumption, and the size of devices have become the most important design criteria of switching power converters. Li-ion battery powered portable electronics, such as laptops, cellular phones have grown massively in recent years. To prolong the service life of these electronic devices efficient power management is required. It is necessary to reduce wasted power energy in the converter. Hence an accurate switching power converter is essential to reduce the more wasted power energy. Generally buck & boost converters may not be capable of using the entire battery output voltage range (e.g.2.5-5v for Li-ion batteries) to provide a fixed output voltage i.e. 3.3v.

The challenges for the designer to provide consumers better conveniences are, to improve the conversion efficiency of power converters & to extend life of battery. Hence it is required to design a accurate switching power converters to reduce the more wasted power energy in the converter [1]. It is necessary to provide a regulated non-inverting output voltage from a variable input battery voltage to portable applications which suffer from the power handling problems. For example cellular phones, personal digital assistants (PDAs), wireless and digital subscriber line (DSL) modems, and digital cameras, need a regulated non-inverting output voltage because the battery voltage keeps on changing as it is charged & discharged. As the battery voltage can be greater than, less than or equal to the output voltage. Hence for this small scale application such as battery it is needed to regulate the output voltage of the converter with high precision & performance. Thus, a trade-off among cost, efficiency, and output transients should be considered [6]. For space-restrained application, the regulation of the output voltage in the midrange of a variable input battery voltage is a common handling issue [11].

There are various topologies which can be implemented to maintain a constant output voltage from a variable input voltage. For example inverting buck-boost converters, single-ended primary inductance converters (SEPICs), Cuk converters, isolated buck-boost converters and cascaded buck and boost converters. The output ripple, efficiency, space and the cost 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.

Transitions will takes place during the charging & discharging of the battery. The converter to lose efficiency during the transition from buck mode to the boost mode & it leads to the spikes in the output voltage. The advantage of having higher efficiency is longer runtime at a given brightness level from the same set of batteries. While designing such power supplies the Cost, size, switching speed, efficiency and flexibility should be considered. Spikes occur during the transition from buck mode to the boost mode in the output voltage. This causes the converter to lose efficiency. To extend the battery life, with increasing low-voltage portable devices and growing requirements of functionalities embedded into devices, efficient power management techniques are required. The dc-dc converters are designed in such a way that it need to supply the portable devices a regulated voltage over a wide battery voltage. So that it effectively use the remaining capacity of the battery. When the converter operates in the transition region of the buck and boost mode, the limitations of standard analog pulse width modulator (PWM) causes...
uncontrolled pulse skipping and significantly increased output voltage ripples.

Buck-boost mode is a buffer region which provides a smooth and stable transition between two modes. The converter can operate in buck, buck-boost and boost modes when the battery voltage decreases. Since the dc-dc converter has different operation modes, the system stability, the output ripple, and the accuracy of the regulated output voltage during mode transition need to be guaranteed [3]. Fig 1 shows the block diagram of proposed converter with fuzzy logic controller.

II. PROPOSED METHOD

The positive buck-boost converter can be operated in buck, boost, and buck-boost mode & in buck-boost mode the highest ratio occurs. Four power transistors cause more switching loss and conduction loss in the positive buck boost converter. So it is necessary to avoid power converters to operate in buck-boost mode to reduce the losses to as the positive buck-boost converter operates in wide-range of supply voltages. Therefore, we design a mode-select circuit to detect the battery energy and select the operation mode [1]. It switches only two power transistors when the converter operates in buck mode or boost mode. The conduction loss and switching loss of the proposed converter can be reduced by the mode select circuit mode select circuit. The proposed converter can operate in wide supply voltage range and extend the battery life. The fuzzy logic controller is wider range of operating conditions than PID. Developing the fuzzy controller is much cheaper than developing a model based or other controllers for the same work.

The proposed circuit operation is explained as below. The proposed positive buck-boost converter with or mode select circuit & feed forward techniques with fuzzy logic converter is shown in figure 1. It is composed of four power transistors, an analog-adder circuit, a mode select circuit, a dynamic ramp generator, a compensator network, a non overlapping circuit, and a driving circuit. When the proposed converter operates, the output feeds back the voltage \( V_b \) to the compensator. Then, the compensator sends an error signal \( V_c \) to the analog-adder circuit. The analog-adder circuit adds the feed-forward supply voltage \( V_{DD} \) and the error signal \( V_c \) to generate a signal \( V_{add} \). Using the analog adder, the output error signal of the compensator can be designed at half of the supply voltage \( V_{DD} \) so that the compensator can achieve the widest bandwidth, which transient response is fastest.

\[ V_{add} \] is compared with a dynamic ramp which depends on the supply voltage \( V_{DD} \) so that the transient response could be improved while the supply voltage \( V_{DD} \) and the load current \( I_{load} \) changed. After that, the digital PWM signal \( V_p \) is sent to non overlapping circuit and generates four signals. Finally, the driving circuit drives the power transistors depending on the operation mode, which includes buck mode, boost mode, and buck-boost mode, and on the boundary reference voltage \( V_{buck} \& V_{boost} \).

![Fig 1 Proposed positive buck boost converter with fuzzy logic controller.](image)

III. MODE SELECT CIRCUIT:

The losses can be reduced by making use of this Mode select circuit. When the proposed converter operates in the high frequency it uses all the four power transistors. And these switches produces more switching losses and conduction losses. To avoid those losses we utilize mode-select circuit and we can operate in three different modes as buck, boost and buck-boost mode. This Mode select circuit can decide the mode of operation & avoids the overlapping of modes when needed. The turning on the power transistors at the same time can also be avoided. Finally, it can determine the operation mode by a control signal from controller. By using this battery life can be extended and the converter can be operated in efficient way.

IV. MODES OF OPERATION:

The proposed converter operates in the two operating intervals for buck, boost & buck boost mode i.e. charging & discharging.

![Fig 2(a) shows Power transistors Mp1 and Mp2 are switched ON proposed converter operates in the charging interval of buck mode; and the power transistors Mn1 and Mn2 are switched OFF. Fig 2(b) the power transistors Mp2 and Mn3 are switched ON and the power transistors Mp1 and MN 4 are switched OFF.](image)

V. BUCK CONVERTER:

In step down converter, the output voltage will be less than the input voltage whereas in step up converter output voltage will be more than the input voltage.

BUCK STEADY-STATE CONTINUOUS CONDUCTION MODE ANALYSIS:

The following is a description of steady-state operation in continuous conduction mode. Steady-state implies that the input voltage, output voltage, output load current, and duty-cycle are fixed and not varying. In continuous conduction...
mode, the Buck power stage assumes two states per switching cycle. The ON state is when $M_{p1}$ is ON. The OFF state is when $M_{p1}$ is OFF and a simple linear circuit can represent each of the two states where the switches in the circuit are replaced by their equivalent circuits during each state. The circuit diagram for each of the two states is shown in Figure 1 a & 1b. The duration of the ON state is $D \times T_s = t_1$ where $D$ is the duty cycle, set by the control circuit, expressed as a ratio of the switch ON time to the time of one complete switching cycle, $T_s$. The duration of the OFF state is called $t_2$. Since there are only two states per switching cycle for continuous mode, $t_2 = (1-D) \times t_1$. The quantity $(1-D)$ is sometimes called $D'$. The amount that the inductor current increases can be calculated by using a version of the familiar relationship.

The voltage across the inductor $L$ is, in general

$$V_L = \frac{\Delta I}{dt}$$

Assume the inductor current rises linearly from $I_1$ to $I_2$ in time $t_1$.

$$V_{dd} - V_0 = \frac{L}{t_1} (I_2 - I_1)$$

Or

$$t_1 = \frac{\Delta I L}{V_{dd} - V_0}$$

And the inductor current falls linearly from $I_2$ to $I_1$ in time $t_2$

$$-V_0 = \frac{-\Delta I L}{t_2}$$

$$t_2 = \frac{\Delta I L}{V_0}$$

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of the inductor $L$.

Equating the value of $\Delta I$ in equations (1) & (3) gives

$$\Delta I = \frac{(V_{dd} - V_0) t_1}{L} = \frac{V_0 t_2}{L}$$

Substituting $t_1 = DTs$ & $t_2 = (1-D)Ts$ in equation the above equation

$$V_0 = D \frac{V_{dd}}{L}$$

To relate the inductor current to the output current, the inductor delivers current to the output capacitor and load resistor combination during the whole switching cycle. The inductor current averaged over the switching cycle is equal to the output current. This is true because the average current in the output capacitor must be zero. In equation form, we have:

$$I_{1(\text{avg})} = I_{\text{load}}$$

Fig 2 a. Power transistors $M_{p1}$ and $M_{p2}$ are switched ON

Proposed converter operates in the charging interval of buck mode; and the power transistors $M_{n3}$ and $M_{n4}$ are switched OFF. Fig.2 (b) the power transistors $M_{n3}$ and $M_{p2}$ are switched ON and the power transistors $M_{p1}$ and $M_{n4}$ are switched OFF.

Similarly the operation of the boost mode & buck boost mode takes place for the charging & discharging intervals.

VI. FUZZY LOGIC CONTROLLER

Fuzzy controllers have got a lot of advantages compared to the classical controllers such as the simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic is one of the successful applications of fuzzy set in which the variables are linguistic rather than the numeric variables. Structure of a fuzzy logic controller consists of: input, fuzzification, rule base, defuzzification, and output. There are specific components characteristic of a fuzzy controller to support a design procedure. The controller between the input and output is as shown in figure 3.

Fig 3. The general structure of an FLC.

a) INPUT:

The inputs are most often hard or crisp measurement from some measuring equipment is converted into fuzzy values for each input fuzzy set with the fuzzification block.
The inputs are selected from the file as explained in FIS editor. And the error & change in error are plotted the membership plot as shown in the figure 4.

**b) FUZZIFICATION:**

The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block matches the input data with the conditions of the rules to determine. There is degree of membership for each linguistic term that applies to the input variable.

c) RULE BASE:

The collection of rules is called a rule base. The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) and change in error. (dE). In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non-specialist end user and an equivalent controller could be implemented using conventional techniques.

d) DEFUZZIFICATION:

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system.

The output levels are depending on the rules that the systems have and the positions depending on the non-linearities existing to the systems. To achieve the result, develop the control curve of the system representing the I/O relation of the systems and based on the information; define the output degree of the membership function with the aim to minimize the effect of the non-linearity.

e) OUTPUT:

The output is output gain that can be tuned and also become as an integrator .The output crisp value can be calculated by the centre of gravity or the weighted average.

i) Fuzzy Basic FIS editor:

The FIS Editor displays high-level information about a Fuzzy Inference System. At the top is a diagram of the system with each input and output clearly labeled. By double-clicking on the input or output boxes, you can bring up the Membership Function Editor. Double-clicking on the fuzzy rule box in the center of the diagram will bring up the Rule Editor.

**ii) mfedit MEMBERSHIP FUNCTION EDITOR:**

mfedit('a') generates a membership function editor that allows you to modify all the membership functions for your FIS stored in the file a.fis.mfedit(a) operates on a MATLAB workspace variable for a FIS structure a. mfedit alone opens the membership function editor with no FIS loaded.

The Membership Function (MF) Editor is used to create, remove, and modify the MFs for a given fuzzy system. On the left side of the diagram is a “variable palette” region that you use to select the current variable by clicking once on one of the displayed boxes. Information about the current variable is displayed in the text region below the palette area. To the right is a plot of all the MFs for the current variable. You can select any of these by clicking once on the line or name of the MF. Once selected, you can modify the properties of the MF using the controls in the lower right.MFs are added and removed using the Edit menu.

Membership function editor is as shown in the figure 5.6 below. It shows the member functions plots versus the input variables “input 1 & input 2 “ The output will be displayed after selecting the output as shown in figure 5.5.3.

![Membership Function Editor](image)

The general rule can be written as equation

If e(k) is X & ∆e(k) is Y then ∆dc(k) is Z

Where X, Y, Z are the fuzzy variables for e(K), ∆e(k) respectively.

The reverse process of fuzzification is called defuzzification. The linguistic variables are converted in to a numerical variable. As the weighted sum method is considered to be the best well-known defuzzification method, it is utilized in the present model.

The defuzzified output is the duty cycle dc (k). The change in duty cycle ∆dc(k) can be obtained by adding the pervious duty cycle pdc(k) with the duty cycle dc(k) which is given in equation.
\[ \Delta dck = dc(k) + pdc(k) \] ... (8)

Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, rule base lookup table, and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function. In this case, five fuzzy levels are used: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big) as shown in the lookup table below.

Table 1. Fuzzy Rule Base Table

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<th>( E \Delta )</th>
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The buck-boost dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of buck-boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (\( e \)) and change of error (\( de \)) are used in this fuzzy logic system. The single output variable (\( u \)) is duty cycle output as shown in figure 6 below.

\[ \text{Output of buck mode operation:} \]

\[ \text{Fig } 7 \text{(b) shows output of buck mode operation} \]

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\[ \text{Output of buck mode operation:} \]

\[ \text{Fig } 7 \text{(b) shows output of buck mode operation} \]

The above Figure 6.2 shows the output of the buck mode operation. Time is represented along X-axis & the voltage is represented along Y-axis. The input voltage is 4.4 v & the output voltage is 3.3v for buck mode.

**BOOST MODE:**

\[ \text{The simulation circuit for buck-boost mode is shown as in Figure 8 (a) for the proposed converter. Here the positive buck-boost converter with mode select circuit using fuzzy logic controller is operated in buck-boost mode. The input to the converter } V_{in} \text{ is 3.3 v. The operating principle is similar to the buck mode operation.} \]
Fig 8a shows the simulation circuit for the proposed converter for boost mode.

**Output of Boost converter:**

Fig 8b shows simulation results for the buck-boost converter.

The above Figure 8 (b) shows the output of the boost mode operation. Time is represented along X-axis & the voltage is represented along Y-axis. The input voltage is 2.7 v & the output voltage is 3.3v for boost mode.

**BUCK-BOOST MODE:**

The simulation circuit for buck-boost mode is shown as in Figure 6.3 (a) for the proposed converter. Here the positive buck-boost converter with mode select circuit using fuzzy logic controller is operated in buck-boost mode. The input to the converter \( V_{dd} \) is 3.3 v. The operating principle is similar to the buck mode operation.

Fig 9a shows the simulation circuit for the proposed converter for the buck-boost mode.

**Output of buck-boost converter:**

Fig 9b shows simulation results for the buck-boost converter.

The above Figure 9(b) shows the output of the boost mode operation. Time is represented along X-axis & the voltage is represented along Y-axis. The input voltage is 3.3 v & the output voltage is 3.3v for boost mode.

**VIII. CONCLUSION**

The implementation of a positive buck-boost converter with mode-select circuit and with wide range of input voltages is proposed in this paper. By mode-select circuit losses are reduce. Four power transistors produce more conduction losses and switching losses when operated in high frequency. By using mode-select circuit we can operate the converter in three different modes as buck, boost and buck-boost mode. To minimize the loss of switches, as the positive buck-boost converter operates in wide range of input voltages, it is
necessary to avoid power converters operating in buck-boost mode. Therefore, the mode-select circuit is designed to detect battery energy and select the operating mode. The feed-forward techniques with fuzzy logic controller is used to improve its transient response when the supply voltage changes. It is typically used to compensate the input variations and provide tighter control response of the output voltage. By using the above mentioned techniques, the proposed converter improves power efficiency and extends the battery life.

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